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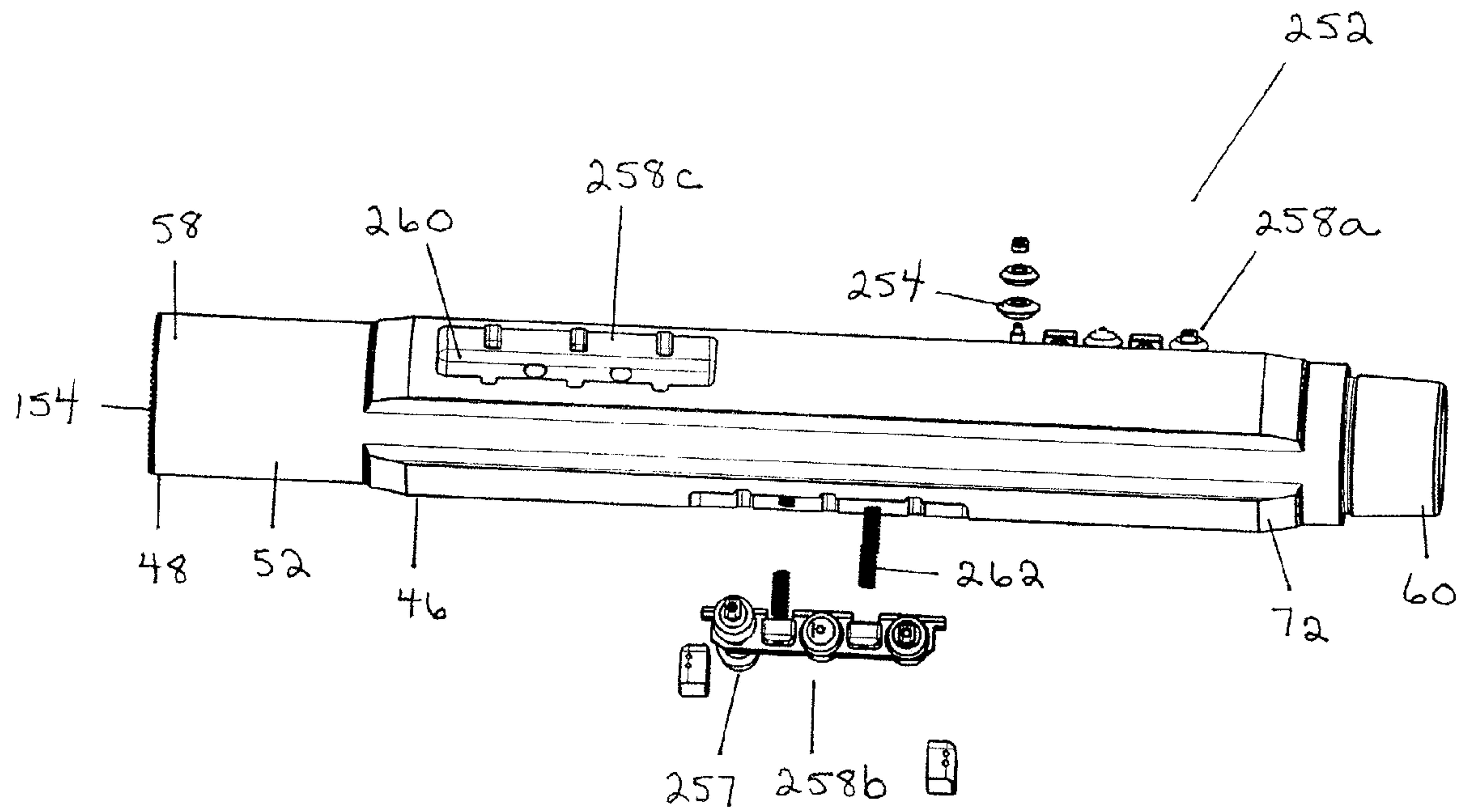


(57) **Abrégé/Abstract**:
In an apparatus for use in a borehole of a type comprising a rotatable shaft and a housing for rotatably supporting the shaft therein, a rotation restraining device associated with the housing for restraining its rotation. The device includes a plurality of rollers, each having an axis of rotation substantially perpendicular to a longitudinal axis of the housing and being oriented such that it is capable of rolling about its axis of rotation in response to a force exerted thereon substantially in the direction of the longitudinal axis, wherein at least two of the rollers are spaced about a circumference of the housing and axially along the housing so that the rollers are staggered axially along the housing. Alternately, the device includes a plurality of pistons, wherein at least two of the pistons are spaced about a circumference of the housing and axially along the housing so that the pistons are staggered axially along the housing.

ABSTRACT

In an apparatus for use in a borehole of a type comprising a rotatable shaft and a housing for rotatably supporting the shaft therein, a rotation restraining device associated with the housing for restraining its rotation. The device includes a plurality of rollers, each having an axis of rotation substantially perpendicular to a longitudinal axis of the housing and being oriented such that it is capable of rolling about its axis of rotation in response to a force exerted thereon substantially in the direction of the longitudinal axis, wherein at least two of the rollers are spaced about a circumference of the housing and axially along the housing so that the rollers are staggered axially along the housing.. Alternately, the device includes a plurality of pistons, wherein at least two of the pistons are spaced about a circumference of the housing and axially along the housing so that the pistons are staggered axially along the housing.

ANTI-ROTATION DEVICE FOR USE IN A BOREHOLE

FIELD OF INVENTION

The present invention relates to a rotation restraining device or an anti-rotation device for an apparatus for use in a borehole, the apparatus being of a type including a rotatable shaft and a housing. Preferably, the rotation restraining device is for particular use in an apparatus such as a downhole rotary drilling device, including a downhole motor, a steerable rotary drilling device or a drilling direction control device.

BACKGROUND OF INVENTION

Directional drilling involves varying or controlling the direction of a wellbore as it is being drilled. Usually the goal of directional drilling is to reach or maintain a position within a target subterranean destination or formation with the drilling string. For instance, the drilling direction may be controlled to direct the wellbore towards a desired target destination, to control the wellbore horizontally to maintain it within a desired payzone or to correct for unwanted or undesired deviations from a desired or predetermined path.

Thus, directional drilling may be defined as deflection of a wellbore along a predetermined or desired path in order to reach or intersect with, or to maintain a position within, a specific subterranean formation or target. The predetermined path typically includes a depth where initial deflection occurs and a schedule of desired deviation angles and directions over the remainder of the wellbore. Thus, deflection is a change in the direction of the wellbore from the current wellbore path.

It is often necessary to adjust the direction of the wellbore frequently while directional drilling, either to accommodate a planned change in direction or to compensate for unintended or unwanted deflection of the wellbore. Unwanted deflection may result from a variety of actors, including the characteristics of the formation being drilled, the makeup of the bottomhole drilling assembly and the manner in which the wellbore is being drilled.

Deflection is measured as an amount of deviation of the wellbore from the current wellbore path and is expressed as a deviation angle or hole angle. Commonly, the initial wellbore path is in a vertical direction. Thus, initial deflection often signifies a point at which the wellbore has deflected off vertical. As a result, deviation is commonly expressed as an angle in degrees from the vertical.

Various techniques may be used for directional drilling. First, the drilling bit may be rotated by a downhole motor which is powered by the circulation of fluid supplied from the surface. This technique, sometimes called "sliding drilling", is typically used in directional drilling to effect a change in direction of the a wellbore, such as the building of an angle of deflection. However, various problems are often encountered with sliding drilling.

Second, directional drilling may be accomplished by rotating the entire drilling string from the surface, which in turn rotates a drilling bit connected to the end of the drilling string. More specifically, in rotary drilling, the bottomhole assembly, including the drilling bit, is connected to the drilling string which is rotatably driven from the surface. This technique is relatively inexpensive because the use of specialized equipment such as downhole drilling motors can usually be kept to a minimum. In addition, traditional problems related to sliding drilling are often reduced. The rate of penetration of the drilling bit tends to be greater, while the wear of the drilling bit and casing are often reduced.

However, rotary drilling tends to provide relatively limited control over the direction or orientation of the resulting wellbore as compared to sliding drilling, particularly in extended-reach wells. Thus rotary drilling has tended to be largely used for non-directional drilling or directional drilling where no change in direction is required or intended.

Third, a combination of rotary and sliding drilling may be performed. Rotary drilling will typically be performed until such time that a variation or change in the direction of the wellbore is desired. The rotation of the drilling string is typically stopped and sliding drilling, through use of the downhole motor, is commenced. Although the use of a combination of sliding and rotary drilling may permit satisfactory control over the direction of the wellbore, the problems and disadvantages associated with sliding drilling are still encountered.

Some attempts have been made in the prior art to address these problems. Specifically, attempts have been made to provide a steerable rotary drilling apparatus or system for use in directional drilling. Many of these downhole apparatuses or systems are of a type comprising a rotatable shaft and a housing for rotatably supporting a length of the shaft for rotation therein. In order to permit the rotation of the shaft relative to the housing within the borehole, a mechanism or device is typically required to restrain the rotation of the housing in the borehole upon the rotation of the shaft, and thus permit the proper functioning of the downhole apparatus.

Thus, there is a need in the industry for a rotation restraining device in an apparatus for use in a borehole, such as a steerable rotary drilling device or a drilling direction control device for use with a rotary drilling string or a downhole motor, for retraining the rotation of a housing upon rotation of a shaft therein.

SUMMARY OF INVENTION

The present invention is directed at a rotation restraining device or anti-rotation device for use in borehole. More particularly, in an apparatus for use in a borehole, wherein the apparatus is of a type comprising a rotatable shaft and a housing for rotatably supporting a length of the shaft for rotation therein, the present invention is directed at a rotation restraining device associated with the housing for restraining rotation of the housing upon the rotation of the shaft therein.

The apparatus, with which the rotation restraining device is associated, may be any apparatus intended for use downhole in a borehole, such as for the drilling or production of the borehole, and which is comprised of the rotatable shaft and housing as described. For instance, the rotation restraining device may be associated with the housing of a downhole motor assembly for drilling or production, a steerable rotary drilling device or a drilling direction control device or any apparatus or sub comprising a portion of a downhole drill string or production string. However, in the preferred embodiment, the apparatus with which the rotation restraining device is associated is a steerable rotary drilling device or drilling direction control device.

The rotation restraining device is preferably associated with the housing of the apparatus for restraining rotation of the housing, particularly upon the rotation of the rotatable shaft within the housing. The rotation restraining device provides a restraining or anti-rotation function between the housing and a wall of the borehole during operation of the apparatus in the borehole.

The rotation restraining device is particularly described for use with a drilling direction control device. However, the rotation restraining device may be used within any apparatus, preferably a drilling apparatus, of the type comprising a rotatable drilling shaft and a housing for rotatably supporting a length of the drilling shaft for rotation therein, wherein the rotation restraining device is associated with the housing for restraining rotation of the housing. The rotation restraining device may be associated with the housing in any manner or by any structure or mechanism permitting the rotation restraining device to restrain or otherwise inhibit the rotation of the housing within the borehole.

The rotation restraining device or anti-rotation device may be comprised of a single member extending from the housing. Preferably, the rotation restraining device is comprised of a plurality of members arranged axially along the housing, about a circumference of the housing or both, each of which members are capable of protruding radially from the housing and are capable of engaging the borehole wall to perform the restraining or anti-rotation function.

In a first aspect of the invention, in an apparatus for use in a borehole, the apparatus being of a type comprising a rotatable shaft and a housing for rotatably supporting a length of the shaft for rotation therein, the invention is comprised of a rotation restraining device associated with the housing for restraining rotation of the housing, the rotation restraining device comprising a plurality of rollers, each roller having an axis of rotation substantially perpendicular to a longitudinal axis of the housing and being oriented such that the roller is capable of rolling about an axis of rotation of the roller in response to a force exerted on the roller substantially in the direction of the longitudinal axis of the housing, wherein at least two of the plurality of rollers are spaced about a circumference of the housing and axially along the housing so that the rollers are staggered axially along the housing.

As indicated, the rotation restraining device is comprised of a plurality of rollers, wherein each roller has an axis of rotation substantially perpendicular to a longitudinal axis of the housing and is oriented such that the roller is capable of rolling about an axis of rotation of the roller in response to a force exerted on the roller substantially in the direction of the longitudinal axis of the housing.

Preferably each roller is comprised of a peripheral surface about a circumference of the roller and preferably the peripheral surface is comprised of an engagement surface for engaging a borehole wall to restrain rotation of the housing. The engagement surface may have any shape or configuration capable of contacting and engaging the borehole wall. Preferably, the engagement surface is comprised of the peripheral surface of the roller being tapered.

Each roller may be positioned on the housing at a fixed radial position extending from the housing, but preferably the roller is capable of movement between a retracted position and an extended position in which it extends radially from the housing. Any mechanism or structure may be operatively associated with the roller to permit the movement of the roller between the retracted and extended positions. However, preferably, the rotation restraining device is further comprised of a biasing device for biasing the roller toward the extended position, which biasing device may be comprised of any apparatus which can perform the biasing function or which can urge the roller towards the extended position. Preferably the biasing device is comprised of at least one spring which acts between the housing and the roller. Alternatively, the rotation restraining device may be comprised of an actuator or actuator device or mechanism for moving the roller between the retracted and extended positions.

As indicated, in the first aspect of the invention, the rotation restraining device is comprised of a plurality of rollers, wherein at least two of the plurality of rollers are spaced about a circumference of the housing and axially along the housing so that the rollers are staggered axially along the housing.

Each of the rollers may be associated with the housing by any structure or assembly permitting the functioning of the roller as described herein. Preferably, the rotation restraining device is comprised of a plurality of rotation restraining carriage assemblies, wherein each rotation restraining carriage assembly is comprised of at least one roller. More preferably, each rotation restraining carriage assembly is comprised of a plurality of rollers.

Further, at least two of the rotation restraining carriage assemblies are preferably spaced about the circumference of the housing and axially along the housing so that the rotation restraining carriage assemblies are staggered axially along the housing. In the preferred embodiment, the plurality of rotation restraining carriage assemblies are spaced substantially evenly about the circumference of the housing.

The rollers comprising each rotation restraining carriage assembly may be arranged relative to each other in any configuration. In the preferred embodiment, each rotation restraining carriage assembly is comprised of a plurality of sets of rollers spaced axially along the housing, and wherein each set of rollers is comprised of a plurality of coaxial rollers spaced side to side.

In the preferred embodiment of the rotation restraining device comprising rollers, the rotation restraining device is comprised of three rotation restraining carriage assemblies spaced substantially evenly about the circumference of the housing, wherein each rotation restraining carriage assembly is comprised of three sets of rollers spaced axially along the housing, and wherein each set of rollers is comprised of four coaxial rollers spaced side to side.

In this instance, as described previously, at least two of the rotation restraining carriage assemblies are also spaced axially along the housing so that the rotation restraining carriage assemblies are staggered axially along the housing.

In a second aspect of the invention, in an apparatus for use in a borehole, the apparatus being of a type comprising a rotatable shaft and a housing for rotatably supporting a length of the shaft for rotation therein, the invention is comprised of a rotation restraining device associated with the housing for restraining rotation of the housing, the rotation restraining device comprising a plurality of pistons, wherein at least two of the plurality of pistons are spaced about a circumference of the housing and axially along the housing so that the pistons are staggered axially along the housing.

Each piston is comprised of an outermost engagement surface for engaging a borehole wall to restrain rotation of the housing. The outermost engagement surface may have any shape or configuration capable of contacting and engaging the borehole wall.

The piston may be a fixed member which does not move radially relative to the housing. However, preferably, each piston is capable of movement between a retracted position and an extended position in which it extends radially from the housing. Any mechanism or structure may be operatively associated with the piston to permit the movement of the piston between the retracted and extended positions. However, preferably, the rotation restraining device is further comprised of an actuator or actuator device or mechanism for moving the piston between the retracted position and the extended position. The actuator device may be comprised of any apparatus which is capable of moving the piston radially relative to the housing. In the preferred embodiment, the actuator device is comprised of a hydraulic pump. Alternatively, the rotation restraining device may be comprised of a biasing device for biasing the piston toward the extended position.

As indicated, in the second aspect of the invention, the rotation restraining device is comprised of a plurality of pistons, wherein at least two of the plurality of pistons are spaced about a circumference of the housing and axially along the housing so that the pistons are staggered axially along the housing.

Each of the pistons may be associated with the housing by any structure or assembly permitting the functioning of the piston as described herein. However, preferably, the rotation restraining device is comprised of a plurality of rotation restraining carriage assemblies, wherein each rotation restraining carriage assembly is comprised of at least one piston. More preferably, each rotation restraining carriage assembly is comprised of a plurality of pistons.

Further, at least two of the rotation restraining carriage assemblies are preferably spaced about the circumference of the housing and axially along the housing so that the rotation restraining carriage assemblies are staggered axially along the housing. In the preferred embodiment, the plurality of rotation restraining carriage assemblies are spaced substantially evenly about the circumference of the housing.

The pistons comprising each rotation restraining carriage assembly may be arranged relative to each other in any configuration. In the preferred embodiment, each rotation restraining carriage assembly is comprised of a plurality of pistons spaced axially along the housing.

In the preferred embodiment of the rotation restraining device comprising pistons, the rotation restraining device is comprised of four rotation restraining carriage assemblies spaced substantially evenly about the circumference of the housing, wherein each rotation restraining carriage assembly is comprised of a plurality of pistons spaced axially along the housing.

In this instance, as described previously, at least two of the rotation restraining carriage assemblies are also spaced axially along the housing so that the rotation restraining carriage assemblies are staggered axially along the housing.

BRIEF DESCRIPTION OF DRAWINGS

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a pictorial side view of a preferred embodiment of a drilling direction control device showing a rotation restraining device associated therewith;

Figure 2(a) is a pictorial side view, having a cut-away portion, of the drilling direction control device shown in Figure 1 contained within a borehole and comprising a drilling shaft, wherein the drilling shaft is in an undeflected condition;

Figure 2(b) is a schematic cross-sectional view of a deflection assembly of the drilling direction control device shown in Figure 2(a) in an undeflected condition;

Figure 3(a) is a pictorial side view, having a cut-away portion, of the drilling direction control device shown in Figure 1 contained within a borehole, wherein the drilling shaft is in a deflected condition;

Figure 3(b) is a schematic cross-sectional view of a deflection assembly of the drilling direction control device shown in Figure 3(a) in a deflected condition;

Figures 4(a) through 4(g) are longitudinal sectional views of the drilling direction control device shown in Figures 2 and 3, wherein Figures 4(b) through 4(g) are lower continuations of Figures 4(a) through 4(f) respectively;

Figure 5 is a more detailed schematic cross-sectional view of the deflection assembly of the drilling direction control device shown in Figures 2(b) and 3(b);

Figure 6 is a pictorial view of a portion of the deflection assembly of the drilling direction control device shown in Figure 1;

Figure 7 is a pictorial side view of a rotation restraining device of the drilling direction control device shown in Figure 1, showing an arrangement of a plurality of rotation restraining carriage assemblies spaced circumferentially about a housing;

Figure 8 is an exploded pictorial side view of the rotation restraining device shown in Figure 7;

Figure 9 is a pictorial side view of an alternate rotation restraining device of the drilling direction control device shown in Figure 1, showing an arrangement of a plurality of rotation restraining carriage assemblies spaced circumferentially about a housing;

Figure 10 is an exploded pictorial side view of the alternate rotation restraining device shown in Figure 9;

Figure 11 is an exploded pictorial side view of a preferred embodiment of the rotation restraining device of the within invention, showing a preferred staggered arrangement of the plurality of rotation restraining carriage assemblies spaced circumferentially about the housing and axially along the housing;

Figure 12 is a further exploded pictorial side view of the rotation restraining device shown in Figure 11;

Figure 13 is an exploded pictorial side view of a preferred alternate embodiment of the rotation restraining device of the within invention, showing a preferred alternate staggered arrangement of the plurality of rotation restraining carriage assemblies spaced circumferentially about the housing and axially along the housing;

Figure 14 is an end view of the alternate rotation restraining device shown in Figure 13.

DETAILED DESCRIPTION

In the preferred embodiment, the within invention, being a rotation restraining device, is for use in an apparatus (20) for use in a borehole, preferably a drilling direction control device. Thus, any reference to the "device (20)" used herein is a reference to the apparatus with which the rotation restraining device is associated in the preferred embodiment. The device (20) permits directional control over a drilling bit (22) connected with the device (20) during rotary drilling operations by controlling the orientation of the drilling bit (22). As a result, the direction of the resulting wellbore or borehole may be controlled. Specifically, in the preferred embodiment, the device (20) maintains the desired orientation of the drilling bit (22) by maintaining the desired toolface of the drilling bit (22) and the desired bit tilt angle, while preferably enhancing the rotations per minute and rate of penetration.

The device (20) is comprised of a rotatable drilling shaft (24) which is connectable or attachable to a rotary drilling string (25) during the drilling operation. More particularly, the drilling shaft (24) has a proximal end (26) and a distal end (28). The proximal end (26) is drivingly connectable or attachable with the rotary drilling string (25) such that rotation of the drilling string (25) from the surface results in a corresponding rotation of the drilling shaft (24). The proximal end (26) of the drilling shaft (24) may be permanently or removably attached, connected or otherwise affixed with the drilling string (25) in any manner and by any structure, mechanism, device or method permitting the rotation of the drilling shaft (24) upon the rotation of the drilling string (25).

Preferably, the device (20) is further comprised of a drive connection for connecting the drilling shaft (24) with the drilling string (25). As indicated, the drive connection may be comprised of any structure, mechanism or device for drivingly connecting the drilling shaft (24) and the drilling string (25) so that rotation of the drilling string (25) results in a corresponding rotation of the drilling shaft (24). However, preferably, the drive connection is comprised of a tolerance assimilation sleeve (30). More particularly, the tolerance assimilation sleeve (30) is interspersed or positioned between the proximal end (26) of the drilling shaft (24) and the adjacent end of the drilling string (25).

Preferably, the drive connection is comprised of a first drive profile (32) on or defined by the drilling shaft (24), and particularly, on or defined by the proximal end (26) of the drilling shaft (24). The drive connection is further comprised of a second drive profile (34), complementary to the first drive profile (32), on or defined by the adjacent end of the drilling string (25) to be drivingly connected with the drilling shaft (24) of the device (20). The tolerance assimilation sleeve (30) is positioned or interspersed between the first drive profile (32) and the second drive profile (34) in order to reduce the tolerance between the first drive profile (32) and the second drive profile (34) and provide a backlash free drive. The first and second drive profiles (32, 34) are thus sized and configured to be complementary to and compatible with the tolerance assimilation sleeve (30) therebetween.

In the preferred embodiment, the first drive profile (32) is defined by an outer surface (33) of the proximal end (26) of the drilling shaft (24). Further, the second drive profile (34) is defined by an inner surface (36) of the adjacent end of the drilling string (25). Thus, the tolerance assimilation sleeve (30) is positioned between the outer surface (33) of the drilling shaft (24) and the inner surface (36) of the drilling string (25). More particularly, the tolerance assimilation sleeve (30) has an outer surface (38) for engaging the inner surface (36) of the drilling string (25) and an inner surface (40) for engaging the outer surface (33) of the drilling shaft (24).

As indicated, the adjacent outer surface (38) of the sleeve (30) and inner surface (36) of the drilling string (25) and adjacent inner surface (40) of the sleeve (30) and outer surface (33) of the drilling shaft (24) may have any shape or configuration compatible with providing a driving connection therebetween and capable of reducing the tolerance between the first drive profile (32) and the complementary second drive profile (34). However, in the preferred embodiment, the tolerance assimilation sleeve (30) has octagonal internal and external profiles. In other words, both the inner and outer surfaces (40, 38) of the sleeve (30) are octagonal on cross-section.

In addition, preferably, the drilling shaft (24), the drilling string (25) and the tolerance assimilation sleeve (30) therebetween are configured such that torque or radial loads only are transmitted between the drilling shaft (24) and the drilling string (25). In other words, preferably, no significant axial forces or loads are transmitted therebetween by the tolerance assimilation sleeve (30). Thus, although the tolerance assimilation sleeve (30) may be tied or anchored with one of the drilling shaft (24) and the drilling string (25), it is preferably not tied or anchored with both the drilling shaft (24) and the drilling string (25). In the preferred embodiment, the tolerance assimilation sleeve (30) is tied or anchored with neither the drilling shaft (24) nor the drilling string (25).

Further, the tolerance assimilation sleeve (30) may reduce the tolerance between the first and second drive profiles (32, 34) in any manner and by any mechanism of action. For instance, preferably, the tolerance assimilation sleeve is comprised of a material having a thermal expansion rate higher than the thermal expansion rate of the drilling string (25). In the preferred embodiment, the drilling shaft (24) has the highest thermal expansion rate and the drilling string (25) has the lowest thermal expansion rate. The thermal expansion rate of the tolerance assimilation sleeve (30) is preferably between that of the drilling shaft (24) and the drilling string (25). Any material providing for this differential rate of thermal expansion and having a relatively high strength compatible with the drilling operation may be used. However, in the preferred embodiment, the tolerance assimilation sleeve (30) is a beryllium copper sleeve.

