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Abstract of the Disclosure

HYDRAULIC CYLINDER WITH SPECIFIC PERFORMANCE DIMENSIONS

An actuator includes a tube having a central, axially extending bore defined in the tube and extending between a closed, distal end of the tube and an open, proximal end of the tube. A rod is slidably mounted within the tube and slidably supported at the proximal end of the tube by a head seal assembly. A piston is mounted at a distal end of the rod, and retained on the rod by a piston retention assembly attached to the distal end of the rod. A trunnion cap bore for receiving a trunnion pin is defined through the closed, distal end of the tube, and a rod eye bore for receiving a rod eye pin is defined through a proximal end of the rod. A retracted pin-to-pin dimension is defined from a center of the trunnion cap bore to a center of the rod eye bore when the rod and piston are fully retracted into the tube. A stroke dimension is defined from a first, fully retracted position of the piston adjacent the closed, distal end of the tube to a second, fully extended position of the piston in contact with the head seal assembly at the proximal end of the tube.

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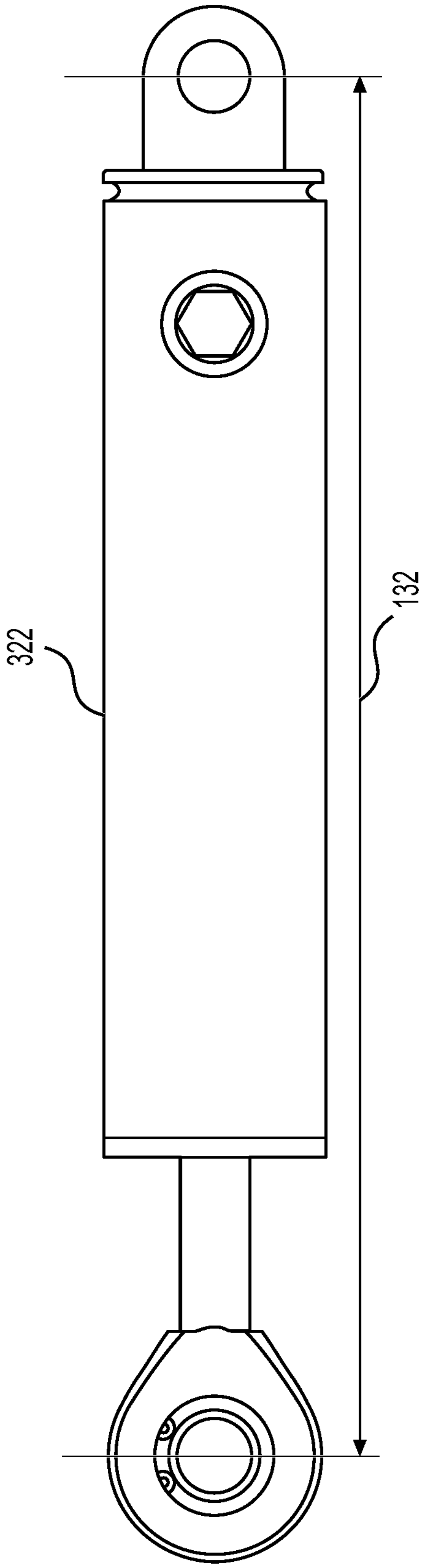