Similarly, the distal end (28) of the drilling shaft (24) is drivingly connectable or attachable with the rotary drilling bit (22) such that rotation of the drilling shaft (24) by the drilling string (25) results in a corresponding rotation of the drilling bit (22). The distal end (28) of the drilling shaft (24) may be permanently or removably attached, connected or otherwise affixed with the drilling bit (22) in any manner and by any structure, mechanism, device or method permitting the rotation of the drilling bit (22) upon the rotation of the drilling shaft (24). In the preferred embodiment, a threaded connection is provided therebetween. More particularly, an inner surface (42) of the distal end (28) of the drilling shaft (24) is threadably connected and drivingly engaged with an adjacent outer surface (44) of the drilling bit (22).

The device (20) provides for the controlled deflection of the drilling shaft (24) resulting in a bend or curvature of the drilling shaft (24), as described further below, in order to provide the desired deflection of the attached drilling bit (22). Preferably, the orientation of the deflection of the drilling shaft (24) may be altered to alter the orientation of the drilling bit (22) or tool face, while the magnitude of the deflection of the drilling shaft (24) may be altered to vary the magnitude of the deflection of the drilling bit (22) or the bit tilt.

The drilling shaft (24) may be comprised of one or more elements or portions connected, attached or otherwise affixed together in any suitable manner providing a unitary drilling shaft (24) between the proximal and distal ends (26, 28). Preferably, any connections provided between the elements or portions of the drilling shaft (24) are relatively rigid such that the drilling shaft (24) does not include any flexible joints or articulations therein. In the preferred embodiment, the drilling shaft (24) is comprised of a single, unitary or integral element extending between the proximal and distal ends (26, 28). Further, the drilling shaft (24) is tubular or hollow to permit drilling fluid to flow therethrough in a relatively unrestricted or unimpeded manner. Finally, the drilling shaft (24) may be comprised of any material suitable for and compatible with rotary drilling. In the preferred embodiment, the drilling shaft (24) is comprised of high strength stainless steel.

Further, the device (20) is comprised of a housing (46) for rotatably supporting a length of the drilling shaft (24) for rotation therein upon rotation of the attached drilling string (25). The housing (46) may support, and extend along, any length of the drilling shaft (24). However, preferably, the housing (46) supports substantially the entire length of the drilling shaft (24) and extends substantially between the proximal and distal ends (26, 28) of the drilling shaft (24).

In the preferred embodiment, the housing (46) has a proximal end (48) adjacent or in proximity to the proximal end (26) of the drilling shaft (24). Specifically, the proximal end (26) of the drilling shaft (24) extends from the proximal end (48) of the housing (46) for connection with the drilling string (25). However, in addition, a portion of the adjacent drilling string (25) may extend within the proximal end (48) of the housing (46). Similarly, in the preferred embodiment, the housing (46) has a distal end (50) adjacent or in proximity to the distal end (28) of the drilling shaft (24). Specifically, the distal end (28) of the drilling shaft

(24) extends from the distal end (50) of the housing (46) for connection with the drilling bit (22).

The housing (46) may be comprised of one or more tubular or hollow elements, sections or components permanently or removably connected, attached or otherwise affixed together to provide a unitary or integral housing (46) permitting the drilling shaft (24) to extend therethrough. However, in the preferred embodiment, the housing (46) is comprised of three sections or portions connected together. Specifically, starting at the proximal end (48) and moving towards the distal end (50) of the housing (46), the housing (46) is comprised of a proximal housing section (52), a central housing section (54) and a distal housing section (56).

More particularly, the proximal end (48) of the housing (46) is defined by a proximal end (58) of the proximal housing section (52). A distal end (60) of the proximal housing section (52) is connected with a proximal end (62) of the central housing section (54). Similarly, a distal end (64) of the central housing section (54) is connected with a proximal end (66) of the distal housing section (56). The distal end (50) of the housing (46) is defined by a distal end (68) of the distal housing section (56).

As indicated, the distal end (60) of the proximal housing section (52) and the proximal end (62) of the central housing section (54), as well as the distal end (64) of the central housing section (54) and the proximal end (66) of the distal housing section (56), may each be permanently or removably attached, connected or otherwise affixed together in any manner and by any structure, mechanism, device or method permitting the formation of a unitary housing (46).

However, in the preferred embodiment, both of the connections are provided by a threaded connection between the adjacent ends. More particularly, the proximal housing section (52) has an inner surface (70) and an outer surface (72). Similarly, the central housing section (54) has an inner surface (74) and an outer surface (76) and the distal housing section (56) has an inner surface (78) and an outer surface (80). The outer surface (72) of the proximal housing section (52) at its distal end (60) is threadably connected with the inner surface (74) of the central housing section (54) at its proximal end (62). Similarly, the outer surface (76) of the central housing section (54) at its distal end (64) is threadably connected with the inner surface (78) of the distal housing section (56) at its proximal end (66).

The device (20) is further comprised of at least one distal radial bearing (82) and at least one proximal radial bearing (84). Each of the radial bearings (82, 84) is contained within the housing (46) for rotatably supporting the drilling shaft (24) radially at the location of that particular radial bearing (82, 84). The radial bearings (82, 84) may be positioned at any locations along the length of the drilling shaft (24) permitting the bearings (82, 84) to rotatably radially support the drilling shaft (24) within the housing (46). In addition, the radial bearings (82, 84) are positioned between the drilling shaft (24) and the housing (46).

In addition, one or more further radial bearings may be contained within the housing (46) to assist in supporting the drilling shaft (24). Where such further radial bearings are provided, these further radial bearings are located distally or downhole to the distal radial bearing (82) and proximally or uphole of the proximal radial bearing (84). In other words, preferably, the further radial bearings are not located between the distal and proximal radial bearings (82, 84).

Preferably, at least one distal radial bearing (82) is contained within the housing (46) for rotatably supporting the drilling shaft (24) radially at a distal radial bearing location (86) defined thereby. In the preferred embodiment, the distal radial bearing (82) is contained within the distal housing section (56), positioned between the inner surface (78) of the distal housing section (56) and the drilling shaft (24), for rotatably supporting the drilling shaft (24) radially at the distal radial bearing location (86) defined thereby.

Although the distal radial bearing (82) may be comprised of any radial bearing able to rotatably support the drilling shaft (24) within the housing (46) at the distal radial bearing location (86), the distal radial bearing (82) is preferably comprised of a fulcrum bearing (88), also referred to as a focal bearing, as described in greater detail below. The fulcrum bearing (88) facilitates the pivoting of the drilling shaft (24) at the distal radial bearing location (86) upon the controlled deflection of the drilling shaft (24) by the device (20) to produce a bending or curvature of the drilling shaft (24) in order to orient or direct the drilling bit (22).

Preferably, the device (20) is further comprised of a near bit stabilizer (89), which in the preferred embodiment is located adjacent to the distal end (50) of the housing (46) and coincides with the distal radial bearing location (86). The near bit stabilizer (89) may be comprised of any type of stabilizer.

Further, preferably, at least one proximal radial bearing (84) is contained within the housing (46) for rotatably supporting the drilling shaft (24) radially at a proximal radial bearing location (90) defined thereby. In the preferred embodiment, the proximal radial bearing (84) is contained within the central housing section (54), positioned between the inner surface (74) of the central housing section (54) and the drilling shaft (24), for rotatably supporting the drilling shaft (24) radially at the proximal radial bearing location (90) defined thereby.

Although the proximal radial bearing (84) may be comprised of any radial bearing able to rotatably radially support the drilling shaft (24) within the housing (46) at the proximal radial bearing location (90), the proximal radial bearing (84) is preferably comprised of a cantilever bearing.

Upon the controlled deflection of the drilling shaft (24) by the device (20), as described further below, the curvature or bending of the drilling shaft (24) is produced downhole of the cantilever proximal radial bearing (84). In other words, the controlled deflection of the drilling shaft (24), and thus the curvature of the drilling shaft (24), occurs between the proximal radial bearing location (90) and the distal radial bearing location (86). The cantilever nature of the proximal radial bearing (84) inhibits the bending of the drilling shaft (24) uphole or above the proximal radial bearing (84). The fulcrum bearing comprising the distal radial bearing (82) facilitates the pivoting of the drilling shaft (24) and permits the drilling bit (22) to tilt in any desired direction. Specifically, the drilling bit (22) is permitted to tilt in the opposite direction of the bending direction.

Further, the device (20) is comprised of a drilling shaft deflection assembly (92) contained within the housing (46) for bending the drilling shaft (24) therein. The deflection assembly (92) may be located axially at any location or position between the distal end (50) and the proximal end (48) of the housing (46). However, the distal radial bearing location (86) is preferably axially located between the distal end (50) of the housing (46) and the deflection assembly (92), while the proximal radial bearing location (90) is preferably axially located between the proximal end (48) of the housing (46) and the deflection assembly (92). In other words, the drilling shaft deflection assembly (92) is preferably located axially along the length of the drilling shaft (24) at a location or position between the distal radial bearing location (86) and the proximal radial bearing location (90). As described previously, in the preferred embodiment, the deflection assembly (92) is provided for bending the drilling shaft (24) between the distal radial bearing location (86) and the proximal radial bearing location (90).

In the preferred embodiment, the deflection assembly (92) is contained within the distal housing section (56) between the inner surface (78) of the distal housing section (56) and the drilling string (24). The distal radial bearing location (86) is axially located between the distal end (68) of the distal housing section (56) and the deflection assembly (92), while the proximal radial bearing location (90) is axially located between the deflection assembly (92) and the proximal end (48) of the housing (46).

In addition to the radial bearings (82, 84) for rotatably supporting the drilling shaft (24) radially, the device (20) further preferably includes one or more thrust bearings for rotatably supporting the drilling shaft (24) axially. Preferably, the device (20) is comprised of at least one distal thrust bearing (94) and at least one proximal thrust bearing (96). As indicated, each of the thrust bearings (94, 96) is contained within the housing (46) for rotatably supporting the drilling shaft (24) axially at the location of that particular thrust bearing (94, 96). The thrust bearings (94, 96) may be positioned at any locations along the length of the drilling shaft (24) permitting the bearings (94, 96) to rotatably support the drilling shaft (24) axially within the housing (46). In addition, the thrust bearings (94, 96) are positioned between the drilling shaft (24) and the housing (46).

However, preferably, at least one distal thrust bearing (94) is contained within the housing (46) for rotatably supporting the drilling shaft (24) axially at a distal thrust bearing location (98) defined thereby. The distal thrust bearing location (98) is preferably located axially between the distal end (50) of the housing (46) and the deflection assembly (92). In the preferred embodiment, the distal thrust bearing (94) is contained within the distal housing section (56), positioned between the inner surface (78) of the distal housing section (56) and the drilling shaft (24), for rotatably supporting the drilling shaft (24) axially. Thus, the distal thrust bearing location (98) is located axially between the distal end (68) of the distal housing section (56) and the deflection assembly (92).

Although the distal thrust bearing (94) may be comprised of any thrust bearing able to rotatably and axially support the drilling shaft (24) within the housing (46) at the distal thrust bearing location (98), the distal thrust bearing (94) is preferably comprised of the fulcrum bearing (88) described above. Thus, the distal thrust bearing location (98) is at the distal radial bearing location (86).

Further, preferably, at least one proximal thrust bearing (96) is contained within the housing (46) for rotatably supporting the drilling shaft (24) axially at a proximal thrust bearing location (100) defined thereby. The proximal thrust bearing location (100) is preferably located axially between the proximal end (48) of the housing (46) and the deflection assembly (92). In addition, more preferably, the proximal thrust bearing location (100) is located axially between the proximal end (48) of the housing (46) and the proximal radial bearing location (90).

Preferably, the proximal thrust bearing (96) is contained within the proximal housing section (52), positioned between the inner surface (70) of the proximal housing section (52) and the drilling shaft (24), for rotatably supporting the drilling shaft (24) axially. More particularly, In the preferred embodiment where the drilling string (25) extends into the proximal end (48) of the housing (46), the proximal thrust bearing (96) is located between the inner surface (70) of the proximal housing section (52) and an outer surface of the drilling string (25). The proximal thrust bearing (96) may be comprised of any thrust bearing.

As a result of the thrust bearings (94, 96), most of the weight on the drilling bit (22) may be transferred into and through the housing (46) as compared to through the drilling shaft (24) of the device (20). Thus, the drilling shaft (24) may be permitted to be slimmer and more controllable. As well, most of the drilling weight bypasses the drilling shaft (24) substantially between its proximal and distal ends (48, 50) and thus bypasses the other components of the device (20) including the deflection assembly (92). More particularly, weight applied on the drilling bit (22) through the drill string (25) is transferred, at least in part, from the drilling string (25) to the proximal end (48) of the housing (46) by the proximal thrust bearing (96) at the proximal thrust bearing location (100). The weight is further transferred, at least in part, from the distal end (50) of the housing (46) to the drilling shaft (24), and thus the attached drilling bit (22), by the fulcrum bearing (88) at the distal thrust bearing location (100).

The fulcrum bearing (88) may be comprised of any combination or configuration of radial and thrust bearings able to radially and axially support the rotating drilling shaft (24) within the housing (46). However, preferably the fulcrum bearing (88) is comprised of a fulcrum bearing assembly. The fulcrum bearing assembly is comprised of at least one row of spherical thrust roller bearings (98) positioned at a first axial position (102) and at least one row of spherical thrust roller bearings (98) positioned at a second axial position (104). In addition, the fulcrum bearing assembly is comprised of at least one row of spherical radial bearings (82) positioned at a third axial position (106), wherein the third axial position (106) is located between the first axial position (102) and the second axial position (104). The spherical thrust bearings (98) and the spherical radial roller bearings (82) are arranged substantially about a common center of rotation. As a result, as described above, the fulcrum bearing assembly allows the drilling bit (22) to tilt in any desired direction and to rotate relatively freely while transferring most of the drilling bit (22) weight into the housing (46).

Each of the distal and proximal thrust bearings (94, 96) is preferably preloaded at the desired distal and proximal thrust bearing locations (98, 100) respectively. Any mechanism, structure, device or method capable of preloading the thrust bearings (94, 96) the desired amount may be utilized. Further, preferably, the mechanism, structure, device or method used substantially maintains the desired preloading during the drilling operation. In addition, although preferred, the same mechanism, structure, device or method need not be used for preloading both thrust bearings (94, 96).

Referring first to the distal thrust bearing (94), the distal thrust bearing (94) is axially maintained within the housing (46) at the distal thrust bearing location (98) between a distal thrust bearing shoulder (108) and a distal thrust bearing collar (110). Thus, in the preferred embodiment, the fulcrum bearing assembly (88) comprising the spherical thrust bearings (98) are axially maintained in position at the first and second axial positions (102, 104) between the distal thrust bearing shoulder (108) and the distal thrust bearing collar (110). More particularly, the distal thrust bearing shoulder (108) abuts, directly or indirectly, against the uppermost or uphole end of the fulcrum bearing assembly (88) comprising the spherical thrust bearings (98), while the distal thrust bearing collar (110) abuts, directly or indirectly, against the lowermost or downhole end of the of the fulcrum bearing assembly (88).

Although any structure or component contained within the housing (46) adjacent the fulcrum bearing assembly uphole may provide or define the distal thrust bearing shoulder (108), the distal thrust bearing shoulder (108) is preferably defined by the inner surface of the housing (46). Thus, in the preferred embodiment, the distal thrust bearing shoulder (108) is defined by the inner surface (78) of the distal housing section (56) adjacent or in proximity to the distal end (50) of the housing (46).

The distal thrust bearing collar (110) is contained within the housing (46) and located about the drilling string (24) for abutment against the lowermost or downhole end of the of the fulcrum bearing assembly (88). Further, the distal thrust bearing collar (110) is axially adjustable relative to the distal thrust bearing shoulder (108) in order to preload the distal thrust bearings (94) located therebetween. In the preferred embodiment, given that the distal thrust bearings (94) are spherical, any radial loads tend to separate the bearings (94), and thus, tend to separate the fulcrum bearing (88). As a result, a sufficient preloading force is applied to the distal thrust bearings (94) such that the radial loads encountered by the thrust bearings (94) will not comprise the thrust bearings (94) within the fulcrum bearing (88).

Further, to facilitate the preloading, one or more springs or washers, preferably Belleville washers (111) are preferably located at, adjacent or in proximity to the opposing ends of the fulcrum bearing assembly (88) such that the Belleville washers (111) are also axially maintained between the distal thrust bearing shoulder (108) and the distal thrust bearing collar (110). Preloading of the distal thrust bearings (94) results in compression of the Belleville washers (111). In other words, in order to preload the bearings (94), the distal thrust bearing collar (110) is axially adjustable relative to the distal thrust bearing shoulder (108) in order to preload the distal thrust bearings (94) located therebetween by compressing the Belleville washers (111).

The distal thrust bearing collar (110) may be adjusted axially in any manner and by any mechanism, structure or device able to axially adjust the distal thrust bearing collar (110) relative to the distal thrust bearing shoulder (108). However, preferably, the distal thrust bearing collar (110) is threaded for adjustment by rotation. More particularly, in the preferred embodiment, the distal thrust bearing collar (110) has a proximal end (114) for abutting against the adjacent fulcrum bearing assembly (88) and a distal end (116) extending from and beyond the distal end (68) of the distal housing section (56). An outer surface (118) of the distal thrust bearing collar (110) at its proximal end (114) is threaded for connection with a complementary threaded inner surface (78) of the distal housing section (56) at its distal end (68). As a result of the threaded connection, rotation of the distal thrust bearing collar (110) axially adjusts the collar (110) either towards or away from the distal thrust bearing shoulder (108) to increase or decrease the preloading respectively on the distal thrust bearings (94).

Further, the device (20) preferably provides for the retention of the distal thrust bearing or bearings (94) at the desired position without causing an increase in the preloading thereon. Any structure, device, mechanism or method able to retain the distal thrust bearing (94) in position without increasing the preloading thereon may be utilized. However, preferably, the device (20) is further comprised of a distal thrust bearing retainer (112) for retaining the spherical distal thrust bearings (94) comprising the fulcrum bearing assembly (88) in position without increasing the preloading on the spherical distal thrust bearings (94).

In the preferred embodiment, the distal thrust bearing retainer (112) is comprised of a locking ring (120) and a locking ring collar (122). The locking ring (120) is slidably mounted on the distal thrust bearing collar (110), about the outer surface (118) of the collar (110). Accordingly, once the distal thrust bearing collar (110) is axially adjusted to preload the bearing (94), the locking ring (120) may be selectively moved longitudinally along the outer surface (118) of the collar (110) to a position abutting the distal end (50) of the housing (46).

Once the locking ring (120) is moved into abutment with the housing (46), the locking ring collar (122) can be tightened against the locking ring (120) to hold the locking ring (120) in position between the housing (46) and the locking ring collar (122). The locking ring (120) acts upon the distal thrust bearing collar (110) to inhibit the rotation of the distal thrust bearing collar (110) away from the distal thrust bearing shoulder (108) and thus maintain the preloading.

Preferably, the locking ring collar (122) is mounted about the drilling string (24) adjacent the distal end (50) of the housing (46) such that the locking ring (120) is located or positioned between the distal end (50) of the housing (46) and a proximal end (124) of the locking ring collar (122). Further, the locking ring collar (122) is axially adjustable relative to the housing (46) such that the locking ring (120) may be held therebetween upon tightening of the locking ring collar (122).

The locking ring collar (122) may be adjusted axially in any manner and by any mechanism, structure or device able to axially adjust the locking ring collar (122) relative to the housing (46). However, preferably, the locking ring collar (122) is threaded for adjustment by rotation. More particularly, in the preferred embodiment, the outer surface (118) of the distal thrust bearing collar (110) at its distal end (116) is threaded for connection with a complementary threaded inner surface (126) of the locking ring collar (122) at its proximal end (124). As a result of the threaded connection, rotation of the locking ring collar (122) axially adjusts the locking ring collar (122) either towards or away from the distal end (50) of the housing (46) to tighten or release the locking ring (120) located therebetween. In the preferred embodiment, the locking ring collar (122) is tightened to between about 8000 to 10,000 ft lbs. The tightening of the locking ring collar (122) holds the locking ring (120) in position without increasing the preloading on the distal thrust bearings (94).

When the locking ring collar (122) is tightened against the locking ring (120), the locking ring (120) acts upon the distal thrust bearing collar (110) to inhibit the rotation of the distal thrust bearing collar (110) away from the distal thrust bearing shoulder (108) and thus to maintain the preloading. In order to enhance or facilitate the action of the distal thrust bearing retainer (112), the locking ring (120) preferably does not rotate, or is inhibited from rotating, relative to the distal thrust bearing collar (110). This relative rotation may be prevented or inhibited in any manner and by any structure, device or mechanism capable of preventing or inhibiting the undesired relative rotation between the locking ring (120) and the distal thrust bearing collar (110). However, preferably, the locking ring (120) is mounted on the distal thrust bearing collar (110) such that the locking ring (120) does not rotate, or is inhibited from rotating, relative to the distal thrust bearing collar (110).

The locking ring (120) may be mounted on the distal thrust bearing collar (110) in any manner and by any structure, device or mechanism capable of preventing or inhibiting the undesired relative rotation between the locking ring (120) and the distal thrust bearing collar (110). For instance, in the preferred embodiment, at least one key and slot configuration is utilized. Specifically, a key (123) extends between a slot or groove defined by each of the adjacent surfaces of the distal thrust bearing collar (110) and the distal locking ring (120).

In addition, in order to further enhance or facilitate the action of the distal thrust bearing retainer (112), the locking ring (120) preferably does not rotate, or is inhibited from rotating, relative to the housing (46). This relative rotation may be prevented or inhibited in any manner and by any structure, device or mechanism capable of preventing or inhibiting the undesired relative rotation between the locking ring (120) and the housing (46). However, preferably, the configurations of the adjacent abutting surfaces of the locking ring (120) and the housing (46) are complementary such that the locking ring (120) does not rotate, or is inhibited from rotating, relative to the housing (46).

In the preferred embodiment, the locking ring is further comprised of a housing abutment surface (128). In addition, the housing (46), and in particular the distal end (68) of the distal housing section (56), is further comprised of a locking ring abutment surface (130). The locking ring abutment surface (130) is complementary to the housing abutment surface (128) such that the engagement of the housing abutment surface (128) and the locking ring abutment surface (130) prevents or inhibits the rotation of the locking ring (120) relative to the housing (46). Although any complementary surface configurations may be used, the locking ring abutment surface (130) and the housing abutment surface (128) each preferably define a plurality of complementary interlocking teeth.

Next, referring to the proximal thrust bearing (96), the proximal thrust bearing (96) is axially maintained within the housing (46) and preloaded in a manner similar to that of the distal thrust bearing (94) and by similar components or structure as described above for the distal thrust bearing (94). The proximal thrust bearing or bearings (96) are axially maintained within the housing (46) at the proximal thrust bearing location (100) between a proximal thrust bearing shoulder (132) and a proximal thrust bearing collar (134). More particularly, the proximal thrust bearing shoulder (132) abuts, directly or indirectly, against the lowermost or downhole end of the proximal thrust bearing (96), while the proximal thrust bearing collar (134) abuts, directly or indirectly, against the uppermost or uphole end of the proximal thrust bearing (96).

Although any structure or component contained within the housing (46) adjacent the proximal thrust bearing (96) uphole may provide or define the proximal thrust bearing shoulder (132), the proximal thrust bearing shoulder (132) is preferably defined by the inner surface of the housing (46). Thus, in the preferred embodiment, the proximal thrust bearing shoulder (132) is defined by the inner surface (70) of the proximal housing section (52) adjacent or in proximity to the proximal end (48) of the housing (46).

The proximal thrust bearing collar (134) is contained within the housing (46) and located about the drilling string (24) for abutment against the uppermost or uphole end of the proximal thrust bearing (96). Further, the proximal thrust bearing collar (134) is axially adjustable relative to the proximal thrust bearing shoulder (132) in order to preload the proximal thrust bearing or bearings (96) located therebetween. In the preferred embodiment, in contrast with the distal thrust bearings (94), the proximal thrust bearings (96) are not spherical. Thus, radial loads do not tend to separate the proximal thrust bearings (96) and the bearing preloading force applied to the proximal thrust bearings (96) may be significantly less than that applied to the distal thrust bearings (94).

To facilitate the preloading, one or more springs or washers, preferably a washer such as a wave washer, is preferably located or associated with the proximal thrust bearings (96) such that the washer is also axially maintained between the proximal thrust bearing shoulder (132) and the proximal thrust bearing collar (134). Preloading of the proximal thrust bearings (96) results in compression of the washer. In other words, in order to preload the bearings (96), the proximal thrust bearing collar (134) is axially adjustable relative to the proximal thrust bearing shoulder (132) in order to preload the proximal thrust bearings (96) located therebetween by compressing the washer.

The proximal thrust bearing collar (134) may be adjusted axially in any manner and by any mechanism, structure or device able to axially adjust the proximal thrust bearing collar (134) relative to the proximal thrust bearing shoulder (132). However, preferably, the proximal thrust bearing collar (134) is threaded for adjustment by rotation. More particularly, in the preferred embodiment, the proximal thrust bearing collar (134) has a proximal end (138) extending from and beyond the proximal end (58) of the proximal housing section (52) and a distal end (140) for abutting against the adjacent proximal thrust bearing (96). An outer surface (142) of the proximal thrust bearing collar (134) at its distal end (140) is threaded for connection with a complementary threaded inner surface (70) of the proximal housing section (52) at its proximal end (58). As a result of the threaded connection, rotation of the proximal thrust bearing collar (134) axially adjusts the collar (134) either towards or away from the proximal thrust bearing shoulder (132) to increase or decrease the preloading respectively on the proximal thrust bearing (96).

Further, the device (20) preferably similarly provides for the retention of the proximal thrust bearing or bearings (96) at the desired position without causing an increase in the preloading thereon. Any structure, device, mechanism or method able to retain the proximal thrust bearing (96) in position without increasing the preloading thereon may be utilized. However, preferably, the device (20) is further comprised of a proximal thrust bearing retainer (136) for retaining the proximal thrust bearing (96) in position without increasing the preloading on the proximal thrust bearing (96).

In the preferred embodiment, the proximal thrust bearing retainer (136) is comprised of a locking ring (144) and a locking ring collar (146). The locking ring (144) is slidably mounted on the proximal thrust bearing collar (134), about the outer surface (142) of the collar (134). Accordingly, once the proximal thrust bearing collar (134) is axially adjusted to preload the bearing (96), the locking ring (144) may be selectively moved longitudinally along the outer surface (142) of the collar (134) to a position abutting the proximal end (48) of the housing (46).

Once the locking ring (144) is moved into abutment with the housing (46), the locking ring collar (146) can be tightened against the locking ring (144) to hold the locking ring (144) in position between the housing (46) and the locking ring collar (146). The locking ring (144) acts upon the proximal thrust bearing collar (134) to inhibit the rotation of the proximal thrust bearing collar (134) away from the proximal thrust bearing shoulder (132) and thus maintain the preloading.

Preferably, the locking ring collar (146) is mounted about the drilling string (24) adjacent the proximal end (48) of the housing (46) such that the locking ring (144) is located or positioned between the proximal end (48) of the housing (46) and a distal end (148) of the locking ring collar (146). Further, the locking ring collar (146) is axially adjustable relative to the housing (46) such that the locking ring (144) may be held therebetween upon tightening of the locking ring collar (146).

The locking ring collar (146) may be adjusted axially in any manner and by any mechanism, structure or device able to axially adjust the locking ring collar (146) relative to the housing (46). However, preferably, the locking ring collar (146) is threaded for adjustment by rotation. More particularly, in the preferred embodiment, the outer surface (142) of the proximal thrust bearing collar (134) at its proximal end (138) is threaded for connection with a complementary threaded inner surface (150) of the locking ring collar (146) at its distal end (148). As a result of the threaded connection, rotation of the locking ring collar (146) axially adjusts the locking ring collar (146) either towards or away from the proximal end (48) of the housing (46) to tighten or release the locking ring (144) located therebetween. In the preferred embodiment, the locking ring collar (146) is tightened to between about 8000 to 10,000 ft lbs. The tightening of the locking ring collar (146) holds the locking ring (144) in position without increasing the preloading on the proximal thrust bearing (96).

When the locking ring collar (146) is tightened against the locking ring (144), the locking ring (144) acts upon the proximal thrust bearing collar (134) to inhibit the rotation of the proximal thrust bearing collar (134) away from the proximal thrust bearing shoulder (132) and thus to maintain the preloading. In order to enhance or facilitate the action of the proximal thrust bearing retainer (136), the locking ring (144) preferably does not rotate, or is inhibited from rotating, relative to the proximal thrust bearing collar (134). This relative rotation may be prevented or inhibited in any manner and by any structure, device or mechanism capable of preventing or inhibiting the undesired relative rotation between the locking ring (144) and the proximal thrust bearing collar (134). However, preferably, the locking ring (144) is mounted on the proximal thrust bearing collar (134) such that the locking ring (144) does not rotate, or is inhibited from rotating, relative to the proximal thrust bearing collar (134).

The locking ring (144) may be mounted on the proximal thrust bearing collar (134) in any manner and by any structure, device or mechanism capable of preventing or inhibiting the undesired relative rotation between the locking ring (144) and the proximal thrust bearing collar (134). For instance, in the preferred embodiment, at least one key and slot configuration is utilized. Specifically, a key (147) extends between a slot or groove defined by each of the adjacent surfaces of the locking ring (144) and the proximal thrust bearing collar (134).

In addition, in order to further enhance or facilitate the action of the proximal thrust bearing retainer (136), the locking ring (144) preferably does not rotate, or is inhibited from rotating, relative to the housing (46). This relative rotation may be prevented or inhibited in any manner and by any structure, device or mechanism capable of preventing or inhibiting the undesired relative rotation between the locking ring (144) and the housing (46). However, preferably, the configurations of the adjacent abutting surfaces of the locking ring (144) and the housing (46) are complementary such that the locking ring (144) does not rotate, or is inhibited from rotating, relative to the housing (46).

In the preferred embodiment, the locking ring (144) is further comprised of a housing abutment surface (152). In addition, the housing (46), and in particular the proximal end (58) of the proximal housing section (52), is further comprised of a locking ring abutment surface (154). The locking ring abutment surface (154) is complementary to the housing abutment surface (152) such that the engagement of the housing abutment surface (152) and the locking ring abutment surface (154) prevents or inhibits the rotation of the locking ring (144) relative to the housing (46). Although any complementary surface configurations may be used, the locking ring abutment surface (154) and the housing abutment surface (152) each preferably define a plurality of complementary interlocking teeth.

As indicated above, the device (20) includes a drilling shaft deflection assembly (92), contained within the housing (46), for bending the drilling shaft (24) as previously described. The deflection assembly (92) may be comprised of any structure, device, mechanism or method capable of bending the drilling shaft (24) or deflecting the drilling shaft (24) laterally or radially within the housing (46) in the described manner. However, preferably, the deflection assembly (92) is comprised of a double ring eccentric mechanism. Although these eccentric rings may be located a spaced distance apart along the length of the drilling shaft (24), preferably, the deflection assembly (92) is comprised of an eccentric outer ring (156) and an eccentric inner ring (158) provided at a single location or position along the drilling shaft (24). The rotation of the two eccentric rings (156, 158) imparts a controlled deflection of the drilling shaft (24) at the location of the deflection assembly (92).

The preferred deflection assembly (92) of the within invention is similar to the double eccentric harmonic drive mechanism described in United States of America Patent No.

5,353,884 issued October 11, 1994 to <u>Misawa et. al.</u> and United States of America Patent No. 5,875,859 issued March 2, 1999 to <u>Ikeda et. al.</u>.

Particularly, the outer ring (156) has a circular outer peripheral surface (160) and defines therein a circular inner peripheral surface (162). The outer ring (156), and preferably the circular outer peripheral surface (160) of the outer ring (156), is rotatably supported by or rotatably mounted on, directly or indirectly, the circular inner peripheral surface of the housing (46). Specifically, in the preferred embodiment, the circular outer peripheral surface (160) is rotatably supported by or rotatably mounted on the circular inner peripheral surface (78) of the distal housing section (56). The circular outer peripheral surface (160) may be supported or mounted on the circular inner peripheral surface (78) by any supporting structure, mechanism or device permitting the rotation of the outer ring (156) relative to the housing (46), such as by a roller bearing mechanism or assembly. Further, in the preferred embodiment, the outer ring (156) is rotatably driven by an outer ring drive mechanism (164), as described below.

The circular inner peripheral surface (162) of the outer ring (156) is formed and positioned within the outer ring (156) such that it is eccentric with respect to the housing (46). In other words, the circular inner peripheral surface (162) is deviated from the housing (46) to provide a desired degree or amount of deviation.

More particularly, the circular inner peripheral surface (78) of the distal housing section (56) is centered on the centre of the drilling shaft (24), or the rotational axis A of the drilling shaft (24), when the drilling shaft (24) is in an undeflected condition or the deflection assembly (92) is inoperative. The circular inner peripheral surface (162) of the outer ring (156) is centered on point B which is deviated from the rotational axis of the drilling shaft (24) by a distance “e”.

Similarly, the inner ring (158) has a circular outer peripheral surface (166) and defines therein a circular inner peripheral surface (168). The inner ring (158), and preferably the circular outer peripheral surface (166) of the inner ring (158), is rotatably supported by or rotatably mounted on, either directly or indirectly, the circular inner peripheral surface (162) of the outer ring (156). The circular outer peripheral surface (166) may be supported by or mounted on the circular inner peripheral surface (162) by any supporting structure, mechanism or device permitting the rotation of the inner ring (158) relative to the outer ring (156), such as by a roller bearing mechanism or assembly. Further, in the preferred embodiment, the inner ring (158) is rotatably driven by an inner ring drive mechanism (170), as described below.

The circular inner peripheral surface (168) of the inner ring (158) is formed and positioned within the inner ring (158) such that it is eccentric with respect to the circular inner peripheral surface (162) of the outer ring (156). In other words, the circular inner peripheral surface (168) of the inner ring (158) is deviated from the circular inner peripheral surface (162) of the outer ring (156) to provide a desired degree or amount of deviation.

More particularly, the circular inner peripheral surface (168) of the inner ring (158) is centered on point C, which is deviated from the centre B of the circular inner peripheral surface (162) of the outer ring (156) by the same distance “e”. As described, preferably, the degree of deviation of the circular inner peripheral surface (162) of the outer ring (156) from the housing (46), defined by distance “e”, is substantially equal to the degree of deviation of the circular inner peripheral surface (168) of the inner ring (158) from the circular inner peripheral surface (162) of the outer ring (156), also defined by distance “e”. However, if desired, the degrees of deviation may be varied such that they are not substantially equal.

The drilling shaft (24) extends through the circular inner peripheral surface (168) of the inner ring (158) and is rotatably supported thereby. The drilling shaft (24) may be supported by the circular inner peripheral surface (168) by any supporting structure, mechanism or device permitting the rotation of the drilling shaft (24) relative to the inner ring (158), such as by a roller bearing mechanism or assembly.

As a result of the above described configuration, the drilling shaft (24) may be moved, and specifically may be laterally or radially deviated within the housing (46), upon the movement of the centre of the circular inner peripheral surface (168) of the inner ring (158). Specifically, upon the rotation of the inner and outer rings (158, 156), either independently or together, the centre of the drilling shaft (24) may be moved with the centre of the circular inner peripheral surface (168) of the inner ring (158) and positioned at any point within a circle having a radius summed up by the amounts of deviation of the circular inner peripheral surface (168) of the inner ring (158) and the circular inner peripheral surface (162) of the outer ring (156). As a result, the drilling shaft (24) is deflected, bent or caused to curve to produce the desired tool face and amount of deviation of the drilling bit (22).

In other words, by rotating the inner and outer rings (158, 156) relative to each other, the centre of the circular inner peripheral surface (168) of the inner ring (158) can be moved in any position within a circle having the predetermined or predefined radius as described above. Thus, the portion or section of the drilling shaft (24) extending through and supported by the circular inner peripheral surface (168) of the inner ring (158) can be deflected by an amount in any direction perpendicular to the rotational axis of the drilling shaft (24). As a result, the drilling direction may be controlled by varying the tool face and deviation of the drilling bit (22) connected with the drilling shaft (24). In this instance, the device (20) is in a deflection mode or is set at a "Deflection ON" setting.

More particularly, since the circular inner peripheral surface (162) of the outer ring (156) has the centre B, which is deviated from the rotational centre A of the drilling shaft (24) by the distance “e”, the locus of the centre B is represented by a circle having a radius “e” around the centre A. Further, since the circular inner peripheral surface (168) of the inner ring (158) has the centre C, which is deviated from the centre B by a distance “e”, the locus of the centre “C” is represented by a circle having a radius “e” around the centre B. As a result, the centre C may be moved in any desired position within a circle having a radius of “2e” around the centre A. Accordingly, the portion of the drilling shaft (24) supported by the circular inner peripheral surface (168) of the inner ring (158) can be deflected in any direction on a plane perpendicular to the rotational axis of the drilling shaft (24) by a distance of up to “2e”.

In addition, as stated, the deviation distances “e” are preferably substantially similar in order to permit the operation of the device (20) such that the drilling shaft (24) is undeflected within the housing (24) when directional drilling is not required. More particularly, since the degree of deviation of each of the centres B and C of the circular inner peripheral surface (162) of the outer ring (156) and the circular inner peripheral surface (168) of the inner ring (158) respectively is defined by the same or equal distance “e”, the centre C of the portion of the drilling shaft (24) extending through the deflection assembly (92) can be positioned on the rotational axis A of the drilling shaft (24). In this instance, the device (20) is in a zero deflection mode or is set at a "Deflection OFF” setting.

The inner and outer ring drive mechanisms (170, 164) of the inner and outer rings (158, 156) respectively may each be comprised of any drive system or mechanism able to rotate the respective inner and outer rings (158, 156). However, preferably, each of the inner and outer ring drive mechanisms (170, 164) rotates the inner and outer rings (158, 156) respectively using the rotation of the drilling shaft (24). In the preferred embodiment, each of the inner and outer ring drive mechanisms (170, 164) is comprised of a harmonic drive mechanism for rotating the inner and outer rings (158, 156) about their respective axes relative to each other.

More preferably, the harmonic drive mechanisms (170, 164) are of the hollow type arranged coaxially relative to each other and spaced apart longitudinally such that the drive mechanisms (170, 164) are located on opposing sides of the deflection assembly (92). In other words, the deflection assembly (92) is located between the harmonic inner and outer ring drive mechanisms (170, 164). For instance, in the preferred embodiment, the outer ring drive mechanism (64) is located or positioned uphole or proximally of the deflection assembly (92), while the inner ring drive mechanism (170) is located or positioned downhole or distally of the deflection assembly (92). Thus, the drilling shaft (24) is arranged such that it extends through the circular inner peripheral surface (168) of the inner ring (158) and through the hollow portions provided by each of the harmonic inner and outer ring drive mechanisms (170, 164).

In the preferred embodiment, the harmonic outer ring drive mechanism (164) is comprised of first and second rigid circular splines (172, 174), a circular flexible spline or flexispline (176) arranged inside of the rigid circular splines (172, 174) and an elliptical-or oval shaped wave generator (178) arranged inside the circular flexispline (176). The wave generator (178) is comprised of a rigid elliptical or oval shaped cam plate (180) enclosed in a bearing mechanism or assembly (182). Thus, the bearing mechanism (182) is inserted between the cam plate (180) and the flexispline (176). The drilling shaft (24) is inserted through the centre of the cam plate (180) such that an amount of clearance is provided therebetween.

The rigid circular splines (172, 174) have internal spline teeth for engaging the external spline teeth of the flexispline (176). The rigid circular splines (172, 174) have slightly different numbers of teeth, which internal spline teeth are simultaneously engaged by the external spline teeth of the flexispline (176).

In the preferred embodiment, the flexispline (176) is provided with less teeth than the first rigid circular spline (172), preferably two less teeth. The first rigid circular spline

(172) is fixedly mounted or connected, directly or indirectly, with the inner surface of the housing (64). In the preferred embodiment, the second rigid circular spline (174) has the same number of teeth as the flexispline (176) and is connected with the outer ring (156) so that the second rigid spline (174) and the outer ring (156) rotate integrally or as a unit.

When the wave generator (178) is inserted into the flexispline (176), it imparts its elliptical shape to the flexispline (176), causing the external teeth of the flexispline (176) to engage with the internal teeth of the rigid circular splines (172, 174) at two equally spaced areas 180 degrees apart on their respective circumferences, being the major elliptical axis of the wave generator (178). As a result, a positive gear mesh is formed at the points of engagement. Further, as the wave generator (178) rotates in a first direction, the points of engagement travel with the major elliptical axis of the wave generator (178). Due to the differences in the number of teeth of the flexispline (176) and the first rigid circular spline (172), when the wave generator (178) has turned 180 degrees, the flexispline (176) has regressed relative to the first rigid spline (172), typically by one tooth where the flexispline (176) includes two less teeth. Thus, each turn or rotation of the wave generator (178) in the first direction moves or rotates the flexispline (176) in an opposing second direction on the first rigid circular spline (172), such as by two teeth where the flexispline (176) includes two less teeth. The second rigid circular spline (174), having the same number of teeth as the flexispline (176), also rotates in the opposing second direction relative to the first rigid circular spline (172) at the same rate as the flexispline (176).

The wave generator (178) thus provides a high speed input, the first rigid circular spline (172) is fixed to the housing (46) and thus does not rotate relative to the housing (46), and the second rigid circular spline (174) rotates relative to the first rigid circular spline (172) and the housing (46) to provide a low speed output.

Further, the wave generator (178) is directly linked to the drilling shaft (24) through an outer ring clutch or clutch mechanism (184), preferably being electromagnetic, and a first Oldham coupling (186). Operation of the clutch mechanism (184) causes a transfer of the rotational force of the drilling shaft (24) to the harmonic outer ring drive mechanism (164). As a result, the outer ring (156) will rotate after the reduction of rotation at a certain level of reduction ratio as determined by the harmonic outer ring drive mechanism (164) as described above.

Thus, the outer ring drive mechanism (164) rotates the outer ring (156) using the rotation of the drilling shaft (24). The outer drive mechanism (164) is comprised of the outer ring clutch (184) for selectively engaging and disengaging the drilling shaft (24) from the outer ring (156). The outer ring clutch (184) may be comprised of any clutch or clutch mechanism able to selectively engage and disengage the drilling shaft (24) from the outer ring (156). In addition, preferably the outer ring clutch (184) is comprised of a clutch and brake mechanism such that the outer ring clutch (184) performs a dual function.

Preferably, the outer ring clutch (184) is comprised of a pair of clutch plates (188) which are separated by a clutch gap (190) when the clutch (184) is disengaged. Alternately, the clutch plates (188) are engaged or come together when the clutch (184) is engaged to selectively engage the drilling shaft (24) with the outer ring (156). Thus, the clutch plates (188) are engaged to engage the drilling shaft (24) with the outer ring (156) to permit the rotation of the drilling shaft (24) to rotate the outer ring (156). In addition, when the clutch plates (188) are disengaged, the clutch plate (188) associated with the outer ring (156) acts to inhibit or prevent the rotation of the outer ring (156) and thus performs a braking function.

Preferably, the outer ring clutch (184) is comprised of a clutch adjustment mechanism (192) for adjusting the clutch gap (190). Any mechanism, structure, device or method capable of adjusting or facilitating the adjustment of the clutch gap (190) may be used. However, preferably, the clutch adjustment mechanism (192) is comprised of a clutch adjustment member (194) associated with one of the pair of clutch plates (188) such that movement of the clutch adjustment member (194) will result in corresponding movement of the associated clutch plate (188) to increase or decrease the clutch gap (190). Further, the clutch adjustment mechanism (192) is comprised of a first guide (196) for guiding the clutch adjustment member (192) for movement in a first direction. Finally, the clutch adjustment mechanism (192) is comprised of a movable key (198) associated with the clutch adjustment member (194), wherein the key (198) comprises a second guide (200) for urging the clutch adjustment member (194) in a second direction.

The second direction has a component parallel to the first guide (196) and has a component perpendicular to the first guide (196). One of the parallel component and the perpendicular component is parallel to a direction of movement of the clutch plate (188) necessary to increase or decrease the clutch gap (190).

In the preferred embodiment, the first guide (196) guides the clutch adjustment member (194) for movement in the first direction which is perpendicular to the direction of movement of the clutch plate (188). The second guide (200) urges the clutch adjustment member (194) in the second direction, wherein the second direction has a component parallel to the first guide (196) and has a component perpendicular to the first guide (196). Therefore, in the preferred embodiment, the component parallel to the first guide (196) is perpendicular to the direction of movement of the clutch plate (188). The component perpendicular to the first guide (196) is parallel to the direction of movement of the clutch plate (188).

The clutch adjustment member (194) may be associated with the movable key (198) in any manner and by any mechanism, device or structure such that movement of the key (198) results in a corresponding movement of the clutch adjustment member (194). More particularly, as a result of the second guide (200), movement of the key (198) results in movement of the clutch adjustment member (194) in the second direction.

Preferably, the clutch adjustment member (194) is connected, mounted or integrally formed with the key (198) such that the member (194) extends therefrom. In the preferred embodiment, the clutch adjustment member (194) is integrally formed with the key (198) to provide a single unit or element.

The first guide (196) may be comprised of any mechanism, device or structure able to guide the clutch adjustment member (194) for movement in the first direction. Preferably, the first guide (196) is affixed, connected or otherwise associated with one of the clutch plates (188). In the preferred embodiment, the first guide (196) is comprised of a first slot (197). More particularly, the first slot (197) is defined by the clutch plate (188). The first slot (197) extends circumferentially in the clutch plate (188) and is thus substantially perpendicular to the direction of movement of the clutch plate (188).

As indicated, the clutch adjustment member (194) is associated with one of the clutch plates (188). Specifically, in the preferred embodiment, the clutch adjustment member (194) is associated with the first slot (197) defined by the clutch plate (188). More particularly, the clutch adjustment member (194) extends from the key (198) for receipt within the first slot (197) such that the member (194) engages the first slot (197).

The second guide (200) may be comprised of any mechanism, device or structure able to urge the clutch adjustment member (194) in the second direction. In the preferred embodiment, the key (198) is positioned in a cavity (206) defined by the outer ring drive mechanism (164) such that the clutch adjustment member (194) may extend from the key (198) for engagement with the first slot (197). Further, the key (198) is preferably comprised of a sloped or ramp surface (204) oriented in the second direction. Similarly, the cavity (206) preferably defines a sloped or ramp surface (208) complementary to the key ramp surface (204). In the preferred embodiment, the second guide (200) is comprised of the key ramp surface (204) and the cavity ramp surface (208).

Further, the clutch adjustment mechanism (192) is preferably comprised of a clutch adjustment control mechanism (202) for controlling the movement of the key (198). The clutch adjustment control mechanism (202) may be comprised of any device, structure or mechanism capable of controlling the movement of the key (198). However, preferably, the clutch adjustment control mechanism (202) is comprised of an adjustment screw connected with the key (198) and which can be rotated inside a threaded bore to finely control the movement of the key (198).

Preferably, adjustment of the adjustment screw acts upon the key (198) resulting in the movement of the key (198) in a direction that is substantially perpendicular to the longitudinal axis of the device (20). More particularly, movement of the key (198) results in the engagement of the key ramp surface (204) and the cavity ramp surface (208). As a result, the second guide (200) preferably converts the movement of the key (198) in a direction that is substantially perpendicular to the longitudinal axis of the device (20) to movement of the key (198) in the second direction, which in turn causes the clutch adjustment member (194) to move in the second direction.

The component of movement of the key (198) along the cavity ramp surface (208) which is parallel to the first slot (197) results in the clutch adjustment member (194) moving in the first slot (197) without imparting a significant rotational force to the clutch plate (188). The component of movement of the key (198) along the cavity ramp surface (208) which is perpendicular to the first slot (197) results in an increase or decrease in the clutch gap (190) by engagement of the clutch adjustment member (194) with the clutch plate (188).

Once the desired clutch gap (190) is achieved, it is preferable that the desired setting be capable of being maintained. Thus, preferably, a clutch adjustment locking mechanism (210) is provided for fixing the position of the key (198) so that the clutch gap (190) can be maintained at the desired setting. Any locking mechanism, structure or device capable of fixing or maintaining the position of the key (198) relative to the first guide (196) may be used. However, preferably, the clutch adjustment locking mechanism (210) is comprised of one or more locking or set screws associated with the clutch adjustment member (194) which may be tightened to fix or maintain the key (198) at its desired position within the cavity (206) such that its further movement is prevented or otherwise inhibited.

Next, referring to the harmonic inner ring drive mechanism (170), the preferred harmonic inner ring drive mechanism (170), and its components and structure, are substantially similar to the harmonic outer ring drive mechanism (164) as described above. Thus, the description provided for the harmonic outer ring drive mechanism (164) is equally applicable to the harmonic inner ring drive mechanism (170).

In the preferred embodiment, the harmonic inner ring drive mechanism (170) is comprised of first and second rigid circular splines (212, 214), a circular flexible spline or flexispline (216) arranged inside of the rigid circular splines (212, 214) and an elliptical-or oval shaped wave generator (218) arranged inside the circular flexispline (216). The wave generator (218) is comprised of a rigid elliptical or oval shaped cam plate (220) enclosed in a bearing mechanism or assembly (222). Thus, the bearing mechanism (222) is inserted between the cam plate (220) and the flexispline (216). The drilling shaft (24) is inserted through the centre of the cam plate (220) such that an amount of clearance is provided therebetween.

The rigid circular splines (212, 214) have internal spline teeth for engaging the external spline teeth of the flexispline (216). The rigid circular splines (212, 214) have slightly different numbers of teeth, which internal spline teeth are simultaneously engaged by the external spline teeth of the flexispline (216).