FIG. 1B

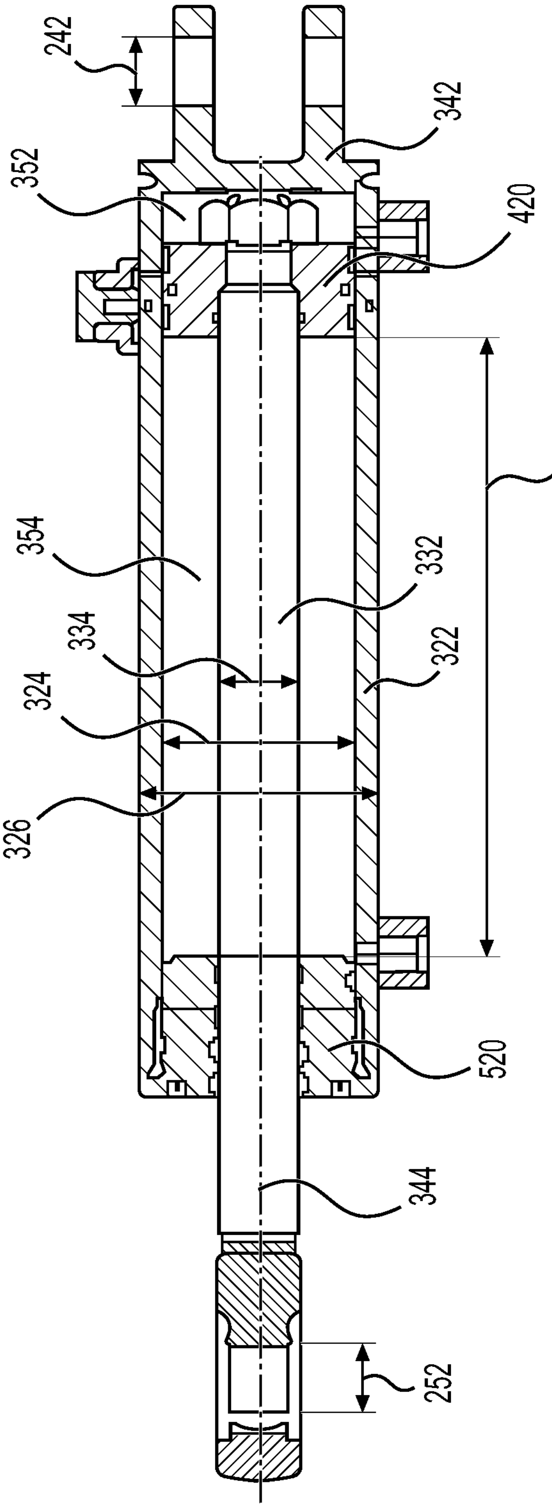

FIG. 1C

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Description

HYDRAULIC CYLINDER WITH SPECIFIC PERFORMANCE DIMENSIONS

Technical Field

[0001] The present disclosure relates generally to a hydraulic cylinder used on heavy machinery such as a paving machine and, more particularly, to a hydraulic cylinder with specific performance dimensions that meet the kinematic, structural, and load requirements for the machinery.

Background

[0002] A conventional hydraulic system onboard heavy machinery such as a paving machine may include pumps that draw low-pressure fluid from a tank, pressurize the fluid, and make the pressurized fluid available to multiple different actuators for use in moving the actuators. The actuators may include hydraulic cylinders specifically designed to meet the various kinematic, structural, and load requirements for moving various structural elements of the machine relative to each other when using the machine to perform its assigned tasks. For example, one or more hydraulic cylinders may be specifically designed to handle the hydraulic fluid pressures, kinematic characteristics, torsional stresses, compressive stresses, tension stresses, hoop stresses, ranges of motion, and speed of motion required when operating a particular machine to perform work tasks such as transferring asphalt or other paving materials from a hopper, via one or more augers, to be applied to a road surface using a floating screed. In various exemplary arrangements, a speed of each actuator can be independently controlled by selectively throttling (i.e., restricting) a flow of the pressurized fluid from the pump into each actuator. For example, to move a particular actuator at a high speed, the flow of fluid from the pump into the actuator is restricted by only a small amount (or not at all). In contrast, to move the same or another actuator at a low speed, the restriction placed on the flow of fluid is increased. Although adequate for many applications, the use of fluid restriction to control actuator speed can result in pressure losses that reduce an overall efficiency of a hydraulic system.

[0003] An alternative type of hydraulic system is known as a closed loop hydraulic system. A closed loop hydraulic system generally includes a pump connected in closed loop fashion to a single actuator or to a pair of actuators operating in tandem. During operation, the pump draws fluid from one chamber of the actuator(s) and discharges pressurized fluid to an opposing chamber of the same

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actuator(s). To move the actuator(s) at a higher speed, the pump discharges fluid at a faster rate. To move the actuator(s) with a lower speed, the pump discharges the fluid at a slower rate. A closed loop hydraulic system is generally more efficient than a conventional hydraulic system because the speed of the actuator(s) is controlled through pump operation as opposed to fluid restriction. That is, the pump is controlled to only discharge as much fluid as is necessary to move the actuator(s) at a desired speed, and no throttling of a fluid flow is required.