In the preferred embodiment, the flexispline (216) is provided with less teeth than the rigid circular spline (212), preferably two less teeth. The first rigid circular spline (212) is fixedly mounted or connected, directly or indirectly, with the inner surface of the housing (64). In the preferred embodiment, the second rigid circular spline (214) has the same number of teeth as the flexispline (216) and is connected with the inner ring (158) through an Oldham type centering coupling (223) so that the rigid spline (214) and the inner ring (158) rotate through the Oldham type centering coupling (223) integrally or as a unit.

When the wave generator (218) is inserted into the flexispline (216), it imparts its elliptical shape to the flexispline (216), causing the external teeth of the flexispline (216) to engage with the internal teeth of the rigid circular splines (212, 214) at two equally spaced areas 180 degrees apart on their respective circumferences, being the major elliptical axis of the wave generator (218). As a result, a positive gear mesh is formed at the points of engagement. Again, due to the differences in the number of teeth of the flexispline (216) and the first rigid circular spline (212), when the wave generator (218) has turned 180 degrees, the flexispline (216) has regressed relative to the first rigid circular splines (212). Thus, each turn or rotation of the wave generator (218) in the first direction moves or rotates the flexispline (216) in an opposing second direction on the first rigid circular spline (212). The second rigid circular spline (214), having the same number of teeth as the flexispline (216), also rotates in the opposing second direction relative to the first rigid circular spline (212) at the same rate as the flexispline (216).

Thus, again, the wave generator (218) thus provides a high speed input, the first rigid circular spline (212) is fixed to the housing (46) and thus does not rotate relative to the housing (46), and the second rigid circular spline (214) rotates relative to the first rigid circular spline (212) and the housing (46) to provide a low speed output.

The wave generator (218) is directly linked to the drilling shaft (24) through an inner ring clutch or clutch mechanism (224), preferably being electromagnetic, and a second Oldham coupling (226), which are substantially similar to the outer ring clutch (184) and first Oldham coupling (186) respectively. Operation of the inner ring clutch (224) causes a transfer of the rotational force of the drilling shaft (24) to the harmonic inner ring drive mechanism (170). As a result, the inner ring (158) will rotate after the reduction of rotation at a certain level of reduction ratio as determined by the harmonic inner ring drive mechanism (170) as described above.

Thus, the inner ring drive mechanism (170) rotates the inner ring (158) also using the rotation of the drilling shaft (24). The inner ring drive mechanism (170) is comprised of the inner ring clutch (224) for selectively engaging and disengaging the drilling shaft (24) from the inner ring (158). The inner ring clutch (224) may also be comprised of any clutch or clutch mechanism able to selectively engage and disengage the drilling shaft (24) from the inner ring (158). In addition, preferably the inner ring clutch (224) is comprised of a clutch and brake mechanism such that the inner ring clutch (224) also performs a dual function.

Preferably, the inner ring clutch (224) is similarly comprised of a pair of clutch plates (228) which are separated by a clutch gap (230) when the clutch (224) is disengaged. Alternately, the clutch plates (228) are engaged or come together when the clutch (224) is engaged to selectively engage the drilling shaft (24) with the inner ring (158) Thus, the clutch plates (228) are engaged to engage the drilling shaft (24) with the inner ring (158) to permit the rotation of the drilling shaft (24) to rotate the inner ring (158). In addition, when the clutch plates (228) are disengaged, the clutch plate (228) associated with the inner ring (158) acts to inhibit or prevent the rotation of the inner ring (158) and thus performs a braking function.

Preferably, the inner ring clutch (224) is comprised of a clutch adjustment mechanism (232) for adjusting the clutch gap (230). Any mechanism, structure, device or method capable of adjusting or facilitating the adjustment of the clutch gap (230) may be used. However, preferably, the clutch adjustment mechanism (232) is comprised of a clutch adjustment member (234) associated with one of the pair of clutch plates (228) such that movement of the clutch adjustment member (234) will result in corresponding movement of the associated clutch plate (228) to increase or decrease the clutch gap (230). Further, the clutch adjustment mechanism (232) is comprised of a first guide (236) for guiding the clutch adjustment member (232) for movement in a first direction. Finally, the clutch adjustment mechanism (232) is comprised of a movable key (238) associated with the clutch adjustment member (234), wherein the key (238) comprises a second guide (240) for urging the clutch adjustment member (234) in a second direction.

The second direction has a component parallel to the first guide (236) and has a component perpendicular to the first guide (236). One of the parallel component and the perpendicular component is parallel to a direction of movement of the clutch plate (228) necessary to increase or decrease the clutch gap (230).

In the preferred embodiment, the first guide (236) guides the clutch adjustment member (234) for movement in the first direction which is perpendicular to the direction of movement of the clutch plate (228). The second guide (240) urges the clutch adjustment member (234) in the second direction, wherein the second direction has a component parallel to the first guide (236) and has a component perpendicular to the first guide (236). Therefore, in the preferred embodiment, the component parallel to the first guide (236) is perpendicular to the direction of movement of the clutch plate (228). The component perpendicular to the first guide (236) is parallel to the direction of movement of the clutch plate (228).

The clutch adjustment member (234) may be associated with the movable key (238) in any manner and by any mechanism, device or structure such that movement of the key (238) results in a corresponding movement of the clutch adjustment member (234). More particularly, as a result of the second guide (240), movement of the key (238) results in movement of the clutch adjustment member (234) in the second direction.

Preferably, the clutch adjustment member (234) is connected, mounted or integrally formed with the key (238) such that the member (234) extends therefrom. In the preferred embodiment, the clutch adjustment member (234) is integrally formed with the key (238) to provide a single unit or element.

The first guide (236) may be comprised of any mechanism, device or structure able to guide the clutch adjustment member (234) for movement in the first direction. Preferably, the first guide (236) is affixed, connected or otherwise associated with one of the clutch plates (228). In the preferred embodiment, the first guide (236) is comprised of a first slot (237). More particularly, the first slot (237) is defined by the clutch plate (228). The first slot (237) extends circumferentially in the clutch plate (228) and is thus substantially perpendicular to the direction of movement of the clutch plate (228).

As indicated, the clutch adjustment member (234) is associated with one of the clutch plates (228). Specifically, in the preferred embodiment, the clutch adjustment member (234) is associated with the first slot (237) defined by the clutch plate (228). More particularly, the clutch adjustment member (234) extends from the key (238) for receipt within the first slot (237) such that the member (234) engages the first slot (237).

The second guide (240) may be comprised of any mechanism, device or structure able to urge the clutch adjustment member (234) in the second direction. In the preferred embodiment, the key (238) is positioned in a cavity (246) defined by the inner ring drive mechanism (170) such that the clutch adjustment member (234) may extend from the key (238) for engagement with the first slot (237). Further, the key (238) is preferably comprised of a sloped or ramp surface (244) oriented in the second direction. Similarly, the cavity (246) preferably defines a sloped or ramp surface (248) complementary to the key ramp surface (244). In the preferred embodiment, the second guide (240) is comprised of the key ramp surface (244) and the cavity ramp surface (248).

Further, the clutch adjustment mechanism (232) is preferably comprised of a clutch adjustment control mechanism (242) for controlling the movement of the key (238). The clutch adjustment control mechanism (242) may be comprised of any device, structure or mechanism capable of controlling the movement of the key (238). However, preferably, the clutch adjustment control mechanism (242) is comprised of an adjustment screw connected with the key (238) and which can be rotated inside a threaded bore to finely control the movement of the key (238).

Preferably, adjustment of the adjustment screw acts upon the key (238) resulting in the movement of the key (238) in a direction that is substantially perpendicular to the longitudinal axis of the device (20). More particularly, movement of the key (238) results in the engagement of the key ramp surface (244) and the cavity ramp surface (248). As a result, the second guide (240) preferably converts the movement of the key (238) in a direction that is substantially perpendicular to the longitudinal axis of the device (20) to movement of the key (238) in the second direction, which in turn causes the clutch adjustment member (234) to move in the second direction.

The component of movement of the key (238) along the cavity ramp surface (248) which is parallel to the first slot (237) results in the clutch adjustment member (234) moving in the first slot (237) without imparting a significant rotational force to the clutch plate (228). The component of movement of the key (238) along the cavity ramp surface (248) which is perpendicular to the first slot (237) results in an increase or decrease in the clutch gap (230) by engagement of the clutch adjustment member (234) with the clutch plate (228).

Once the desired clutch gap (230) is achieved, it is preferable that the desired setting be capable of being maintained. Thus, preferably, a clutch adjustment locking mechanism (250) is provided for fixing the position of the key (238) so that the clutch gap (230) can be maintained at the desired setting. Any locking mechanism, structure or device capable of fixing or maintaining the position of the key (238) relative to the first guide (236) may be used. However, preferably, the clutch adjustment locking mechanism (250) is comprised of one or more locking or set screws associated with the clutch adjustment member (234) which may be tightened to fix or maintain the key (238) at its desired position within the cavity (246) such that its further movement is prevented or otherwise inhibited.

Further, as a result of the rotation of the drilling shaft (24) during rotary drilling, there will be a tendency for the housing (46) to rotate during the drilling operation. As a result, referring to Figures 7 - 14, an anti-rotation device or rotation restraining device (252) is preferably associated with the housing (46) for restraining rotation of the housing (46) within the wellbore or borehole.

In the preferred embodiment, the anti-rotation device or rotation restraining device (252) is associated with the housing (46) of the drilling direction control device (20) as described herein. However, the anti-rotation device (252) may be utilized with any type of apparatus comprised of a rotatable drilling shaft and a housing for rotatably supporting a length of the drilling shaft for rotation therein. In other words, the anti-rotation device (252) may be associated with the housing of any apparatus, including any drilling or production apparatus, where it is desirable to restrain the rotation of a housing rotatably supporting a drilling shaft therein.

In the preferred embodiment of the drilling direction control device (20), any type of anti-rotation device or rotation restraining device (252) or any mechanism, structure, device or method capable of restraining or inhibiting the tendency of the housing (46) to rotate upon rotary drilling may be used. Further, one or more such rotation restraining devices (252) may be used as necessary to provide the desired result.

The rotation restraining device (252) may be associated with any portion of the housing (46) including its proximal, central and distal housing sections (52, 54, 56). In other words, the rotation restraining device (252) may be located at any location or position along the length of the housing (46) between its proximal and distal ends (48, 50). In the preferred embodiment, the rotation restraining device (252) is associated with the proximal housing section (52). Finally, the rotation restraining device (252) may be associated with the housing (46) in any manner permitting the functioning of the rotation restraining device (252) to inhibit or restrain rotation of the housing (46). However, preferably, the rotation restraining device (252) is associated with an outer surface of the housing (46), preferably being the outer surface (72) of the proximal housing section (52). Specifically, the rotation restraining device (252) is preferably positioned on or connected, affixed or mounted with the outer surface (72).

Referring to Figures 7, 8, 11 and 12, in a first embodiment of the rotation restraining device (252), the device (252) is comprised of at least one roller (254), and preferably a plurality of rollers (254), on or associated with the outer surface (72) of the housing (46). Each roller (254) contacts the wall of the wellbore or borehole to slow or inhibit the turning of the housing (46) with the drilling shaft (24) while drilling. As well, the roller (254) preferably exerts only a slight load. As a result, the axial motion of the drilling device (20), or the longitudinal motion of the device (20) through the wellbore, is relatively undisturbed such that the housing (46) is permitted to roll through the wellbore.

In the preferred embodiment, where the rotation restraining device (252) is comprised of at least one roller (254), and preferably a plurality of rollers (254), on the housing (46), each roller (254) has an axis of rotation substantially perpendicular to a longitudinal axis (256) of the housing (46). Further, each roller (254) is oriented such that it is capable of rolling about its axis of rotation in response to a force exerted on the roller (254) substantially in the direction of the longitudinal axis (256) of the housing (46). For instance, as a longitudinal force is exerted through the drilling string (25) from the surface to the drilling shaft (24) in order to increase or decrease the necessary weight on the drilling bit (22), the roller (254) rolls about its axis to permit the drilling device (20) to move through the wellbore in either a downhole or uphole direction as required.

As indicated, the rotation restraining device (252) may be comprised of one or more rollers (254). Preferably, the rotation restraining device (252) is comprised of a plurality of rollers (254) spaced about a circumference of the housing (46), being defined by the outer surface of the housing (46), such that the rollers (254) may engage the wall of the borehole. Any number of rollers (254) able to effectively restrain the rotation of the housing (46) during drilling to the desired degree may be used.

In addition to circumferentially spacing the rollers (254) about the housing (46), the plurality of rollers (254) are preferably spaced axially along the housing (46). For instance, at least two of the plurality of rollers (254) are preferably spaced axially along the housing (46) so that the rollers (254) are staggered or offset axially along the housing (46). The staggered configuration of the rollers (254) may assist or facilitate the effective restraint of the rotation of the housing (46) during drilling.

As indicated, the rollers (254) may be mounted with or positioned about the circumference of the housing (46) and axially along the housing (46) in any manner and by any mechanism, structure or device. However, preferably, the rollers (254) are mounted or positioned about the circumference of the housing (46) and axially along the housing (46) in one or more sets (257) of rollers (254) such that each set (257) of rollers (254) has a substantially common axis of rotation which is substantially perpendicular to the longitudinal axis (256) of the housing (46). Further, one or more sets (257) of rollers (254) are preferably mounted or positioned axially or longitudinally along the housing (46) within one or more rotation restraining roller carriage assemblies (258).

Each rotation restraining carriage assembly (258) is preferably comprised of at least one roller (254), and preferably a plurality of rollers (254). In the preferred embodiment, the plurality of rollers (254) are arranged in a plurality of sets (257) of rollers (254), wherein the sets (257) are spaced axially along the housing (46) within the carriage assembly (258). Further, each set (257) of rollers (254) is preferably comprised of a plurality of coaxial rollers (254) spaced side by side within the carriage assembly (258).

Preferably, as shown in Figures 7, 8, 11 and 12, the rotation restraining device (252) is comprised of a plurality of rotation restraining carriage assemblies (258). In the preferred embodiment, the rotation restraining device (252) is comprised of three rotation restraining carriage assemblies (258a, 258b, 258c). Further, each rotation restraining carriage assembly (258) is comprised of three sets (257) of rollers (254) spaced axially or longitudinally along the housing (46). Finally, each set (257) of rollers (254) is comprised of four coaxial rollers (254) spaced side to side.

The rotation restraining carriage assemblies (258) may be spaced or positioned in any manner or configuration with respect to the housing (46) capable of effectively restraining the rotation of the housing (46). Preferably, as shown in Figures 7, 8, 11 and 12, the carriage assemblies (258) are spaced substantially evenly about the circumference of the housing (46). Accordingly, in the preferred embodiment, the three carriage assemblies (258a, 258b, 258c), or a centreline thereof, are spaced about 120 degrees apart about the circumference of the housing (46).

Referring to Figures 7 and 8, the rotation restraining carriage assemblies (258a, 258b, 258c) are spaced substantially evenly about the circumference of the housing (46). However, the carriage assemblies (258) are not staggered so that the carriage assemblies (258) are positioned axially or longitudinally on the housing (46) at substantially the same location. In other words, the carriage assemblies (258) are positioned axially or longitudinally at about the same location between, and distances from, the proximal end (58) and the distal end (60) of the proximal housing section (52).

However, preferably, referring to Figures 11 and 12, the carriage assemblies (258a, 258b, 258c) are spaced axially or longitudinally along the housing (46) so that at least two of the rotation restraining carriage assemblies (258) are staggered or offset axially along the housing (46). In other words, the location or position of at least two carriage assemblies (258) differ axially or longitudinally along the housing (46). Thus, the location between, and distances from, the proximal end (58) and the distal end (60) of the proximal housing section (52) varies between at least two of the carriage assemblies (258). The combination of circumferentially and axially spacing at least two of the carriage assemblies (258a, 258b, 258c) with respect to the housing (46) results in the axially staggered configuration of the carriage assemblies (258a, 258b, 258c) shown in Figures 11 and 12. The staggered configuration of the carriage assemblies (258) is believed to assist or facilitate the effective restraint of the rotation of the housing (46) during drilling.

Each rotation restraining carriage assembly (258) may be mounted, connected or affixed with the outer surface of the housing (46) in any manner. For instance, the carriage assembly (258) may be integrally formed with the housing (46) or may be connected, attached, affixed or otherwise mounted with the outer surface of the housing (46), particularly the outer surface (72) of the proximal housing section (52). In the preferred embodiment, the outer surface (72) of the proximal housing section (52) defines a separate cavity (260) therein for fixedly or removably receiving each of the carriage assemblies (258) therein. The carriage assembly (258) may be fixedly or removably received in the cavity (260) and mounted, connected or otherwise affixed therewith in any manner and by any method, mechanism, structure or device able to relatively rigidly maintain the carriage assembly (258) in the cavity (260) during the drilling operation.

Further, in order to facilitate the movement of the rollers (254) through the wellbore or borehole and to enhance the rotation restraining action of the rollers (254), each of the rollers (254) is preferably capable of movement between a retracted position and an extended position in which the roller (254) extends radially from the housing (46). Further, the roller (254) is preferably biased towards the extended position to enhance or facilitate the engagement of the roller (254) with the wellbore. Any method, mechanism, structure or device may be used for biasing the roller (254) to the extended position. However, preferably, the rotation restraining device (252) is further comprised of a biasing device (262) for biasing the roller (254) toward the extended position. In the preferred embodiment, the biasing device (262) is comprised of at least one spring which acts, directly or indirectly, between the housing (46) and the carriage assembly (258) or the rollers (254). The outwardly biasing force or spring force may be selected according to the expected drilling conditions.

Each roller (254) may have any shape or configuration permitting it to roll or move longitudinally through the borehole, while also restraining the rotation of the housing (46) within the borehole. Specifically, each roller (254) has a peripheral surface (264) about its circumference permitting it to roll or move longitudinally within the borehole. In addition, the peripheral surface (264) is preferably comprised of an engagement surface (266) for engaging the wall of the borehole to restrain rotation of the housing (46). The engagement surface (266) may have any shape or configuration able to restrain the rotation of the housing (46). However, preferably, the engagement surface (266) is comprised of the peripheral surface (264) of the roller (254) being tapered.

Referring to Figures 9, 10, 13 and 14, in a second or alternate embodiment of the anti-rotation device or rotation restraining device (252), the device (252) is comprised of at least one piston (268), and preferably a plurality of pistons (268), on or associated with the housing (46), and specifically the outer surface (72) of the housing (46). In this instance, each piston (268) contacts the wall of the wellbore or borehole to slow or inhibit the turning of the housing (46) with the drilling shaft (24) while drilling. More particularly, an outer surface (270) of the piston (268) extends from the housing (46) for engagement with the wall of the borehole.

In order to facilitate the placement of the drilling device (20) within the wellbore, each piston (268) is preferably capable of movement between a retracted position and an extended position. In the extended position, the outer surface (270) of the piston (268) extends radially from the housing (46) for engagement with the borehole wall. In the retracted position, the outer surface (270) is moved towards the housing (46) and thus, away from or out of contact with the borehole wall. Any piston (268) or piston assembly may be used to comprise the rotation restraining device (252).

Any device, structure, mechanism or method may be used for actuating the piston or pistons (268) between the retracted and extended positions. However, preferably, the rotation restraining device (252) is comprised of an actuator device (272) for moving the piston (268) between the retracted and extended positions. The actuator device (272) may be driven or powered in any manner such as hydraulically or pneumatically. However, preferably the actuator device (272) is hydraulically powered. More particularly, in the preferred embodiment, the actuator device (272) is comprised of a hydraulic pump, preferably a miniature co-axial gear type hydraulic pump, operatively connected with each piston (268).

As indicated, the second or alternate embodiment of the rotation restraining or anti-rotation device (252) may be comprised of one or more pistons (268). However, preferably, the rotation restraining device (252) is comprised of a plurality of pistons (268) spaced about the circumference of the housing (46), being defined by the outer surface of the housing (46), such that the pistons (268) may engage the wall of the borehole. Any number of pistons (268) able to effectively restrain the rotation of the housing (46) during drilling to the desired degree may be used.

In addition to circumferentially spacing the pistons (268) about the housing (46), the plurality of pistons (268) are preferably spaced axially along the housing (46). For instance, where a plurality of pistons (268) are spaced circumferentially about the housing (46), at least two of the plurality of pistons (268) are also preferably spaced axially along the housing (46) so that the pistons (268) are staggered or offset axially along the housing (46). The staggered configuration of the pistons (268) may assist or facilitate the effective restraint of the rotation of the housing (46) during drilling.

As indicated, the pistons (268) may be mounted with or positioned about the circumference of the housing (46) and axially along the housing (46) in any manner and by any mechanism, structure or device. However, preferably, the pistons (268) are mounted or positioned about the circumference of the housing (46) and axially along the housing (46) within one or more rotation restraining piston arrays, also referred to as the rotation restraining piston carriage assemblies (274).

The rotation restraining piston carriage assembly (274) may be comprised of a separate element or member of the rotation restraining device (252) connected, attached or mounted therewith or the rotation restraining piston carriage assembly (274) may be integral with the rotation restraining device (252) or defined by a portion or area of the outermost surface of the rotation restraining device (252) within which one or more pistons (268) are mounted. For instance, referring to Figures 13 - 14, the rotation restraining piston carriage assembly (274) is defined by the portion of the rotation restraining device (252) indicated with a dotted line.

In this alternate embodiment, each piston array or rotation restraining carriage assembly (274) is preferably comprised of at least one piston (268), and preferably a plurality of pistons (268) spaced axially along the housing (46) within the carriage assembly (274). Further, as shown in Figures 9, 10, 13 and 14, the rotation restraining device (252) is preferably comprised of a plurality of rotation restraining carriage assemblies or arrays (274). In the preferred alternate embodiment, the rotation restraining device (252) is comprised of four rotation restraining carriage assemblies (274a, 274b, 274c, 274d). Further, each rotation restraining carriage assembly (274) is comprised of three pistons (268) spaced axially or longitudinally along the housing (46) within the carriage assembly (274).

The rotation restraining piston carriage assemblies (274) may be spaced or positioned in any manner or configuration with respect to the housing (46) capable of effectively restraining the rotation of the housing (46). Preferably, as shown in Figures 9, 10, 13 and 14, the carriage assemblies (274a, 274b, 274c, 274d) are spaced substantially evenly about the circumference of the housing (46). Accordingly, in the preferred embodiment, the four carriage assemblies (274a, 274b, 274c, 274d), or a centreline thereof, are spaced about 90 degrees apart about the circumference of the housing (46).

Referring to Figures 9 and 10, the rotation restraining carriage assemblies (274a, 274b, 274c, 274d) are spaced substantially evenly about the circumference of the housing (46). However, the carriage assemblies (274) are not staggered so that the carriage assemblies (274) are positioned axially or longitudinally on the housing (46) at substantially the same location. In other words, the carriage assemblies (274) are positioned axially or longitudinally at about the same location between, and distances from, the proximal end (58) and the distal end (60) of the proximal housing section (52).

However, preferably, referring to Figures 13 and 14, the carriage assemblies (274a, 274b, 274c, 274d) are spaced axially or longitudinally along the housing (46) so that at least two of the rotation restraining carriage assemblies (274) are staggered or offset axially along the housing (46). In other words, the location or position of at least two carriage assemblies (274) differs axially or longitudinally along the housing (46). Thus, the location between, and distances from, the proximal end (58) and the distal end (60) of the proximal housing section (52) varies between at least two of the carriage assemblies (274). The combination of circumferentially and axially spacing at least two of the carriage assemblies (274a, 274b, 274c, 274d) with respect to the housing (46) results in the axially staggered configuration of the carriage assemblies (274a, 274b, 274c, 274d) shown in Figures 13 and 14. The staggered configuration of the carriage assemblies (274) is believed to assist or facilitate the effective restraint of the rotation of the housing (46) during drilling.

As indicated above, each rotation restraining piston array or carriage assembly (274) may be mounted, connected or affixed with the outer surface of the housing (46) in any manner. For instance, the carriage assembly (274) may be integrally formed with the housing (46) or may be connected, attached, affixed or otherwise mounted with the outer surface of the housing (46), particularly the outer surface (72) of the proximal housing section (52). In addition, each piston (268) may be mounted, connected or affixed with the carriage assembly (274) in any manner. In the preferred embodiment, the rotation restraining carriage assembly or piston array (274) is preferably integral with the outer surface (72) of the proximal housing section (52). Further, each carriage assembly (274) defines at least one cavity (276) therein for fixedly or removably receiving the pistons (268) of the carriage assembly (274) therein. The pistons (268) comprising each carriage assembly (274) may be fixedly or removably received in the respective cavities (276) and mounted, connected or otherwise affixed therewith in any manner and by any method, mechanism, structure or device able to relatively rigidly maintain the pistons (268) in the cavity or cavities (276) during the drilling operation.

Each piston (268) may have any shape or configuration capable of restraining the rotation of the housing (46) within the borehole when in the extended position. Specifically, each piston (268) has an outermost engagement surface (278) for engaging the wall of the wellbore or borehole to restrain rotation of the housing (46). The engagement surface (278) may have any shape or configuration able to engage the wall of the borehole and restrain the rotation of the housing (46) within the borehole.

In addition, the drilling device (20) is preferably further comprised of one or more seals or sealing assemblies for sealing the distal and proximal ends (50, 48) of the housing (46) such that the components of the device (20) located therebetween are not exposed to various drilling fluids, such as drilling mud. In addition to inhibiting the entrance of drilling fluids into the device (20) from outside, the seals or sealing assemblies also facilitate the maintenance or retention of desirable lubricating fluids within the device (20).

Preferably, the device (20) is comprised of a distal seal or sealing assembly (280) and a proximal seal or sealing assembly (282). The distal seal (280) is radially positioned and provides a rotary seal between the housing (46) and the drilling shaft (24) at, adjacent or in proximity to the distal end (50) of the housing (46). Thus, in the preferred embodiment, the distal seal (280) is radially positioned and provides a seal between the drilling shaft (24) and the distal housing section (56) at, adjacent or in proximity to it distal end (68).

The proximal seal (282) is radially positioned and provides a rotary seal between the housing (46) and the drilling shaft (24) at, adjacent or in proximity to the proximal end (48) of the housing (46). However, where the drilling string (25) extends within the proximal end (48) of the housing (46), the proximal seal (282) is more particularly positioned between the housing (46) and the drilling string (25). Thus, the proximal seal (282) is radially positioned and provides a seal between the drilling shaft (24) and the proximal housing section (52) at, adjacent or in proximity to it distal end (60). However, more particularly, the proximal seal (282) is radially positioned and provides a seal between an outer surface of the drilling string (25) and the proximal housing section (52) at, adjacent or in proximity to it distal end (60).

As well, the interior of the housing (46) preferably defines a fluid chamber (284) between the distal and proximal ends (50, 48) of the housing (46). Thus, the fluid chamber (284) is positioned or defined between the distal and proximal seals (280, 282) associated with the distal and proximal ends (50, 48) of the housing (46) respectively. As indicated above, the fluid chamber (284) is preferably filled with a lubricating fluid for lubricating the components of the device (20) within the housing (46).

In addition, one or both of the distal seal (280) and the proximal seal (282) are also preferably lubricated with the lubricating fluid from the fluid chamber (284) of the housing (46). In other words, each of the rotary distal and proximal seals (280, 282) is lubricated using fluid, typically oil, from the internal lubricating system of the drilling device (20). In addition, as described further below, each of the distal and proximal seals (280, 282) are lubricated or provided with filtered fluid in order to prevent or minimize any damage to the seals (280, 282) from any damaging metallic particles or other damaging contaminants which may be found within the lubricating fluid from the fluid chamber (284) of the housing (46) of the device (20). By filtering the lubricating fluid passing from the fluid chamber (284) of the housing (46) into either or both of the distal and proximal seals (280, 282), a relatively clean fluid environment is provided for the seals (280, 282).

As well, the distal and proximal seals (280, 282) are preferably mounted about the drilling shaft (24) and drilling string (25) respectively such that the drilling shaft (24) and attached drilling string (25) are permitted to rotate therein while maintaining the sealing. Further, the distal and proximal seals (280, 282) preferably provide a flexible sealing arrangement or flexible connection between the housing (46) and the drilling shaft (24) or drilling string (25) in order to maintain the seal provided thereby, while accommodating any movement or deflection of the drilling shaft (24) or drilling string (25) within the housing (46). This flexible connection is particularly important for the distal seal (280) which is exposed to the pivoting of the drilling shaft (24) by the deflection assembly (92).

In the preferred embodiment, the distal seal (280) is comprised of an inner portion (286) fixedly mounted about the drilling shaft (24) at, adjacent or in proximity to the distal end (50) of the housing (46) such that the inner portion (286) of the distal seal (280) rotates integrally with the drilling shaft (24). The distal seal (280) is further comprised of an outer portion (288), a section or part of which is rotatably mounted about the inner portion (286) to permit relative rotation therebetween and such that a channel or space (290) is defined between the inner and outer portions (286, 288). Further, the outer portion (288) is fixedly mounted, directly or indirectly, with the distal end (50) of the housing (46). Thus, upon the rotation of the drilling shaft (24), the inner portion (286) rotates with the drilling shaft (24) relative to the outer portion (288) which remains substantially stationary with the housing (46). Any structure, mechanism or device may be used to permit the relative rotation between the inner and outer portions (286, 288) of the distal seal (280). However, in the preferred embodiment, one or more bearings (292) are located between the inner and outer portions (286, 288) within the channel or space (290). Preferably, the bearings (292) are angular contact thrust bearings which serve a dual function as both radial and thrust bearings.

As indicated, the outer portion (288) of the distal seal (280) is fixedly mounted, directly or indirectly, with the distal end (50) of the housing (46). However, in the preferred embodiment, the outer portion (288) is fixedly connected or mounted with the distal thrust bearing collar (110) which is fixedly connected or mounted with the distal end (50) of the housing (46). Accordingly, the distal seal (280) is located or positioned adjacent the distal end (50) of the housing (46) within the distal thrust bearing retainer (112).

In addition, in the preferred embodiment, the outer portion (288) is comprised of a flexible collar (294) which provides the flexible connection or flexible sealing arrangement to accommodate the deflection or pivoting of the drilling shaft (24) within the housing (46). The flexible collar (294) is particularly located adjacent the point of connection of the outer portion (288) of the distal seal (280) with the distal thrust bearing collar (110). As a result, upon deflection of the drilling shaft (24), the inner portion (286) of the distal seal (280) and the section or part of the outer portion (288) mounted about the inner portion (286) are permitted to pivot about the point of connection of the outer portion (288) with the distal thrust bearing collar (110).

The distal seal (280) is further comprised of at least two rotary seals (298, 300) located within the channel or space (290) between the inner and outer portions (286, 288) of the distal seal (280) such that a chamber (296) is defined therebetween. Fluid is provided within the chamber (296) for lubricating the components of the distal seal (280). Preferably, the distal seal (280) is further comprised of a distal filtering mechanism for filtering the lubricating fluid from the fluid chamber (284) of the housing (46) so that the distal seal (280) is lubricated with filtered lubricating fluid. Any structure, mechanism, device or method may be used which is capable of filtering the lubricating fluid entering the distal seal (280). However, in the preferred embodiment, one or more filters (302) are located within the chamber (296) of the distal seal (280).

More particularly, an upper internal wiper seal (298) defines the uppermost or proximal end of the chamber (296). In addition, at least one filter (302) is preferably provided adjacent the internal wiper seal (298). As indicated, the distal seal (280) is preferably lubricated with the lubricating fluid from the fluid chamber (284) of the housing (46). In addition, the fluid is preferably filtered in order to prevent or minimize any damage to the distal seal (280) from any damaging metallic particles or other contaminants which may be found within the lubricating fluid from the fluid chamber (284) of the housing (46). Thus, the internal wiper seal (298) and the filter (302) assist in providing a relatively clean fluid environment for the distal seal (280).

In addition, a lower external barrier seal (300) defines the lowermost or distal end of the chamber (296). The external barrier seal (300) prevents or inhibits the passage of external contaminants and abrasive wellbore material into the distal seal (280). Thus, the external barrier seal (300) also assists in providing a relatively clean fluid environment for the distal seal (280).

Finally, in the preferred embodiment, a rotary face seal (304) is provided adjacent of the external barrier seal (300) outside of the chamber (296) for further preventing or inhibiting the passage of contaminants and abrasive material from the wellbore into the distal seal (280). The rotary face seal (304) provides a seal between the adjacent lowermost faces or distal ends of the inner and outer portions (286, 288) of the distal seal (280). Although any rotary face seal may be used, the rotary face seal (304) is preferably biased or spring loaded to maintain the sealing action.

The proximal seal (282) is also comprised of an inner portion (306) fixedly mounted about the drilling string (25) at, adjacent or in proximity to the proximal end (48) of the housing (46) such that the inner portion (306) of the proximal seal (282) rotates integrally with the drilling string (25) and the drilling shaft (24). The proximal seal (282) is further comprised of an outer portion (308), a section or part of which is rotatably mounted about the inner portion (306) to permit relative rotation therebetween and such that a channel or space (310) is defined between the inner and outer portions (306, 308). Further, the outer portion (308) is fixedly mounted, directly or indirectly, with the proximal end (48) of the housing (46). Thus, upon the rotation of the drilling string (25), the inner portion (306) rotates with the drilling string (25) relative to the outer portion (308) which remains substantially stationary with the housing (46). .Any structure, mechanism or device may be used to permit the relative rotation between the inner and outer portions (306, 308) of the proximal seal (282). However, in the preferred embodiment, one or more bearings (312) are located between the inner and outer portions (306, 308) within the channel or space (310). Preferably, the bearings (312) are angular contact thrust bearings which serve a dual function as both radial and thrust bearings.

As indicated, the outer portion (308) of the proximal seal (282) is fixedly mounted, directly or indirectly, with the proximal end (48) of the housing (46). However, in the preferred embodiment, the outer portion (308) is fixedly connected or mounted with the proximal thrust bearing collar (134) which is fixedly connected or mounted with the proximal end (48) of the housing (46). Accordingly, the proximal seal (282) is located or positioned adjacent the proximal end (48) of the housing (46) within the proximal thrust bearing retainer (136).

In addition, in the preferred embodiment, the outer portion (308) is comprised of a flexible collar (314) which provides the flexible connection or flexible sealing arrangement to accommodate any movement or deflection of the drilling string (25) within the housing (46). The flexible collar (314) is particularly located adjacent the point of connection of the outer portion (308) of the proximal seal (282) with the proximal thrust bearing collar (134). As a result, upon deflection of the drilling string (25), the inner portion (306) of the proximal seal (282) and the section or part of the outer portion (308) mounted about the inner portion (306) are permitted to pivot about the point of connection of the outer portion (308) with the proximal thrust bearing collar (134).

The proximal seal (282) is further comprised of at least two rotary seals (318, 320) located within the channel or space (310) between the inner and outer portions (306, 308) of the proximal seal (282) such that a chamber (316) is defined therebetween. Fluid is provided within the chamber (316) for lubricating the components of the proximal seal (282). Preferably, the proximal seal (282) is further comprised of a proximal filtering mechanism for filtering the lubricating fluid from the fluid chamber (284) of the housing (46) so that the proximal seal (282) is lubricated with filtered lubricating fluid. Any structure, mechanism, device or method may be used which is capable of filtering the lubricating fluid entering the proximal seal (282). However, in the preferred embodiment, one or more filters (322) are located within the chamber (316) of the proximal seal (282).

More particularly, a lower internal wiper seal (318) defines the lowermost or distal end of the chamber (316). In addition, at least one filter (322) is preferably provided adjacent the internal wiper seal (318). As indicated, the proximal seal (282) is preferably lubricated with the lubricating fluid from the fluid chamber (284) of the housing (46). In addition, the fluid is preferably filtered in order to prevent or minimize any damage to the proximal seal (282) from any damaging metallic particles or other contaminants which may be found within the lubricating fluid from the fluid chamber (284) of the housing (46). Thus, the internal wiper seal (318) and the filter (322) assist in providing a relatively clean fluid environment for the proximal seal (282).

In addition, an upper external barrier seal (320) defines the uppermost or proximal end of the chamber (316). The external barrier seal (320) prevents or inhibits the passage of external contaminants and abrasive wellbore material into the proximal seal (282). Thus, the external barrier seal (320) also assists in providing a relatively clean fluid environment for the proximal seal (282).

Finally, in the preferred embodiment, a rotary face seal (324) is provided adjacent of the external barrier seal (320) outside of the chamber (316) for further preventing or inhibiting the passage of contaminants and abrasive material from the wellbore into the proximal seal (282). The rotary face seal (324) provides a seal between the adjacent uppermost faces or proximal ends of the inner and outer portions (306, 308) of the proximal seal (282). Although any rotary face seal may be used, the rotary face seal (324) is preferably biased or spring loaded to maintain the sealing action.

Further, the lubricating fluid contained within the fluid chamber (284) of the housing (46) between the proximal and distal seals (282, 280) has a pressure. Preferably, the device (20) is further comprised of a pressure compensation system (326) for balancing the pressure of the lubricating fluid contained in the fluid chamber (284) within the housing (46) with the ambient pressure outside of the housing (46). The pressure compensation system (326) may be located at any position or location along the length of the housing (46) between the distal and proximal seals (280, 282). In addition, the pressure compensation system (326) may be connected, mounted or otherwise associated with one or more of the distal, central and proximal housing sections (52, 54, 56). However, preferably, the pressure compensation system (326) is connected, mounted or otherwise associated with the central housing section (54). More preferably, the pressure compensation system (326) is connected, mounted or otherwise associated with the central housing section (54) proximal to or uphole of the proximal radial bearing (84).

The pressure compensation system (326) may be comprised of any mechanism, device or structure capable of providing for or permitting the balancing of the pressure of the lubricating fluid contained in the fluid chamber (284) with the ambient pressure outside of the housing (46). Preferably, the pressure compensation system (326) is comprised of at least one pressure port (328) in the housing (46) so that the ambient pressure outside of the housing (46) can be communicated to the fluid chamber (284). In the preferred embodiment, a pressure port (328) is located and mounted within the central housing section (54) to permit the communication of the ambient pressure of the wellbore fluids outside of the central housing section (54) to the lubricating fluid within the fluid chamber (284), which is contained or defined at least in part by the central housing section (54). Thus, in the wellbore, the pressure of the lubricating fluid within the housing (46) is determined at least in part by the ambient pressure outside of the housing (46) within the annulus of the wellbore.

Further, the pressure compensation system (326) is preferably comprised of a lubricating fluid regulating system (331) which facilitates charging of the fluid chamber (284) with lubricating fluid and provides adjustment of the amount of lubricating fluid in the fluid chamber (284) during drilling in response to increased temperatures and pressures downhole experienced by the lubricating fluid.

Preferably, the lubricating fluid regulating system (331) is comprised of a charging valve (332) and a relief valve (334). Both valves (332, 334) are located or mounted within the housing (46), preferably in the central housing section (54). The charging valve (332) permits or provides for the entry or charging of a sufficient amount of the lubricating fluid into the fluid chamber (284). The relief valve (334) is set to permit the passage of fluid out of the fluid chamber (284) through the relief valve (334) at a predetermined or preselected pressure.

More particularly, the drilling device (20) is charged with lubricating oil at the surface through the charging valve (332) until the fluid pressure in the fluid chamber (284) exceeds the pressure value of the relief valve (334). In addition, as the device (20) is moved downhole in the wellbore and the temperature increases, the fluid expands and the excess fluid is ejected or expelled from the fluid chamber (284) through the relief valve (334).

Preferably, the pressure of the lubricating fluid contained in the fluid chamber (284) of the housing (46) is maintained higher than the ambient pressure outside of the housing (46) or the annulus pressure in the wellbore. Specifically, the pressure compensation system (326) preferably internally maintains a positive pressure across the distal and proximal seals (280, 282). As a result, in the event there is any tendency for the distal and proximal seals (280, 282) to leak and permit the passage of fluid across the seals (280, 282), the passage of any such fluid will tend to be lubricating fluid from within the fluid chamber (284) to outside of the device (20). Accordingly, the higher internal pressure will facilitate the maintenance of a clean fluid environment within the fluid chamber (284), as described above, by inhibiting or preventing the passage of wellbore annulus fluids into the fluid chamber (284).

In order to provide a pressure within the fluid chamber (284) of the housing (46) higher than the outside annulus pressure, the pressure compensation system (326) is further preferably comprised of a supplementary pressure source (330). The supplementary pressure source (330) exerts pressure on the lubricating fluid contained in the fluid chamber (284) so that the pressure of the lubricating fluid contained in the fluid chamber (284) is maintained higher than the ambient pressure outside of the housing (46). The pressure differential between the fluid chamber (284) and outside the housing (46) may be selected according to the expected drilling conditions. However, preferably, only a slightly positive pressure is provided in the fluid chamber (284) by the supplementary pressure source (330).

The supplementary pressure may be provided in any manner or by any method, and the supplementary pressure source (330) may be comprised of any structure, device or mechanism, capable of providing the desired supplementary pressure within the fluid chamber (284) to generate the desired pressure differential between the fluid chamber (284) and outside the housing (46). However, preferably, the pressure compensation system (326) is further comprised of a balancing piston assembly (336).

The balancing piston assembly (336) is comprised of a piston chamber (338) defined by the interior of the housing (46), preferably the inner surface (74) of the central housing section (54). The balancing piston assembly (336) is further comprised of a movable piston (340) contained within the piston chamber (338). The piston (340) separates the piston chamber (338) into a fluid chamber side (342) and a balancing side (344). The fluid chamber side (342) is connected with the fluid chamber (284) and is preferably located distally or downhole of the piston (340). The pressure port (328) communicates with the balancing side (344) of the piston chamber (338), which is preferably located proximally or uphole of the piston (340). Further, the supplementary pressure source (330) acts on the balancing side (344) of the piston chamber (338). Specifically, the supplementary pressure source (330) acts on the balancing side (344) by exerting the supplementary pressure on the piston (340).

In the preferred embodiment, the supplementary pressure source (330) is comprised of a biasing device located within the balancing side (344) of the piston chamber (338) and which exerts the supplementary pressure on the piston (340). More particularly, the biasing device biases the piston (340) distally or downhole to generate or exert the supplementary pressure within the fluid chamber side (342) of the piston chamber (338), which supplementary pressure is communicated to the lubricating fluid within the fluid chamber (284) of the housing (46).

Thus, the supplementary pressure source (330) may be comprised of any device, structure or mechanism capable of biasing the piston (340) in the manner described above. However, in the preferred embodiment, the biasing device is comprised of a spring (346). As indicated, the spring (346) is contained in the balancing side (344) of the piston chamber (338). When charging the device (20) with lubricating oil, the spring (346) is preferably fully compressed. As lubricating oil leaks or otherwise passes out of the fluid chamber (284), the spring (346) continues to exert the supplementary pressure on the piston (340) and the piston (340) is moved distally or in a downhole direction.

As a safety provision, an indicator is preferably provided with the device (20) for indicating the level of the lubricating oil in the fluid chamber (284) and communicating this information to the surface. Preferably, a two position switch is provided which indicates a "low" oil level and "no" oil level. This allows the device (20) to be pulled from the wellbore in the case of an oil leak, while avoiding or minimizing any damage to the device (20).

In the preferred embodiment, the pressure compensation system (326) is further comprised of an oil level limit switch (348). The oil level limit switch (348) is preferably positioned within the fluid chamber side (342) of the piston chamber (338). Specifically, as the oil is depleted and the level thus decreases within the fluid chamber (284), the spring (346) exerts the supplementary pressure on the piston (340) and the piston (340) is moved distally or in a downhole direction within the piston chamber (338) towards the oil level limit switch (348). Once the oil is depleted to a preselected level, or the oil is fully depleted, the piston (340) is moved within the piston chamber (338) for contact with and depression or movement of the oil level limit switch (348) distally in a downhole direction. Depression of the oil level limit switch (348) actuates the oil level limit switch (348) to indicate either a "low oil level" or "no oil level" in the fluid chamber (284) depending upon the amount or extent to which the switch (348) is depressed.

In the preferred embodiment of the device (20), there is a need to communicate electrical signals between two members which rotate relative to each other without having any contact therebetween. For example, this communication is required when downloading operating parameters for the device (20) or communicating downhole information from the device (20) either further uphole along the drilling string (25) or to the surface. Specifically, the electrical signals must be communicated between the drilling shaft (24) and the housing (46), which rotate relative to each other during the rotary drilling operation.

The communication link between the drilling shaft (24) and the housing (46) may be provided by any direct or indirect coupling or communication method or any mechanism, structure or device for directly or indirectly coupling the drilling shaft (24) with the housing (46). For instance, the communication between the housing (46) and the drilling shaft (24) may be provided by a slip ring or a gamma-at-bit communication toroid coupler. However, in the preferred embodiment, the communication between the drilling shaft (24) and the housing (46) is provided by an electromagnetic coupling device.

In the preferred embodiment, the communication between the drilling shaft (24) and the housing (46) is provided by an electromagnetic coupling device (350). More particularly, the electromagnetic coupling device (350) is comprised of a housing conductor or coupler (352) positioned on the housing (46) and fixedly mounted or connected with the housing (46) such that it remains substantially stationary relative to the drilling shaft (24) during drilling. Further, the electromagnetic coupling device (350) is comprised of a drilling shaft conductor or coupler (354) positioned on the drilling shaft (24) and fixedly mounted or connected with the drilling shaft (24) such that the drilling shaft conductor (354) rotates with the drilling shaft (24). The housing conductor (352) and the drilling shaft conductor (354) are positioned on the housing (46) and drilling shaft (24) respectively sufficiently close to each other so that electrical signals may be induced between them.

The housing conductor (352) and the drilling shaft conductor (354) may be comprised of a single wire or a coil and may be either wrapped or not wrapped around a magnetically permeable core.

Further, in the preferred embodiment, proximal electrical conductors, such as proximal electrical wires (356), run or extend along or through the drilling string (25) to the drilling shaft (24) within the device (20) to the drilling shaft conductor (354). Similarly, distal electrical conductors, such as distal electrical wires (358), run or extend from the housing conductor (352) along or through the housing (46) to a controller (360) of the device (20) and to the various sensors as outlined below.

The electromagnetic coupling device (350) may be positioned at any location along the length of the device (20). However, in the preferred embodiment, the electromagnetic coupling device (350) is positioned or located within the central housing section (54). More particularly, the electromagnetic coupling device (350) is positioned or located within the central housing section (54) at, adjacent or in proximity to its proximal end (62), proximal to or uphole of the proximal radial bearing (84) and the pressure compensation system (326).

The deflection assembly (92) may be actuated manually. However, as indicated, the device (20) is preferably further comprised of a controller (360) for controlling the actuation of the drilling shaft deflection assembly (92) to provide directional drilling control. The controller (360) of the device (20) is associated with the housing (46) and is preferably comprised of an electronics insert positioned within the central housing section (54). More preferably, the controller (360), and particularly the electronics insert, is positioned within the central housing section (54) distal to or downhole of the proximal radial bearing (84). Information or data provided by the various downhole sensors of the device (20) is communicated to the controller (360) in order that the deflection assembly (92) may be actuated with reference to and in accordance with the information or data provided by the sensors.

More particularly, the deflection assembly (92) is preferably actuated to orient the inner and outer rings (158, 156) relative to a reference orientation in order to provide directional control over the drilling bit (22) during drilling operations. In the preferred embodiment, the deflection assembly (92) is actuated with reference to the orientation of the housing (46) in the wellbore.

Thus, the drilling device (20) is preferably comprised of a housing orientation sensor apparatus (362) which is associated with the housing (46) for sensing the orientation of the housing (46) within the wellbore. Given that the housing (46) is substantially restrained from rotating during drilling, the orientation of the housing (46) which is sensed by the housing orientation sensor apparatus (362) provides the reference orientation for the device (20). The housing orientation sensor apparatus (362) may be comprised of any sensor or sensors, such as one or a combination of magnetometers and accelerometers, capable of sensing the position of the housing at a location at, adjacent or in proximity to the distal end (60) of the housing (46). More particularly, the housing orientation sensor apparatus (362) is preferably located as close as possible to the distal end (50) of the housing (46). In addition, the housing orientation sensor apparatus (362) preferably senses the orientation of the housing (46) in three dimensions in space.

In the preferred embodiment, the housing orientation sensor apparatus (362) is contained within or comprised of an ABI or At-Bit-Inclination insert (364) associated with the housing (46). Preferably, the ABI insert (364) is connected or mounted with the distal housing section (56) at, adjacent or in close proximity with its distal end (68). In the preferred embodiment, the ABI insert (364) is positioned or located within the distal housing section (56) axially between the deflection assembly (92) and the fulcrum bearing (88).

As well, the drilling device (20) is preferably further comprised of a deflection assembly orientation sensor apparatus (366) which is associated with the deflection assembly (92) for sensing the orientation of the deflection assembly (92). More particularly, the deflection assembly orientation sensor apparatus (366) senses the particular orientation of the inner and outer rings (158, 156) of the deflection assembly (92) relative to the housing (46).

The deflection assembly orientation sensor apparatus (366) may be comprised of any sensor or sensors, such as one or a combination of magnetometers and accelerometers, capable of sensing the position of the deflection assembly (92) relative to the housing (46). In addition, the deflection assembly orientation sensor apparatus (366) preferably senses the orientation of the deflection assembly (92) in three dimensions in space. Where one sensor is provided, the sensor must be capable of sensing the orientation of the inner peripheral surface (168) of the inner ring (158) relative to the housing (46). However, preferably, the deflection assembly orientation sensor apparatus (366) is comprised of a separate sensor for sensing the orientation of each of the inner ring (158) and the outer ring (156) relative to the housing (46).

In the preferred embodiment, the deflection assembly orientation sensor apparatus (366) is comprised of an inner ring home reference sensor (368) for sensing the orientation of the inner ring (158) relative to the housing (46) and an outer ring home reference sensor (370) for sensing the orientation of the outer ring (156) relative to the housing (46). The inner and outer ring home reference sensors (368, 370) may be associated with the respective inner and outer rings (158, 156) in any manner and by any structure, mechanism or device permitting or capable of providing for the sensing of the orientation of the associated ring (158, 156) by the respective sensor (368, 370). However, preferably, the inner and outer ring home reference sensors (368, 370) are mounted or connected with the inner ring drive mechanism (170) and the outer ring drive mechanism (164) respectively. In addition, each of the inner and outer ring home reference sensors (368, 370) provides information or data to the controller (360) with respect to the orientation of the respective rings (158, 156) as compared to a home or reference position relative to the housing (46).