[0004] An exemplary closed loop hydraulic system is disclosed in U.S. Patent 4,369,625 of Izumi et al. that published on January 25, 1983 (the ’625 patent). In the ’625 patent, a multi-actuator meterless-type hydraulic system is described that has flow combining functionality. The hydraulic system includes a swing circuit, a boom circuit, a stick circuit, a bucket circuit, a left travel circuit, and a right travel circuit. Each of the swing, boom, stick, and bucket circuits have a pump connected to a specialized hydraulic cylinder in a closed loop manner. In addition, a first combining valve is connected between the swing and stick circuits, a second combining valve is connected between the stick and boom circuits, and a third combining valve is connected between the bucket and boom circuits. The left and right travel circuits are connected in parallel to the pumps of the bucket and boom circuits, respectively. In this configuration, any one hydraulic cylinder can receive pressurized fluid from more than one pump such that its speed is not limited by the capacity of a single pump.

[0005] Although an improvement over existing closed loop hydraulic systems, the closed loop hydraulic system of the ’625 patent described above may still be less than optimal. In particular, connected circuits of the system may only be sequentially performed. In addition, the speeds and forces of the various actuators may be difficult to control. Moreover, hydraulic cylinders are preferably designed with specific ranges of dimensions for a stroke, a pin-to-pin length when fully retracted, a bore diameter of a tube that forms the body of the hydraulic cylinder, an outer diameter of the tube, a diameter of a rod that extends from a piston assembly slidably supported within the tube to define a head-end chamber on one side of the piston assembly and a rod-end chamber on the opposite side of the piston assembly, a diameter of a rod-end pin, and a diameter of a trunnion pin at the head end of the cylinder, depending on the specific machines and load applications where the hydraulic cylinders will be used. Additionally, hydraulic cylinders used on heavy machinery may benefit from a combination of the specific performance dimensions disclosed herein along with features such as damping devices and head seal arrangements that improve the operational characteristics, fatigue life, and performance under extreme conditions.

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[0006] Hydraulic cylinders of the present disclosure are designed with ranges of specific performance dimensions determined through extensive analysis including application of physics-based equations, finite element analysis, and other computational analyses taking into consideration the kinematics and structural stresses that will be placed on the cylinders during use, in combination with empirical data and other customer-centric data directed toward meeting specific job requirements and solving one or more of the problems set forth above and/or other problems of the prior art.

Summary

[0007] In one aspect, the present disclosure is directed to an actuator configured for actuating a first structural element of a paving machine relative to a second structural element of the machine. The actuator may include a tube, with the tube comprising a central, axially extending bore that is defined in the tube extending between a closed, distal end of the tube and an open, proximal end of the tube, and a thickness of the tube being defined by the radial distance between an outer diameter of the tube and the bore diameter of the tube. A rod may be slidably mounted within the tube, with the rod being slidably supported at the proximal end of the tube by a head seal assembly. A piston may be mounted at a distal end of the rod, and a piston retention assembly may be attached to the distal end of the rod and configured to retain the piston on the distal end of the rod. A trunnion cap bore may be defined through the closed, distal end of the tube and configured for receiving a trunnion pin adapted for pivotally connecting the distal end of the tube to the first structural element of the machine. A rod eye bore may be defined through a proximal end of the rod and configured for receiving a rod eye pin adapted for pivotally connecting the proximal end of the rod to the second structural element of the machine.

[0008] In another aspect, the present disclosure is directed to a paving machine that includes a plurality of structural elements and a plurality of hydraulic actuators each interconnecting two of the structural elements, wherein each hydraulic actuator is configured for actuating a first structural element on the paving machine relative to a second structural element on the paving machine. Each hydraulic actuator may include a tube, with the tube comprising a central, axially extending bore that is defined in the tube extending between a closed, distal end of the tube and an open, proximal end of the tube, and a thickness of the tube being defined by the radial distance between an outer diameter of the tube and the bore diameter of the tube. A rod may be slidably mounted within the

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tube, with the rod being slidably supported at the proximal end of the tube by a head seal assembly. A piston may be mounted at a distal end of the rod, and a piston retention assembly may be attached to the distal end of the rod and configured to retain the piston on the distal end of the rod. A trunnion cap bore may be defined through the closed, distal end of the tube and configured for receiving a trunnion pin adapted for pivotally connecting the distal end of the tube to the first structural element of the paving machine. A rod eye bore may be defined through a proximal end of the rod and configured for receiving a rod eye pin adapted for pivotally connecting the proximal end of the rod to the second structural element of the paving machine.

[0009] In yet another aspect, the present disclosure is directed to a hydraulic cylinder configured for actuating a first structural element on a paving machine relative to a second structural element on the paving machine. The hydraulic cylinder may include a tube, with the tube comprising a central, axially extending bore that is defined in the tube extending between a closed, distal end of the tube and an open, proximal end of the tube, and a thickness of the tube being defined by the radial distance between an outer diameter of the tube and the bore diameter of the tube. A rod may be slidably mounted within the tube, with the rod being slidably supported at the proximal end of the tube by a head seal assembly. A piston may be mounted at a distal end of the rod, and a piston retention assembly may be attached to the distal end of the rod and configured to retain the piston on the distal end of the rod. A trunnion cap bore may be defined through the closed, distal end of the tube and configured for receiving a trunnion pin adapted for pivotally connecting the distal end of the tube to the first structural element of the paving machine. A rod eye bore may be defined through a proximal end of the rod and configured for receiving a rod eye pin adapted for pivotally connecting the proximal end of the rod to the second structural element of the paving machine.

Brief Description of the Drawings

[0010] Figs. 1A – 1C illustrate an exemplary hydraulic cylinder that may be used to raise and lower an auger of an asphalt paving machine;

[0011] Figs. 2A – 2C illustrate another exemplary hydraulic cylinder that may be used to raise and lower an auger of an asphalt paving machine;

[0012] Figs. 3A – 3C illustrate an exemplary hydraulic cylinder that may be used to control a hopper of an asphalt paving machine;

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[0013] Figs. 4A – 4C illustrate an exemplary hydraulic cylinder that may be used as a tow point hydraulic cylinder for adjusting a distance between an auger and a floating screed on a paving machine;

[0014] Figs. 5A – 5C illustrate another exemplary hydraulic cylinder that may be used as a tow point hydraulic cylinder on a paving machine;

[0015] Figs. 6A – 6C illustrate an exemplary hydraulic cylinder that may be used to lift a screed of a paving machine;

[0016] Figs. 7A – 7C illustrate another exemplary hydraulic cylinder that may be used to lift a screed of a paving machine;

[0017] Figs. 8A – 8C illustrate another exemplary hydraulic cylinder that may be used in steering a paving machine;

[0018] Figs. 9A – 9C illustrate another exemplary hydraulic cylinder that may be used to apply tension on a paving machine;

[0019] Figs. 10A – 10C illustrate another exemplary hydraulic cylinder that may be used as a power endgate cylinder on a paving machine;

[0020] Figs. 11A – 11C illustrate another exemplary hydraulic cylinder that may be used in controlling the slope of a paving machine;

[0021] Figs. 12A – 12C illustrate another exemplary hydraulic cylinder that may be used in controlling the slope of a paving machine;

[0022] Figs. 13A – 13C illustrate another exemplary hydraulic cylinder that may be used as a berm cylinder for controlling screed extenders to form a shoulder berm adjacent a paving mat formed by a paving machine; and

[0023] Figs. 14A – 22C illustrate exemplary hydraulic cylinders that may be used as extend hydraulic cylinders for various purposes where parts of a paving machine are moved relative to each other.

Detailed Description

[0024] The hydraulic cylinders shown in Figs. 1A – 22C are exemplary hydraulic cylinders that may be used as actuators on a paving machine or other heavy machinery having multiple systems and components that cooperate to accomplish a task. For example, an asphalt paving machine may include a variety of hydraulic cylinders used as actuators for moving various portions, components,

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or assemblies of components of the paving machine relative to each other and/or relative to the substrate on which the paving machine is operating. An asphalt paving machine is commonly used to apply, spread and compact a paving, i.e., a mat of asphalt or other paving material, relatively evenly over a work surface. These machines are generally used in the construction of roads, parking lots and other areas. An asphalt paving machine generally includes a hopper for receiving asphalt material from a truck or material transfer vehicle, and a conveyor system for transferring the asphalt rearwardly from the hopper for discharge onto a roadbed. A screed plate smooths and compacts the asphalt material, ideally leaving behind a roadbed of uniform depth and smoothness.