In the preferred embodiment, each of the inner and outer ring home reference sensors (368, 370) is comprised of a plurality of magnets associated with a rotating or rotatable component of the inner ring drive mechanism (170) and the outer ring drive mechanism (164) respectively such that the magnets rotate therewith. The magnetic fields generated by the magnets of each of the inner and outer ring home reference sensors (368, 370) are sensed by a stationary counter associated with a non-rotating or non-rotatable component of the inner ring drive mechanism (170) and the outer ring drive mechanism (164) respectively. The stationary counter is provided to sense how far the inner and outer rings (158, 156) have rotated from each of their reference or home positions.

In addition, the deflection assembly orientation sensor apparatus (366) may also be comprised of one or more position sensors, such as high speed position sensors, associated with each of the inner and outer ring drive mechanisms (170, 164). In the preferred embodiment, the deflection assembly orientation sensor apparatus (366) is comprised of an inner ring high speed position sensor (372) associated with the inner ring drive mechanism (170) and an outer ring high speed position sensor (374) associated with the outer ring drive mechanism (164). Each of the high speed sensors (372, 374) is provided for sensing the rotation which is actually transmitted from the drilling shaft (24) through the inner ring clutch (224) and outer ring clutch (184) respectively to the inner and outer ring drive mechanisms (170, 164) respectively.

The inner and outer ring high speed position sensors (372, 374) may be associated with the respective inner and outer ring drive mechanisms (170, 164) in any manner and by any structure, mechanism or device permitting the sensing of the rotation actually transmitted from the drilling shaft (24) through the clutch (224, 184) to the drive mechanisms (170, 164). However, preferably, the inner and outer ring high speed position sensors (372, 374) are mounted or connected with the inner ring drive mechanism (170) and the outer ring drive mechanism (164) respectively.

In addition, one and preferably both of the high speed position sensors (372, 374) may be associated with an rpm sensor (375). The rpm sensor (375) is connected, mounted or associated with the drilling shaft (24) for sensing the rotation of the drilling shaft (24). In the preferred embodiment, the rpm sensor (375) is positioned within the central housing section (54) adjacent the electromagnetic coupling device (350). Further, the rpm sensor (375) is associated with the high speed position sensors (372, 374) such that a comparison may be made between the rotation sensed by the high speed position sensors (372, 374) and the rotation sensed by the rpm sensor (375). The comparison of the rotation sensed by the high speed position sensors (372, 374) and the rotation sensed by the rpm sensor (375) may be used to determine slippage through one or both clutches (224, 184) and to detect possible malfunctioning of the clutch (224, 184).

Each of the inner and outer ring high speed position sensors (372, 374) may similarly be comprised of any sensor or sensors capable of sensing rotation as described above.

As indicated, the controller (360) is operatively connected with both the housing orientation sensor apparatus (362) and the deflection assembly orientation sensor apparatus (366) so that the deflection assembly (92) may be actuated with reference to the orientation of both the housing (46) and the deflection assembly (92). The deflection assembly (92) is preferably actuated with reference to the orientation of both the housing (46) and the deflection assembly (92) since the housing orientation sensor apparatus (362) preferably senses the orientation of the housing (46) in three-dimensional space, while the deflection assembly orientation sensor apparatus (366) preferably senses the orientation of the inner and outer rings (158, 156) of the deflection assembly (92) relative to the housing (46).

Although the controller (360) may be operatively connected with both the housing orientation sensor apparatus (362) and the deflection assembly orientation sensor apparatus (366) in any manner and by any mechanism, structure, device or method permitting or providing for the communication of information or data therebetween, the operative connection is preferably provided by an electrical conductor, such as electrical wiring.

The controller (360) may also be operatively connected with a drilling string orientation sensor apparatus (376) so that the deflection assembly (92) may further be actuated with reference to the orientation of the drilling string (25). The drilling string orientation sensor apparatus (376) is connected, mounted or otherwise associated with the drilling string (25). The controller (360) may be operatively connected with the drilling string orientation sensor apparatus (376) in any manner and by any mechanism, structure, device or method permitting or providing for the communication of information or data therebetween.

However, preferably, the operative connection between the controller (360) and the drilling string orientation sensor apparatus (376) is provided by the electromagnetic coupling device (350). Specifically, as discussed above, the distal wires (358) extend from the controller (360) to the housing conductor (352) of the electromagnetic coupling device (350). The proximal wires (356) preferably extend along the drilling string (25) from the drilling string orientation sensor apparatus (376) to the drilling shaft (24) and the drilling shaft conductor (354). Electrical signals are induced between the housing conductor (3520 and the drilling shaft conductor (354).

The drilling string orientation sensor apparatus (376) may be comprised of any sensor or sensors, such as one or a combination of magnetometers and accelerometers, capable of sensing the orientation of the drilling string (25)). In addition, the drilling string orientation sensor apparatus (376) preferably senses the orientation of the drilling string (25) in three dimensions in space.

Thus, in the preferred embodiment, the deflection assembly (92) may be actuated to reflect a desired orientation of the drilling string (25) by taking into consideration the orientation of the drilling string (25), the orientation of the housing (46) and the orientation of the deflection assembly (92) relative to the housing (46).

As well, while drilling, the housing (46) may tend to slowly rotate in the same direction of rotation of the drilling shaft (24) due to the small amount of torque that is transmitted from the drilling shaft (24) to the housing (46). This motion causes the toolface of the drilling bit (22) to move out of the desired position. The various sensor apparatuses (362, 366, 376) sense this change and communicate the information to the controller (360). The controller (360) preferably keeps the toolface of the drilling bit (22) on target by automatically rotating the inner and outer rings (158, 156) of the deflection assembly (92) to compensate for the rotation of the housing (46).

Further, in order that information or data may be communicated along the drilling string (25) from or to downhole locations, such as from or to the controller (360) of the device (20), the device (20) may be comprised of a drilling string communication system (378). More particularly, the drilling string orientation sensor apparatus (376) is also preferably operatively connected with the drilling string communication system (378) so that the orientation of the drilling string (25) may be communicated to an operator of the device (20). The operator of the device (20) may be either a person at the surface in charge or control of the drilling operations or may be comprised of a computer or other operating system for the device (20).

The drilling string communication system (378) may be comprised of any system able to communicate or transmit data or information from or to downhole locations. However, preferably, the drilling string communication system (378) is comprised of an MWD or Measurement-While–Drilling system or device.

The device (20) may be comprised of any further number of sensors as required or desired for any particular drilling operation, such as sensors for monitoring other internal parameters of the device (20).

Finally, the device (20) may be further comprised of a device memory (380) for storing data generated by one or more of the housing orientation sensor apparatus (362), the deflection assembly orientation sensor apparatus (366), the drilling string orientation sensor apparatus (376) or data obtained from some other source such as, for example an operator of the device (20). The device memory (380) is preferably associated with the controller (20), but may be positioned anywhere between the proximal and distal ends (48, 50) of the housing (46), along the drilling string (25), or may even be located outside of the borehole. During operation of the device (20), data may be retrieved from the device memory (380) as needed in order to control the operation of the device (20), including the actuation of the deflection assembly (92).

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. In an apparatus for use in a borehole, the apparatus being of a type comprising a rotatable shaft and a housing for rotatably supporting a length of the shaft for rotation therein, a rotation restraining device associated with the housing for restraining rotation of the housing, the rotation restraining device comprising a plurality of rotation restraining carriage assemblies wherein each rotation restraining carriage assembly is comprised of at least one member for engaging a borehole wall to restrain rotation of the housing and wherein at least two of the rotation restraining carriage assemblies are spaced about the circumference of the housing and axially along the housing so that the rotation restraining carriage assemblies are staggered axially along the housing.

2. The device as claimed in claim 1 wherein each rotation restraining carriage assembly is comprised of a plurality of members.

3. The device as claimed in claim 1 or 2 wherein the plurality of rotation restraining carriage assemblies are spaced substantially evenly about the circumference of the housing.

4. The device as claimed in Claim 1 wherein at least one member for engaging the borehole wall is comprised of a roller having an axis of rotation substantially perpendicular to a longitudinal axis of the housing and being oriented such that the roller is capable of rolling about an axis of rotation of the roller in response to a force exerted on the roller substantially in the direction of the longitudinal axis of the housing.

5. The device as claimed in claim 4 wherein each rotation restraining carriage assembly is comprised of a plurality of rollers.

6. The device as claimed in claim 4 or 5 wherein the plurality of rotation restraining carriage assemblies are spaced substantially evenly about the circumference of the housing.

7. The device as claimed in claim 4 wherein each roller is comprised of a peripheral surface about a circumference of the roller and wherein the peripheral surface is comprised of an engagement surface for engaging the borehole wall to restrain rotation of the housing.

8. The device as claimed in claim 6 wherein each roller is comprised of a peripheral surface about a circumference of the roller and wherein the peripheral surface is comprised of an engagement surface for engaging the borehole wall to restrain rotation of the housing.

9. The device as claimed in claim 7 or 8 wherein the engagement surface is comprised of the peripheral surface of the roller being tapered.

10. The device as claimed in claim 7 or 8 wherein the roller is capable of movement between a retracted position and an extended position in which it extends radially from the housing.

11. The device as claimed in claim 10 further comprising a biasing device for biasing the roller toward the extended position.

12. The device as claimed in claim 11 wherein the biasing device is comprised of at least one spring which acts between the housing and the roller.

13. The device as claimed in claim 6 wherein each rotation restraining carriage assembly is comprised of a plurality of sets of rollers spaced axially along the housing, and wherein each set of rollers is comprised of a plurality of coaxial rollers spaced side to side.

14. The device as claimed in claim 13 wherein the rotation restraining device is comprised of three rotation restraining carriage assemblies spaced substantially evenly about the circumference of the housing, wherein each rotation restraining carriage assembly is comprised of three sets of rollers spaced axially along the housing, and wherein each set of rollers is comprised of four coaxial rollers spaced side to side.

15. The device as claimed in Claim 1 wherein at least one member for engaging the borehole wall is comprised of a piston.

16. The device as claimed in claim 15 wherein each rotation restraining carriage assembly is comprised of a plurality of pistons.

17. The device as claimed in claim 15 or 16 wherein the plurality of rotation restraining carriage assemblies are spaced substantially evenly about the circumference of the housing.

18. The device as claimed in claim 15 wherein each piston is comprised of an outermost engagement surface for engaging the borehole wall to restrain rotation of the housing.

19. The device as claimed in claim 17 wherein each piston is comprised of an outermost engagement surface for engaging the borehole wall to restrain rotation of the housing.

20. The device as claimed in claim 18 or 19 wherein each piston is capable of movement between a retracted position and an extended position in which it extends radially from the housing.

21. The device as claimed in claim 20 further comprising an actuator device for moving the piston between the retracted position and the extended position.

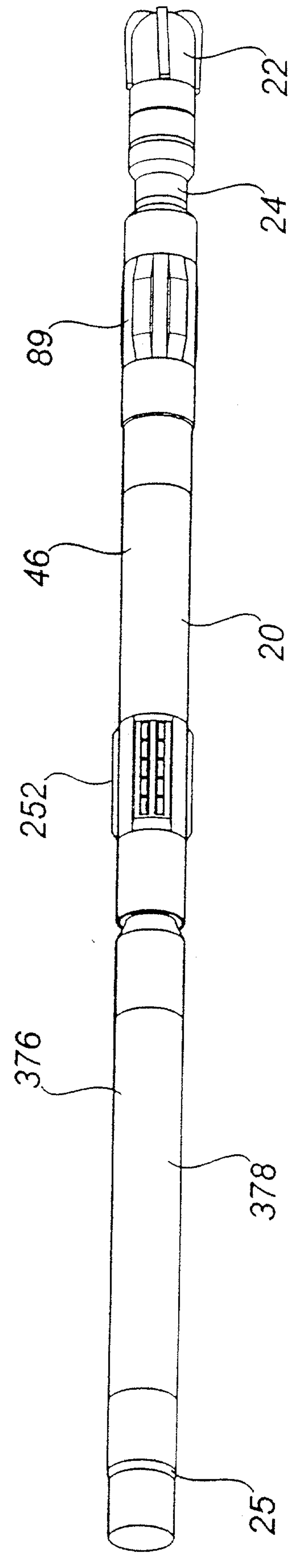
22. The device as claimed in claim 21 wherein the actuator device is comprised of a hydraulic pump.

23. The device as claimed in claim 17 wherein each rotation restraining carriage assembly is comprised of a plurality of pistons spaced axially along the housing.

24. The device as claimed in claim 23 wherein the rotation restraining device is comprised of four rotation restraining carriage assemblies spaced substantially evenly about the

circumference of the housing and wherein each rotation restraining carriage assembly is comprised of a plurality of pistons spaced axially along the housing.

FIG. 1



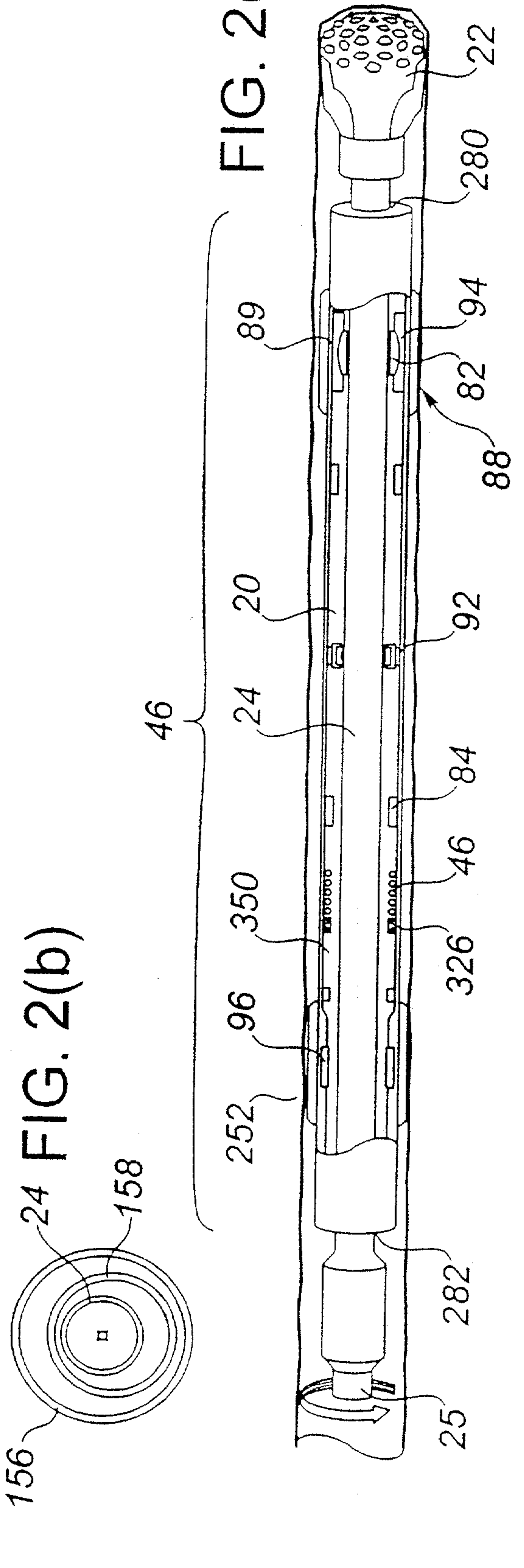


FIG. 2(a)

FIG. 2(b)

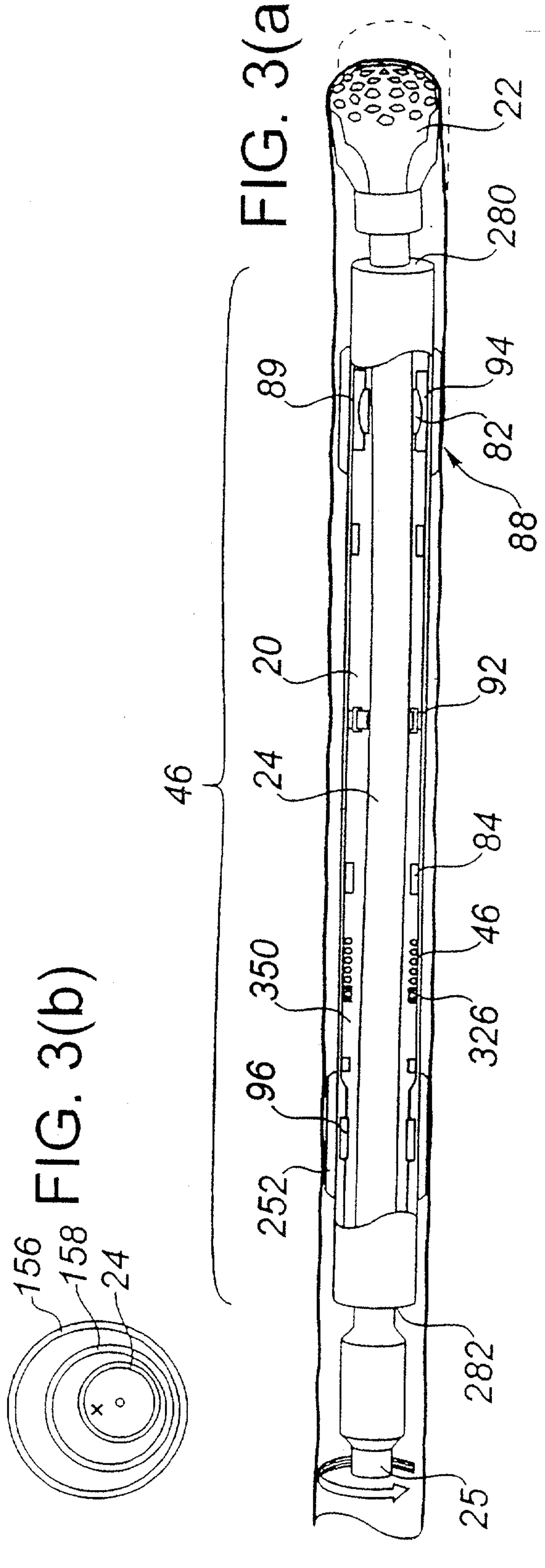


FIG. 3(a)

FIG. 3(b)

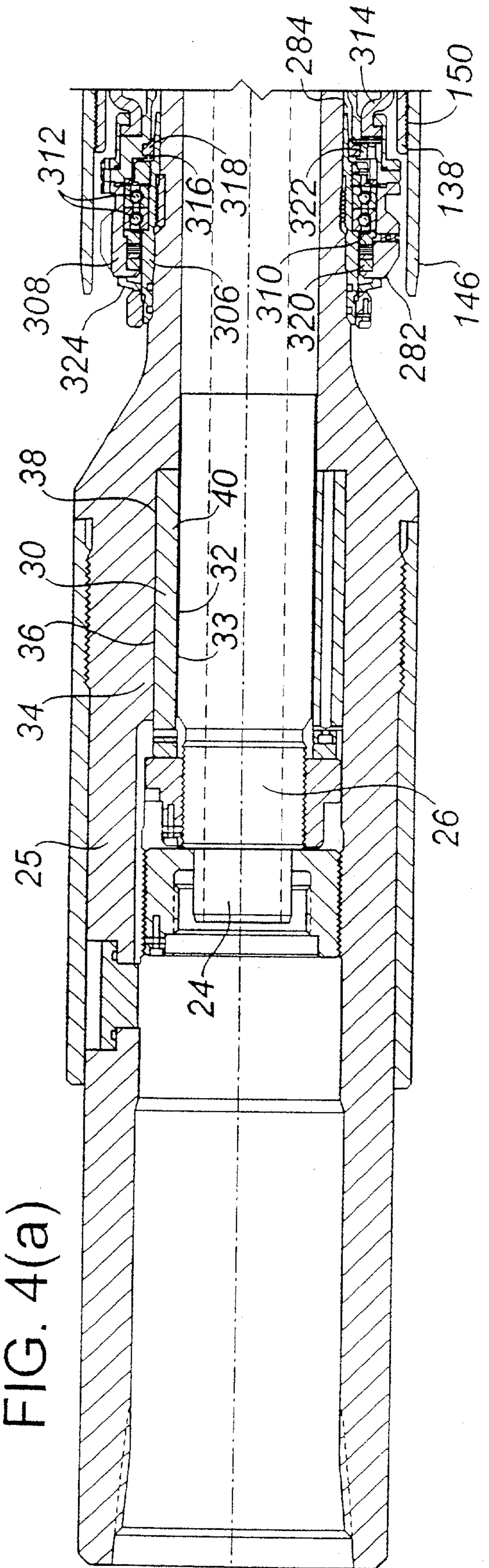


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FIG. 4(a)

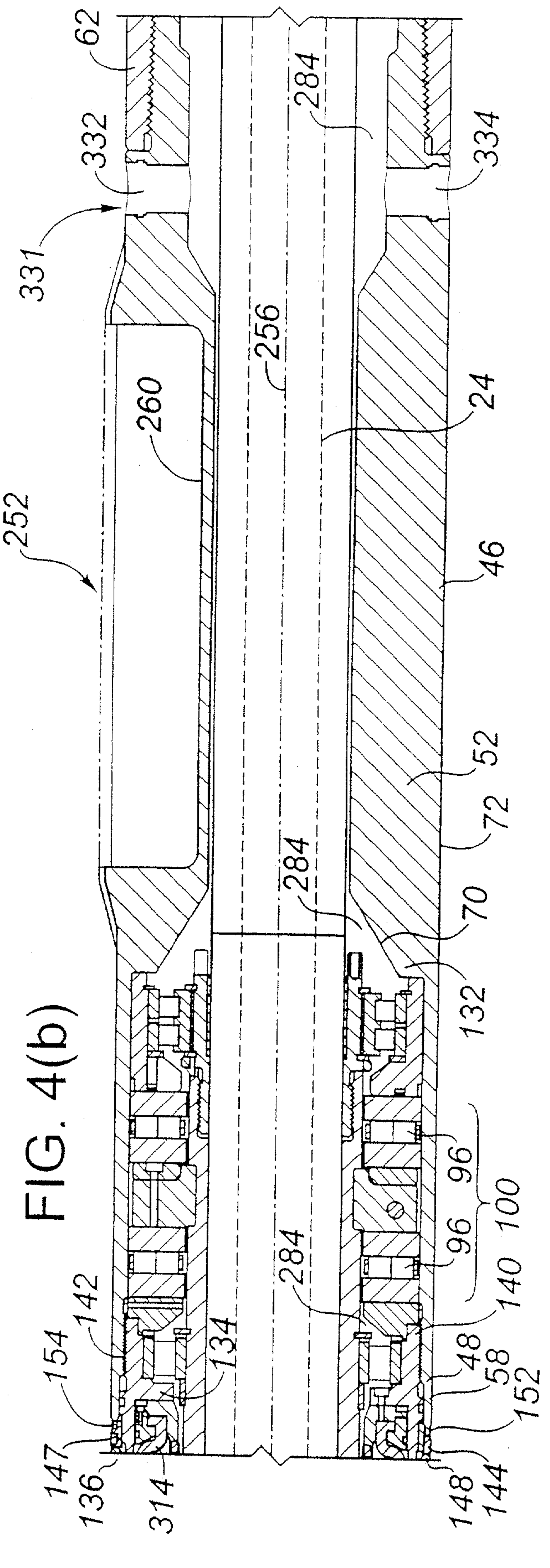

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FIG. 4(b)

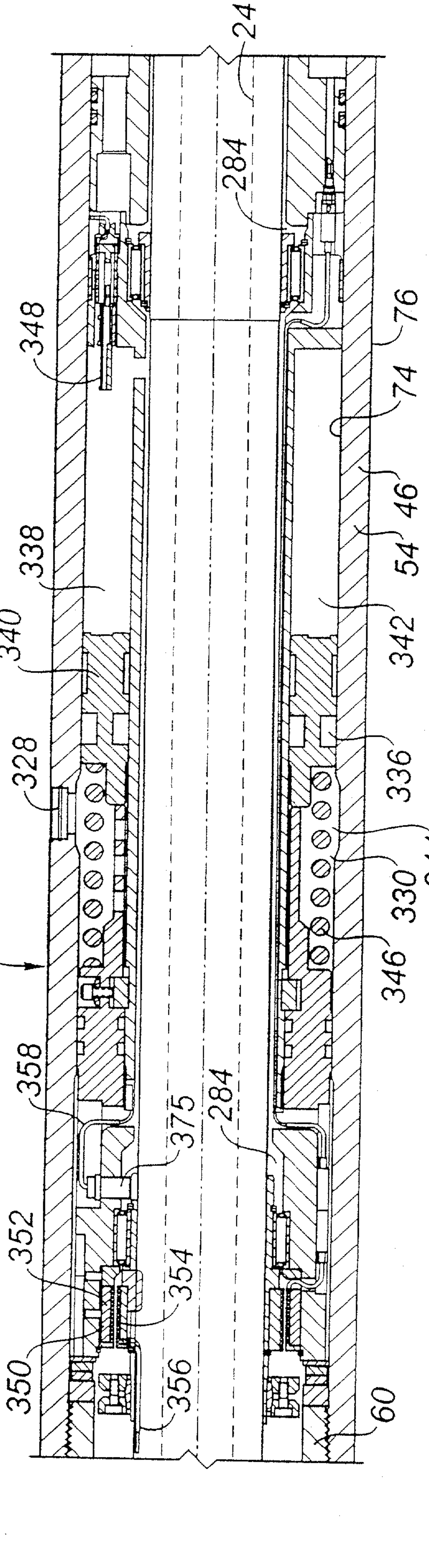
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FIG. 4(c)