[0025] In order to help achieve the desired uniform depth and smoothness, as well as to accommodate different desired roadbed configurations, a screed assembly may include a variety of screed sections and adjustments. These adjustments can be used to vary, for example, the thickness of the mat as well as the degree of any crown and the cross slopes of the same, and the configuration of a shoulder berm adjacent the paving mat. To improve the asphalt compaction and spreading capability of the various screed sections, screed assemblies often utilize a tamping mechanism. The tamping mechanism may pre-compact the asphalt before the paving material passes underneath the screed plate. The tamping mechanism may include a tamper bar and a wear plate on each screed section. The tamper bar may pre-compact and feed the asphalt under the screed plate for effective spreading and further compacting on the paving surface. The wear plate may be found behind the tamper bar and may be mounted to a screed frame such that a bottom surface of the wear plate is substantially aligned with a bottom surface of the screed plate. The wear plate may be configured and positioned to act as a sacrificial plate between the tamper bar and the screed frame and screed plate, preventing damage to the screed frame and screed plate as the tamper bar reciprocates upward and downward relative to the wear plate during a tamping operation.

[0026] The wear plate minimizes wear and tear to the screed plate and the screed frame to which the wear bar is mounted. The wear plate, which is a replaceable component, is generally mounted to the screed frame such that a bottom surface of the wear plate is above the bottom edge of the screed plate. In other words, the wear plate maintains a height tolerance relative to the bottom (asphalt finishing surface) plane of the screed plate. Such a height tolerance is often desired to prevent the wear plate from protruding or otherwise extending beyond the bottom edge of the screed plate (and therefore the screed section) and, thus, leaving a pattern or marking on the paving surface as the associated screed section compacts and spreads the asphalt. Existing tamper bars and wear plates

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may experience accelerated wear as a result of limitations on the amount of tamper bar material present at an interface between a surface of the tamper bar that experiences the most reactionary force from the asphalt during a tamping operation and the asphalt that is being tamped, and on the amount of material present at an interface between the tamper bar and the wear plate.

[0027] A paving machine includes a frame with a set of ground-engaging elements such as wheels or tracks coupled with the frame. The ground-engaging elements may be driven by an engine in a conventional manner. The engine may further drive an associated generator that can be used to power various systems on the paving machine. A screed assembly is operatively associated with the engine and is attached at the rear end of the paving machine to spread and compact paving material into an asphalt mat having a desired thickness, size, uniformity, crown profile and cross slope. The paving machine also includes an operator station having a seat and a console, which includes various controls for directing operations of the paving machine.

[0028] The paving machine further includes a hopper for storing a paving material, and a conveyor system including one or more conveyors configured to move paving material from the hopper to the screed assembly at the rear of the paving machine. One or more augers are arranged near the forward end of the screed assembly to receive the paving material supplied by the conveyor and spread the material evenly beneath the screed assembly. The height of the augers is adjustable via one or more height adjustment actuators, for example, hydraulic cylinders. The screed assembly is pivotally connected behind the paving machine by a pair of tow arms that extend between the frame of the paving machine and the screed assembly. The tow arms are pivotally connected to the frame such that the relative position and orientation of the screed assembly relative to the screed frame and to the surface being paved may be adjusted by pivoting the tow arms, for example, in order to control the thickness of the paving material deposited by the paving machine. To this end, tow arm actuators are provided that are arranged and configured to raise and lower the tow arms and thereby raise and lower the screed assembly. The tow arm actuators may be any suitable actuators, for example, hydraulic cylinders.

[0029] The screed assembly may have any of a number of configurations known in the art, in particular, it may be a multiple section screed that has an adjustable crown profile and may include extensions with additional screed plates extending in a lateral direction to accommodate wider pavement areas. The screed assembly is provided with a screed plate. The screed plate is configured to float on the paving material of an asphalt mat laid upon a prepared paving bed and to

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"smooth" or level and compact the paving material on the base surface, such as for example a roadway or roadbed. The screed plate may be connected, preferably by means of a carrier, to a vibrating shaft coupled to a vibratory, eccentric drive. The vibrating shaft may include weights placed eccentrically so that when a vibratory drive rotates the vibrating shaft, the shaft causes the carrier and screed plate to vibrate. A vibrating screed plate improves compaction and quality of the asphalt mat being laid on a prepared paving bed.

[0030] A power source for the paving machine may embody an engine such as, for example, a diesel engine, a gasoline engine, a gaseous fuel-powered engine, or any other type of combustion engine known in the art. It is contemplated that the power source may alternatively embody a non-combustion source of power such as a fuel cell, a power storage device, a tethered motor, or another source known in the art. The power source may produce a mechanical or electrical power output that may then be converted to hydraulic power for moving the various hydraulic cylinders that are used as actuators to move. An operator station on the paving machine may include devices that receive input from a machine operator indicative of desired machine maneuvering. Specifically, the operator station may include one or more operator interface devices, for example a joystick, a steering wheel, or a pedal, that are located proximate an operator seat. Operator interface devices may initiate movement of the paving machine, for example travel and/or tool movement, by producing displacement signals that are indicative of desired machine maneuvering. As an operator moves the interface device, the operator may affect a corresponding machine movement in a desired direction, with a desired speed, and/or with a desired force.