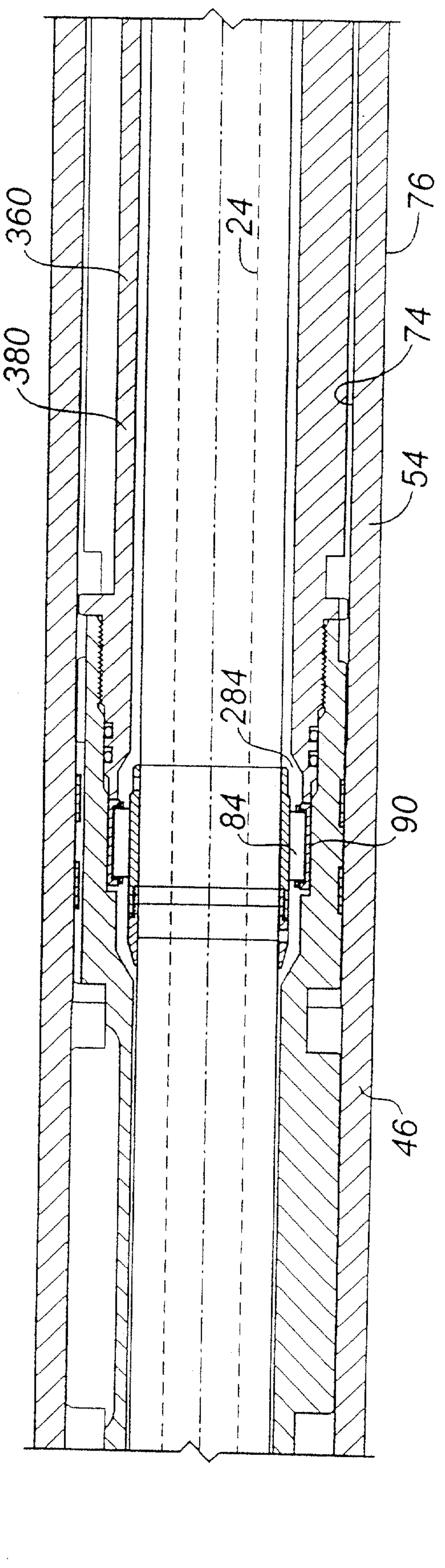
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FIG. 4(d)

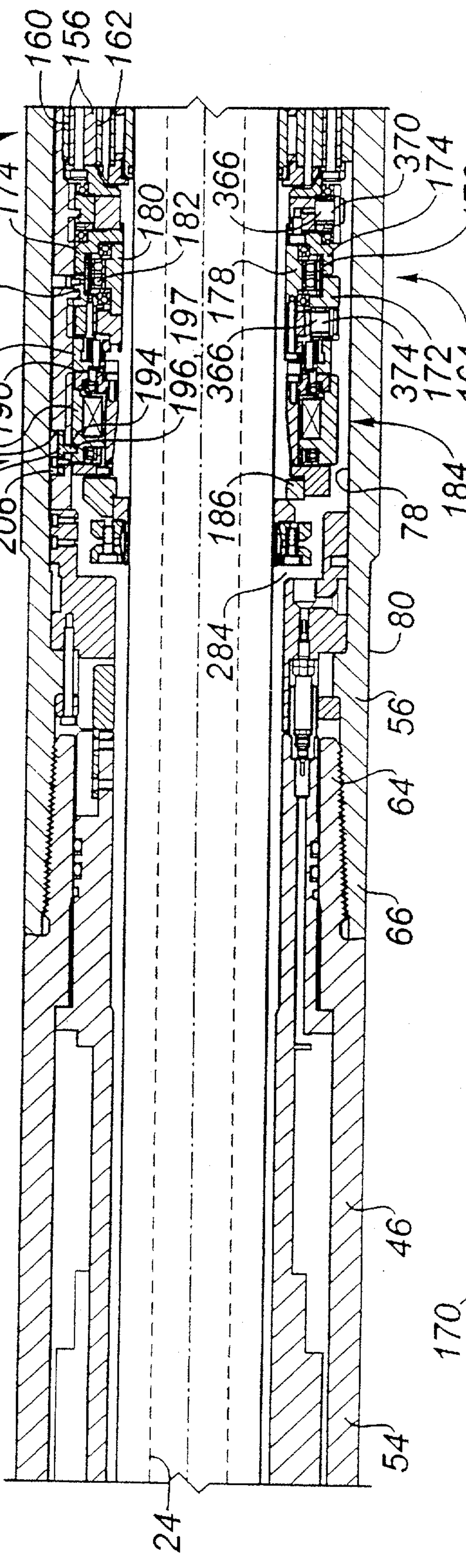
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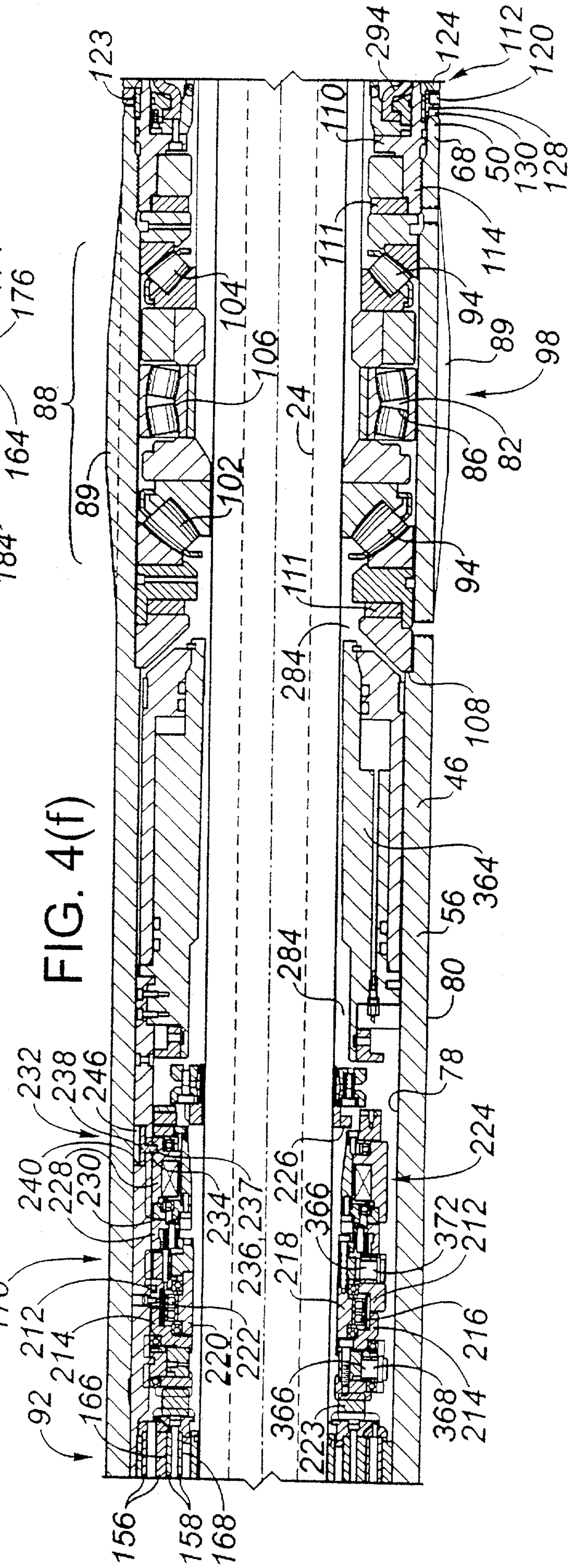
FIG. 4(e)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366
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FIG. 4(f)

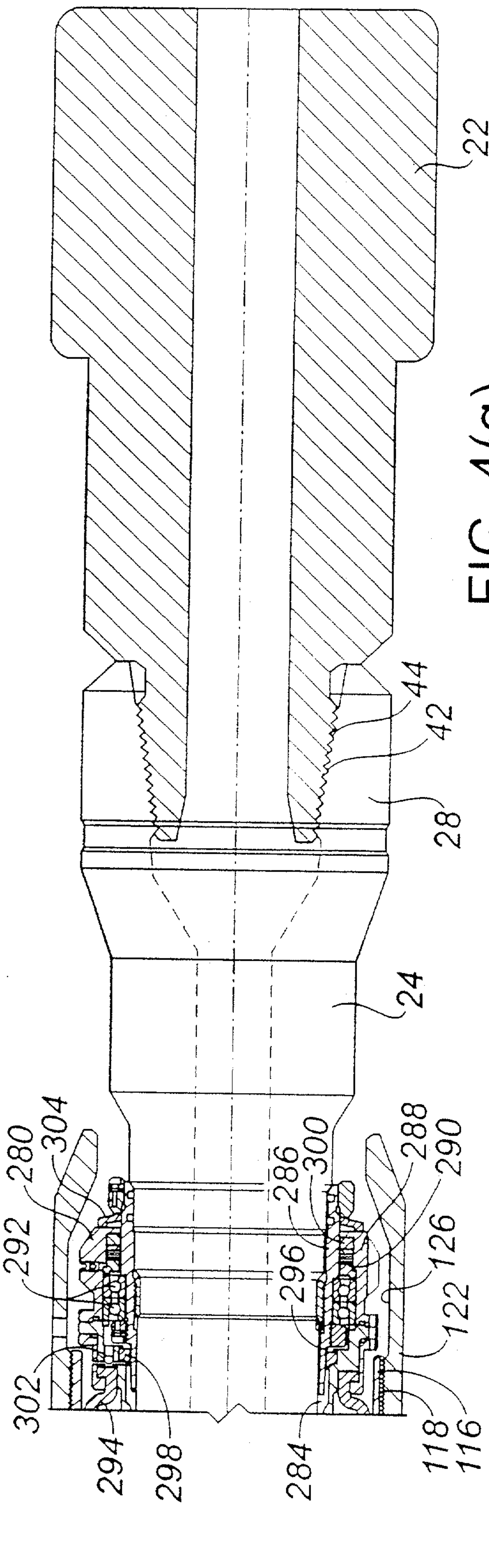
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FIG. 4(g)

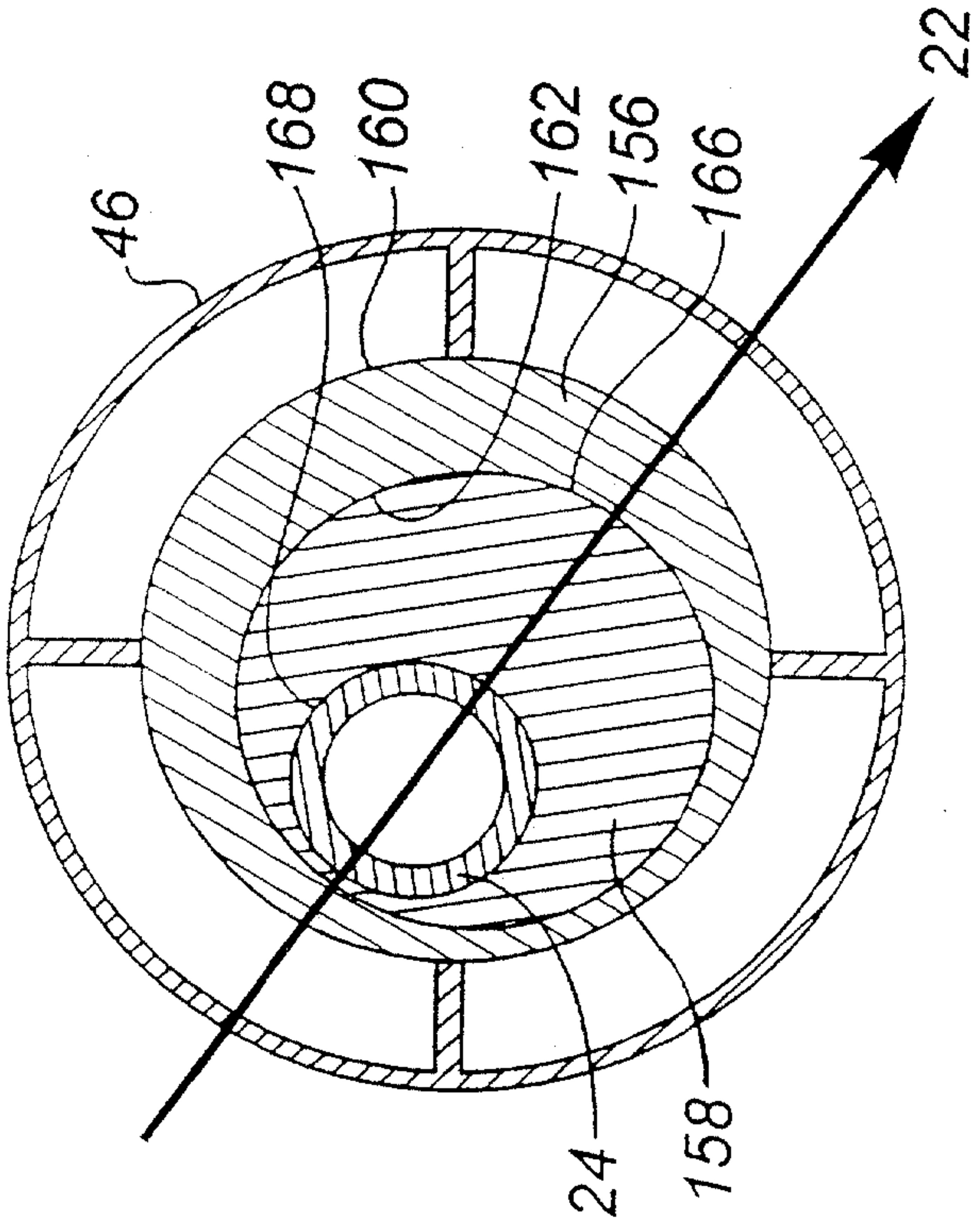
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FIG. 5