[0031] As shown in Figs. 1A – 1C, an exemplary hydraulic cylinder 102, which may be used as an actuator for raising and lowering an auger on a paving machine, may include a tube (or cylinder barrel) 322 and a piston assembly 420 arranged at the distal end of a rod 332 within tube 322 to form a first chamber 352 and an opposing second chamber 354 on opposite sides of piston assembly 420. Tube 322 is closed on one end by a cylinder bottom or trunnion cap at a distal end 342. At the opposite end, tube 322 is closed by a cylinder head and head seal assembly 520 where piston rod 332 comes out of the cylinder. First chamber 352 on the cap end side of piston assembly 420 may be considered the “rod-end” chamber, and second chamber 354 may be considered the “head-end” chamber of the hydraulic cylinders. An exemplary embodiment of piston assembly 420, shown in Fig. 1C, may be provided at a distal end of rod 332. Piston assembly 420 may be held on the distal end of rod 332 by various means, such as between a piston retention assembly and a bushing, or by a nut at the distal end of piston rod 332, as shown in Fig. 1C. Rod 332 may have a diameter 334, and piston assembly 420 may also include a plurality of annular seals spaced along the outer periphery of piston assembly 420 and forming a slidable seal between piston assembly 420 and an inner circumferential surface of tube 322 as rod 332 and piston assembly 420 reciprocate back and forth within tube 322 with changes in the pressure and/or flow rate of hydraulic fluid supplied to and released from head-end chamber 354 and rod-end chamber 352.

[0032] Head-end chamber 354 and rod-end chamber 352 may each be selectively supplied with pressurized fluid and drained of the pressurized fluid to cause piston assembly 420 to displace within tube 322, thereby extending and retracting rod 332 from tube 322, and changing an effective length of the hydraulic cylinder. Extension and retraction of rod 332 from tube 322 results in moving one part of the machine or linkage structure connected to rod 332 relative to another part of the machine or linkage structure connected to the trunnion cap fixed at the distal end 342 of tube 322. A flow rate of fluid into and out of head-end chamber 354 and rod-end chamber 352 may relate to a translational velocity of the hydraulic cylinder, while a pressure differential between chambers 354, 352 may relate to a force imparted by the hydraulic cylinder on the associated linkage structure of the paving machine.

[0033] As shown in Fig. 1C, a proximal end 344 of rod 332 may pass through head seal assembly 520 attached at the end of tube 322 through which rod 332 passes. Head seal assembly 520 may include a plurality of axially spaced seals along the inner, circumferential periphery of head seal assembly 520, configured to form a slidable seal with the outer periphery of the proximal end 344 of rod 332. A plurality of bolts may fix head seal assembly 520 to a rod end boss, with a portion of head seal assembly 520 extending at least partially radially inward from a rod end boss of tube 322, and configured for radially supporting the proximal end 344 of rod 332 as rod 332 and piston 420 reciprocate relative to tube 322. The proximal end 344 of rod 332 may include a rod eye bore of diameter 252 extending through rod 332 orthogonal to the central axis of rod 332, and configured to receive a rod eye pin for pivotally attaching the proximal end 344 of rod 332 to a first structural element of machine 10, such as a rod eye pin pivotally connecting the rod-end of the hydraulic cylinder to a first structural element of the paving machine. The distal end 342 of tube 322 may similarly include a trunnion cap bore of diameter 242 extending through the distal end 342 of tube 322 orthogonal to the central axis of rod 332 and tube 322, and configured to receive a trunnion pin pivotally attaching distal end 342 of tube 322 to a second structural element of machine 10, such as a

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trunnion pin configured to pivotally connect the head-end of the hydraulic cylinder to the second structural element.

[0034] In all of the exemplary embodiments of hydraulic cylinders 102, 104, 106, 108, 110, 112, 114, 116, 118, 120, 122, 124, 126, 128, 130, 131, 134, 136, 138, 140, 142, and 144, shown in Figs. 1A – 22C, values for different dimensions of the hydraulic cylinders are determined based on the specific performance requirements for each hydraulic cylinder in a particular application on a paving machine. The specific performance dimensions include, but are not limited to, the tube bore diameter 324 and outside diameter 326 for each tube 322, the rod diameter 334 for each rod 332, the diameter 252 of a rod eye bore extending through proximal end 344 of rod 332, the diameter 242 of a trunnion cap bore extending through the distal end 342 of tube 322, the pin-to-pin length 132 between the center of the rod eye bore and the center of the trunnion cap bore when rod 332 is fully retracted into tube 322, and the stroke 222 determined by the total distance rod 332 moves when traveling from a fully retracted position within tube 322 to a fully extended position. The diameter 252 of a rod eye bore, and hence the diameter of a rod eye pin configured for pivotally connecting rod 332 of each hydraulic cylinder to a structural element of machine 10, and the diameter 242 of a trunnion cap bore extending through the distal end 342 of tube 322, and hence the diameter of a trunnion pin configured for pivotally connecting tube 322 of each hydraulic cylinder to another structural element of machine 10, are determined based at least in part on the size of the structural elements of the paving machine to which the pins are pivotally attached, and the loads and structural stresses experienced by these elements during operation, such as shear stresses, torsional stresses, compression stresses, and tension stresses that will be experienced under load during actuation of each hydraulic cylinder. The pin-to-pin dimension 132, shown in Fig. 1B, for each hydraulic cylinder is determined based at least in part on the sizes, ranges of motion, working loads, and structural interrelationships of the structural elements of a particular machine, such as the auger and the screed of each paving machine. The stroke 222 for each hydraulic cylinder, shown in Fig. 1C, is similarly determined based at least in part on the sizes, ranges of motion, working loads, and structural interrelationships of the structural elements of each machine. Rod 332 and piston 420 are shown in Fig. 1C fully contracted into tube 322, with stroke 222 being determined by the distance that piston 420 can travel from this fully contracted position when bottomed out at the closed, distal end 342 of tube 322 to a fully extended position of rod 332 when piston 420 contacts head seal assembly 520 connected to the proximal end of tube 322.

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[0035] A paving machine may include a hydraulic system having a plurality of circuits that drive the fluid actuators (hydraulic cylinders) described above to move one part of the paving machine, such as at least one side of an auger, relative to another part of the machine. Each of the circuits may be similar and include a plurality of interconnecting and cooperating fluid components that facilitate the use and control of the associated actuators. For example, each of the circuits may include a pump fluidly connected to its associated actuator(s) via a closed loop formed by left-side and right-side passages. Specifically, each of the circuits may include a common left pump passage, a common right pump passage, a left actuator passage for each actuator, and a right actuator passage for each actuator. In circuits having linear actuators, left and right actuator passages may be commonly known as head-end and rod-end passages, respectively. Within each circuit, the corresponding pump may be connected to its associated actuators via a combination of left and right, pump and actuator passages.

[0036] To retract a linear actuator, the right actuator passage of a particular circuit may be filled with fluid pressurized by the pump, while the corresponding left actuator passage may be filled with fluid returned from the linear actuator. In contrast, to extend the linear actuator, the left actuator passage may be filled with fluid pressurized by the pump, while the right actuator passage may be filled with fluid exiting the linear actuator. Each pump may have variable displacement and be controlled to draw fluid from its associated actuators and discharge the fluid at a specified elevated pressure back to the actuators in a single direction. That is, the pump may include a stroke-adjusting mechanism, for example a swashplate, a position of which is hydro-mechanically adjusted based on, among other things, a desired speed of the actuators to thereby vary an output (e.g., a discharge rate) of the pump. The displacement of the pump may be adjusted from a zero displacement position at which substantially no fluid is discharged from the pump, to a maximum displacement position at which fluid is discharged from the pump at a maximum rate into the right pump passage. The pump may be drivably connected to a power source of the paving machine by, for example, a countershaft, a belt, or in another suitable manner. Alternatively, the pump may be indirectly connected to the power source via a torque converter, a gear box, an electrical circuit, or in any other manner known in the art. It is contemplated that pumps of different circuits may be connected to the power source in tandem (e.g., via the same shaft) or in parallel (via a gear train), as desired.

[0037] Pumps configured to provide pressurized hydraulic fluid to hydraulic actuators may also be selectively operated as motors. More specifically, when an associated actuator is operating in an overrunning condition, the fluid discharged from the actuator may have a pressure elevated higher than an output pressure of the corresponding pump. In this situation, the elevated pressure of the actuator fluid directed back through the pump may function to drive the pump to rotate with or without assistance from the power source. Under some circumstances, the pump may even be capable of imparting energy to the power source, thereby improving an efficiency and/or capacity of the power source.