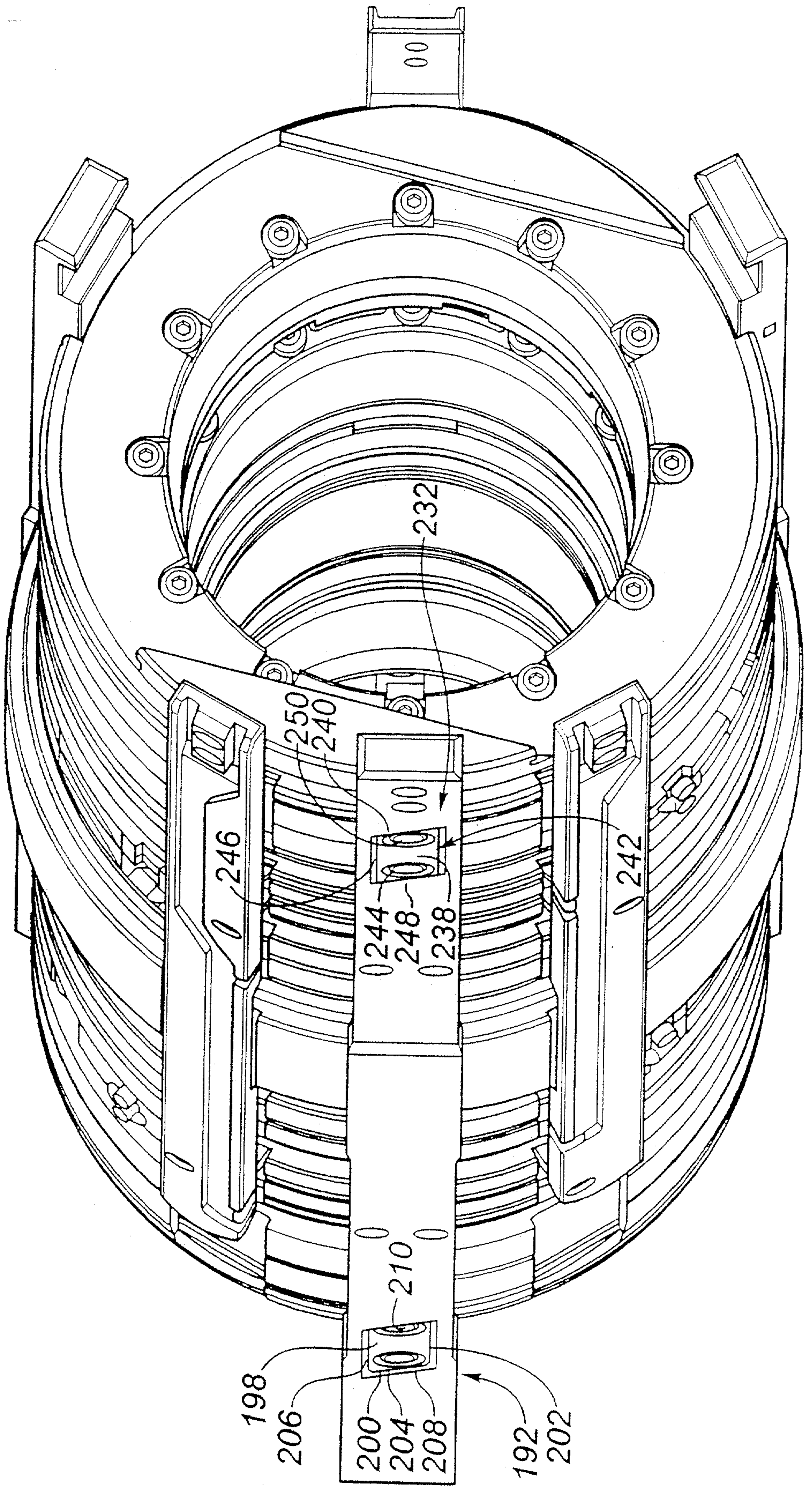

FIG. 6

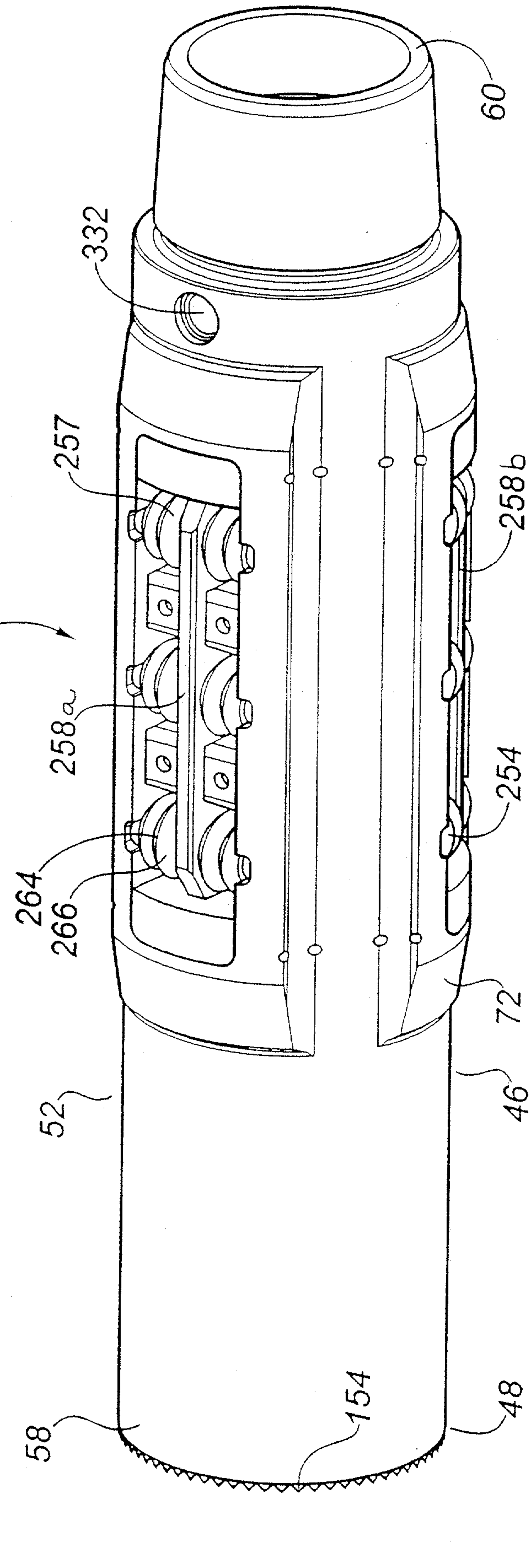

FIG. 7

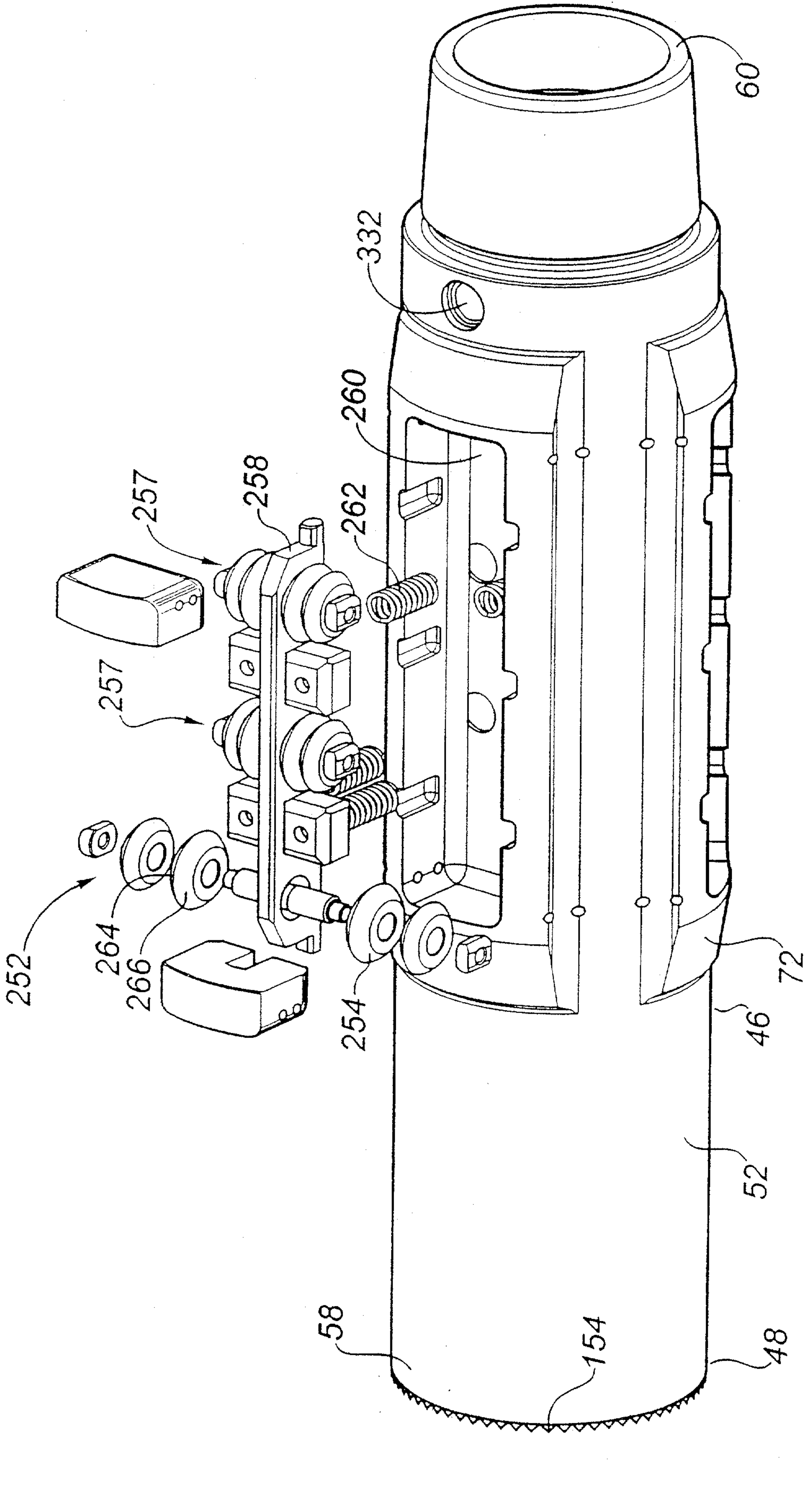

FIG. 8

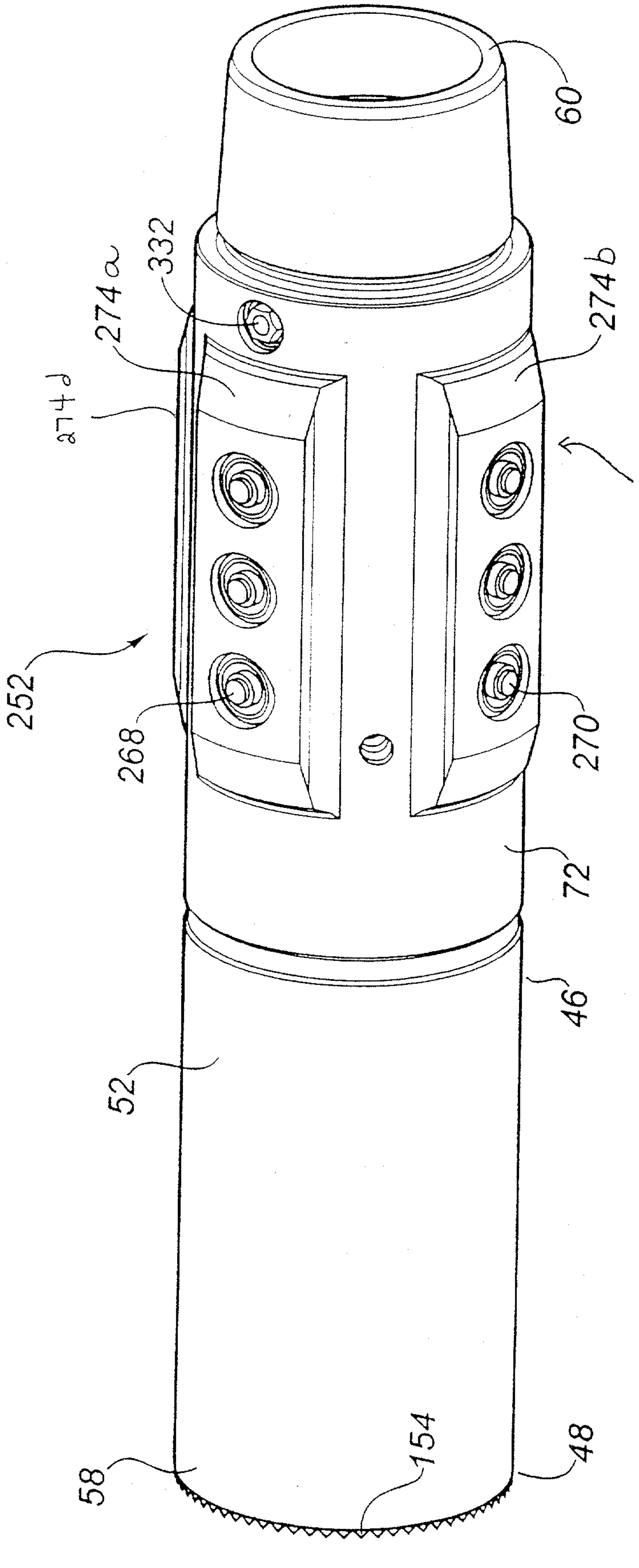

FIG. 9

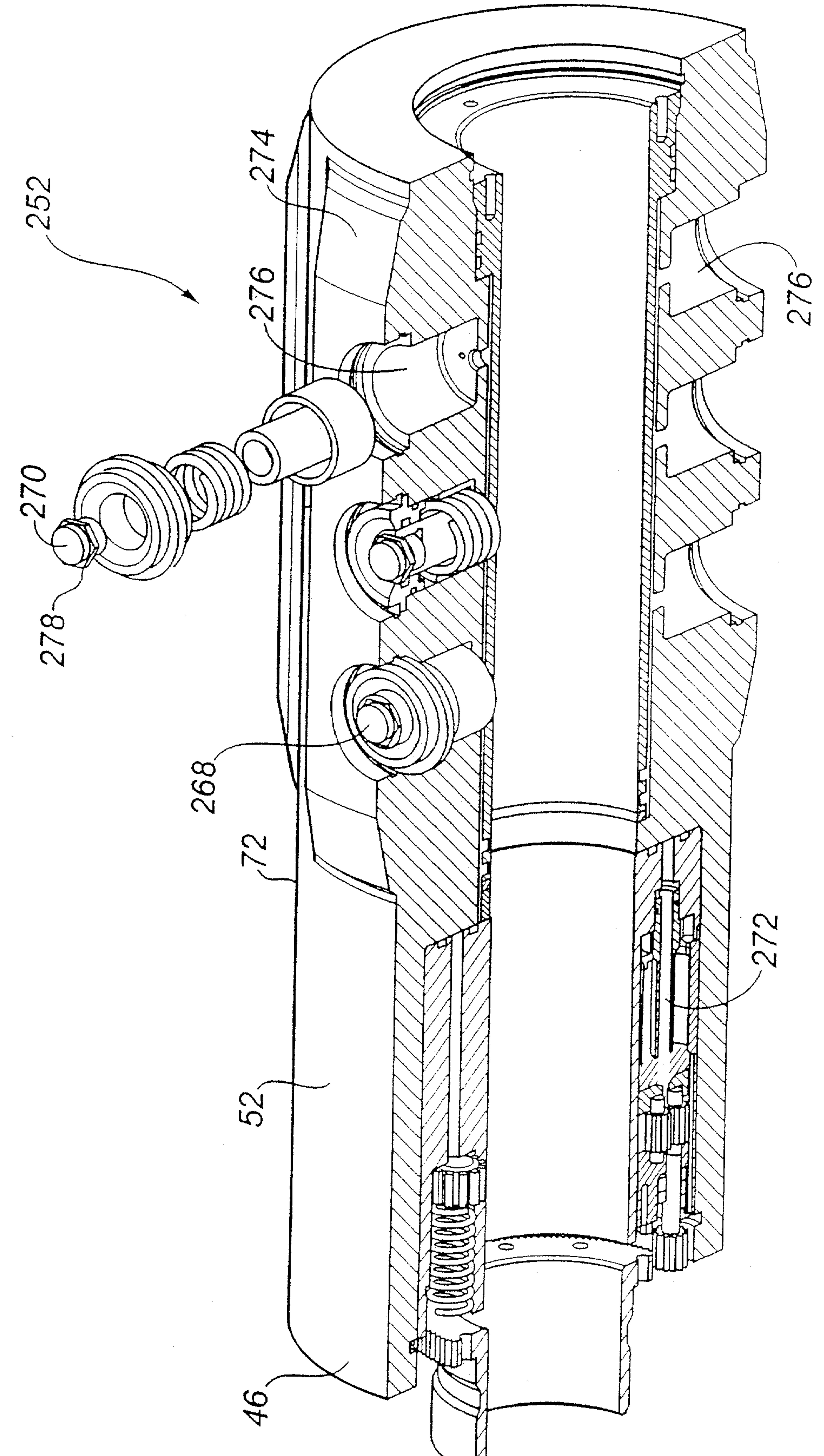

FIG. 10

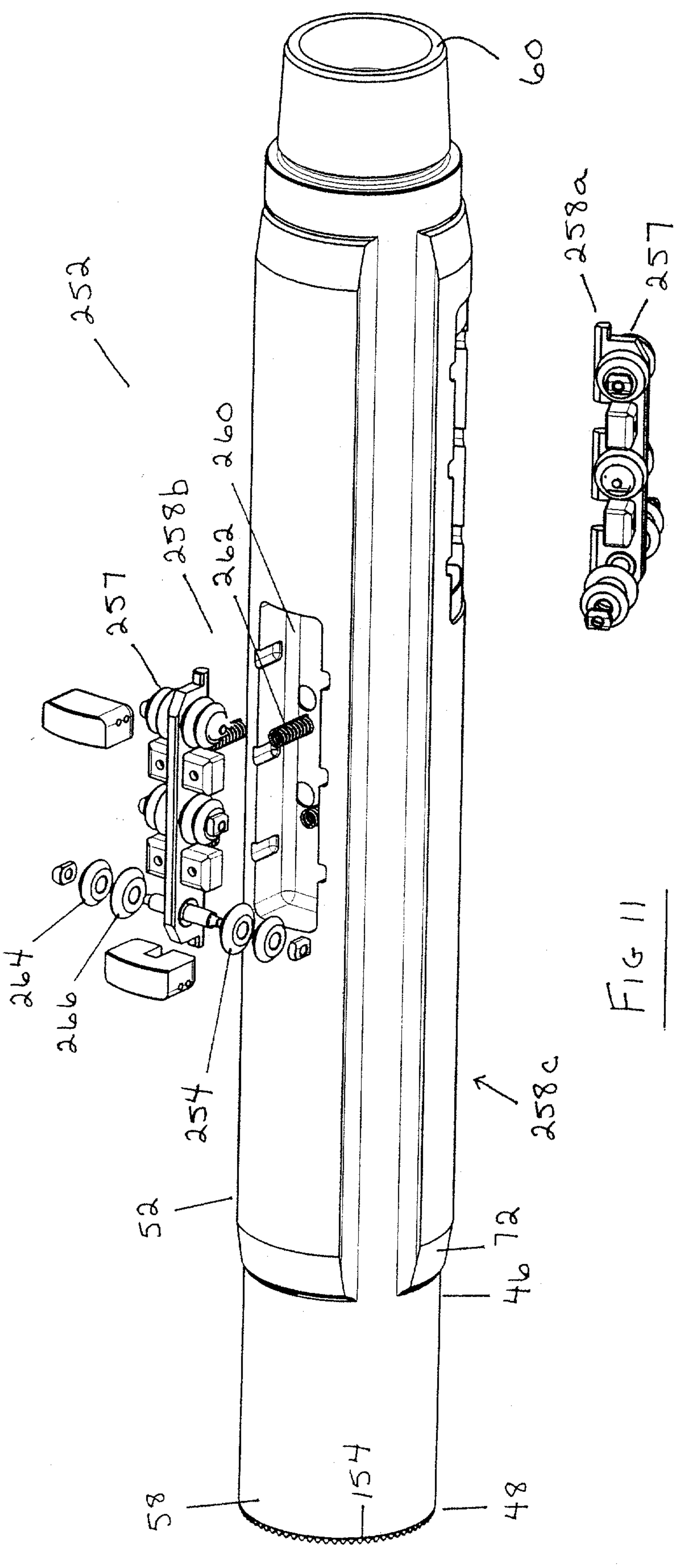
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FIG 11

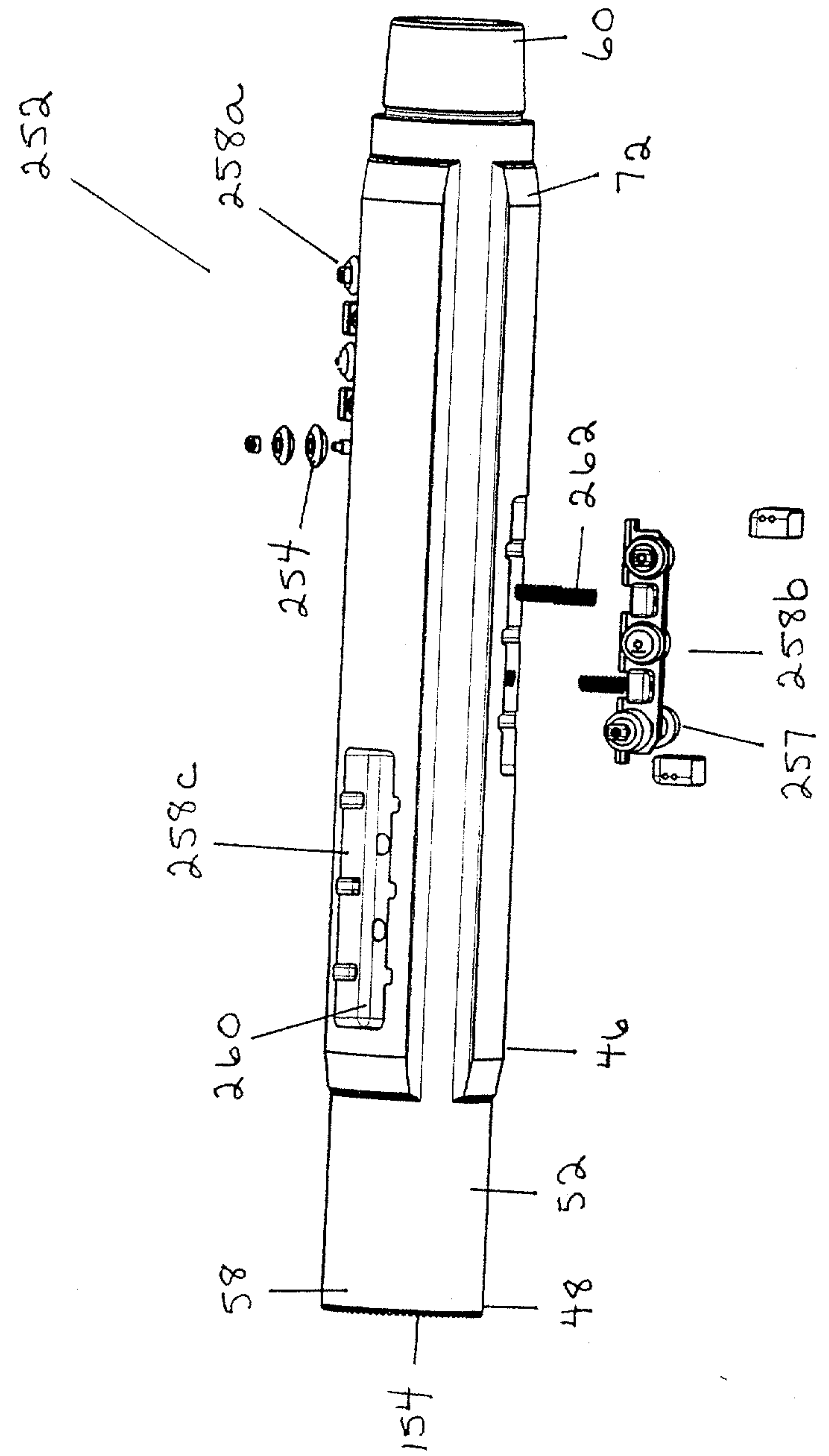


FIG 12

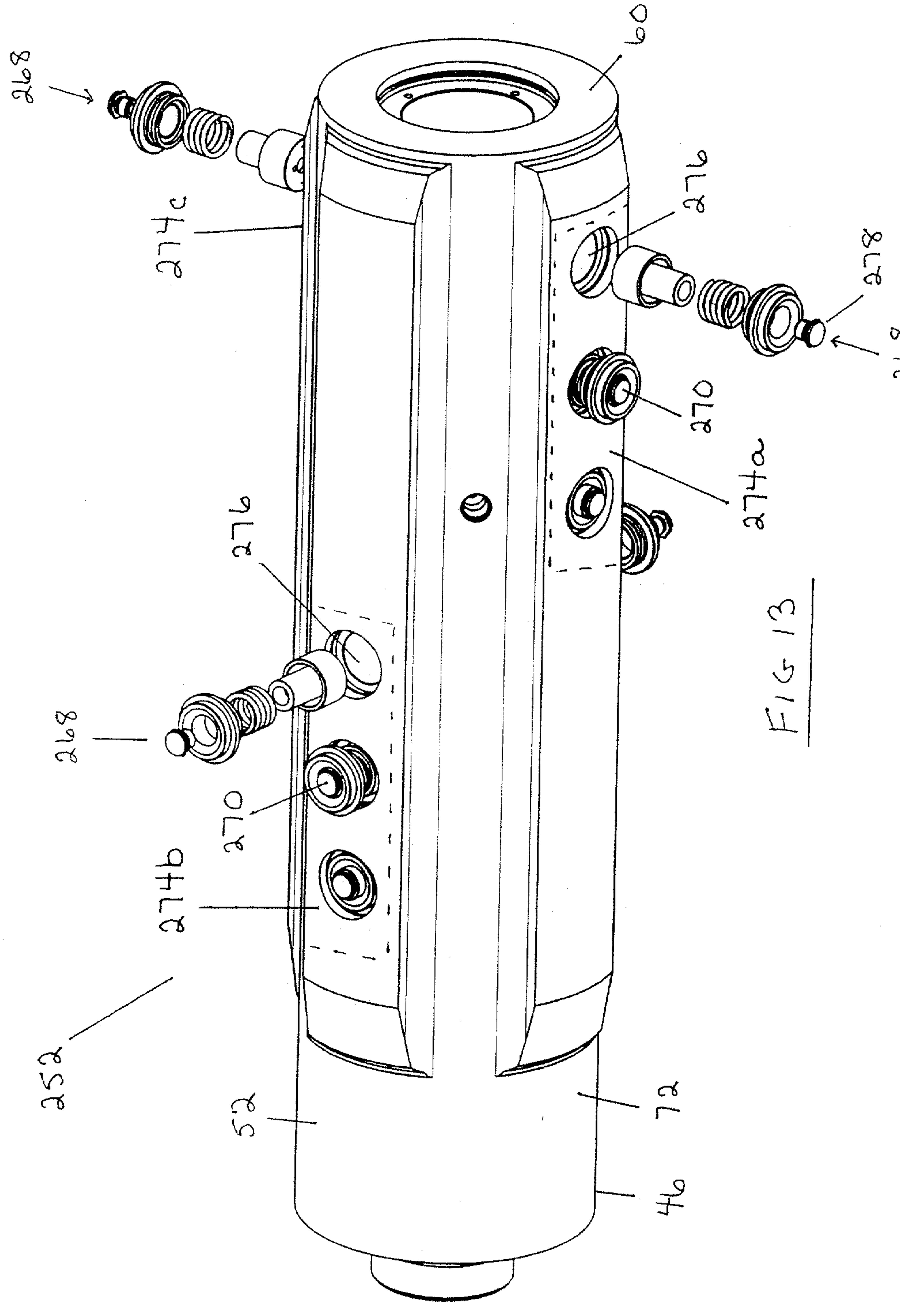


FIG 13

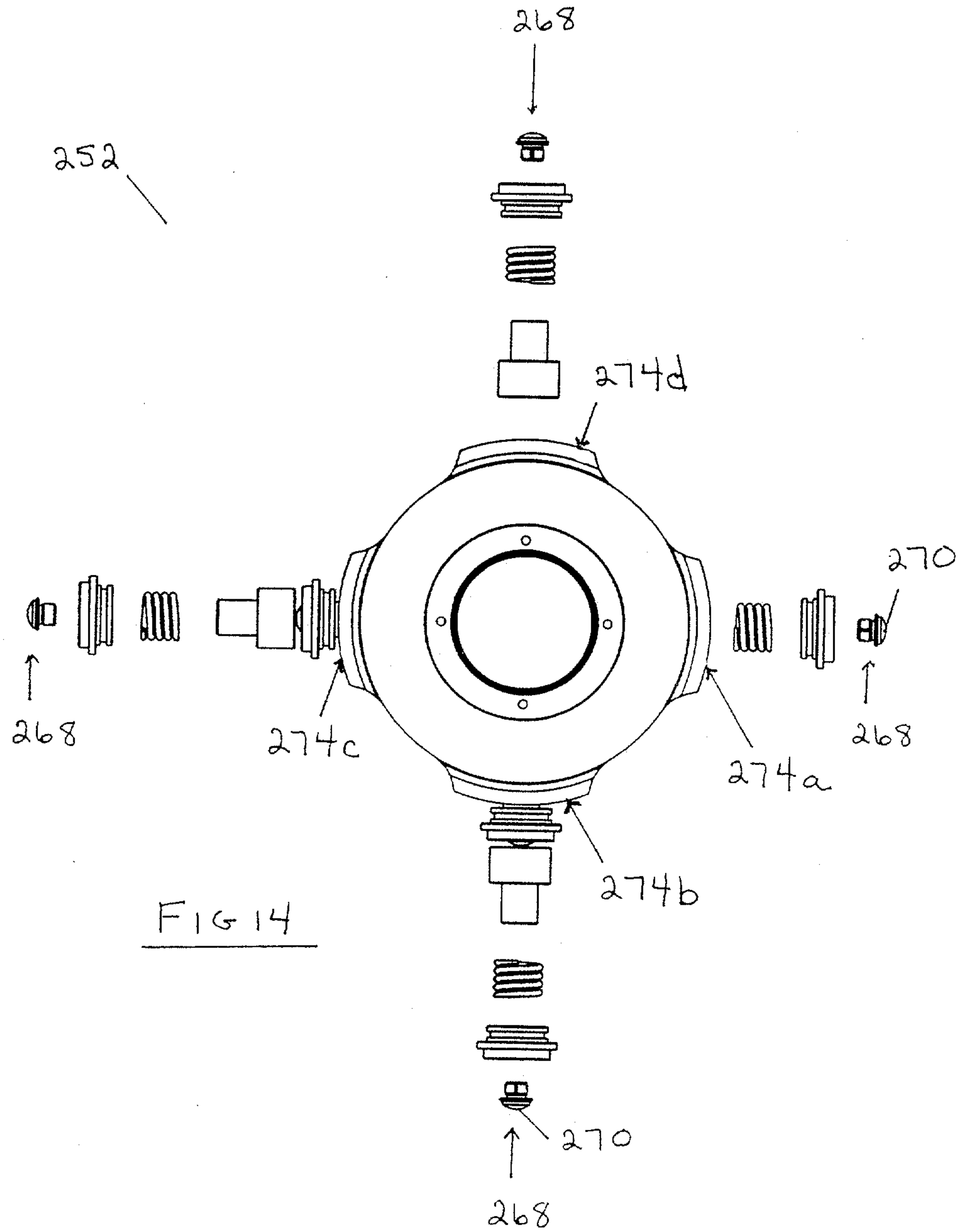
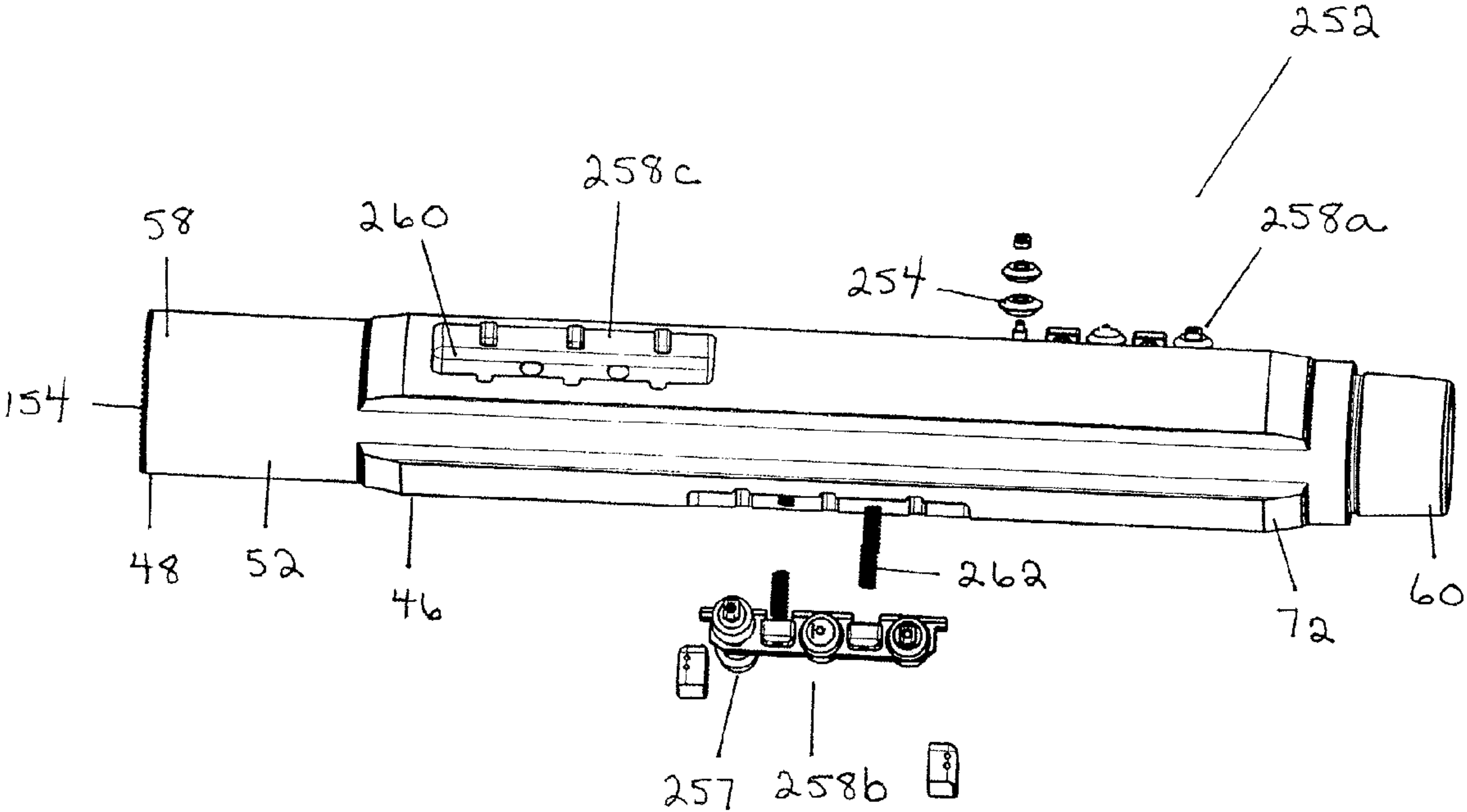


FIG 14


252
258c
260
58
258a
254
154
48
52
46
262
72
60
257
258b