[0038] In one exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 102 used in raising and lowering an auger of a paving machine, as shown in Figs. 1A – 1C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 485.6 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 230 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 65 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 78 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 25 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.4 mm ± 0.25 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0039] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 104 used in raising and lowering an auger of a paving machine, as shown in Figs. 2A – 2C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 485.6 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 230 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 60.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 73.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 25.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.4 mm ± 0.25 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence,

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historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0040] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 106 used in raising and lowering a hopper of a paving machine, as shown in Figs. 3A – 3C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 595.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 3425 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 57.15 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 68.8 ± 0.5 mm. The diameter 334 of rod 332 may be equal to 31.75 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 19.05 mm ± 0.025 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0041] In yet another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 108 used as a tow point cylinder for adjusting a distance between an auger and a floating screed on a paving machine, as shown in Figs. 4A – 4C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 799 mm ± 2.5 mm. The stroke 222 for this exemplary tow point cylinder may be equal to 350 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 44.45 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 54 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 25.4 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.4 mm ± 0.025 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational

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analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0042] In yet another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 110 used as a tow point cylinder for adjusting a distance between an auger and a floating screed on a paving machine, as shown in Figs. 5A – 5C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 799 mm ± 2.5 mm. The stroke 222 for this exemplary tow point cylinder may be equal to 350 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 45.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 55 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 25.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.4 mm ± 0.025 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0043] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 112 used in raising and lowering a screed of a paving machine, as shown in Figs. 6A – 6C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 661.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 420 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 68.85 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 82.55 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 31.75 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.4 mm + 0.10 mm and – 0.07 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis,

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empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0044] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 114 used in raising and lowering a screed of a paving machine, as shown in Figs. 7A – 7C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 720.9 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 368.4 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 88.9 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 101.6 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 38.1 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 32.26 mm ± 0.25 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0045] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 116 used in steering a paving machine, as shown in Figs. 8A – 8C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 463.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 166.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 90.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 102 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 40.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.4 mm ± 0.025 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic

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interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0046] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 118 used as a mobile track solution (MTS) tension cylinder, as shown in Figs. 9A – 9C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 380.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 210.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 82.55 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 95.25 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 69.85 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 30.4 mm ± 0.25 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0047] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 120 used as a power endgate hydraulic cylinder in a paving machine, as shown in Figs. 10A – 10C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 28.6 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 203.2 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 40.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 50.0 ± 0.5 mm. The diameter 334 of rod 332 may be equal to 25.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 12.5 mm ± 0.25 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and

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the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0048] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 122 used in controlling a slope on a paving machine, as shown in Figs. 11A – 11C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 327.9 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 116.8 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 40.0 mm ± 0.5 mm, and the tube outer diameter may be equal to 50.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 20.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.4 mm ± 0.025 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0049] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 124 used in controlling a slope on a paving machine, as shown in Figs. 12A – 12C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 288.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 118.4 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 40.0 mm ± 0.5 mm, and the outer diameter 326 of the tube may be equal to 50.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 20.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 19.1 mm ± 0.05 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be

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experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0050] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a berm hydraulic cylinder 126 used for controlling screed extenders to form a shoulder berm adjacent a paving mat formed by a paving machine, as shown in Figs. 13A – 13C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 267.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 71.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 40.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 50 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 25.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 19.05 mm ± 0.05 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0051] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as an extend hydraulic cylinder 128 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 14A – 14C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 350.5 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 1140.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 63.5 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 73.5 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 31.75 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.2 mm ± 0.1 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder,

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ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0052] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a front extend hydraulic cylinder 130 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 15A – 15C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 975.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 570.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 70.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 80.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 32.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.2 mm ± 0.1 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0053] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a rear extend hydraulic cylinder 131 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 16A – 16C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 290.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 655.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 70.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 80.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 32.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.2 mm ± 0.1 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0054] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a front extend hydraulic cylinder 134 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 17A – 17C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 975.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 570.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 70.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 85.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 38.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.2 mm ± 0.1 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0055] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a rear extend hydraulic cylinder 136 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 18A – 18C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 290.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 655.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 70.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 85.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 38.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 25.2 mm ± 0.1 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational

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analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0056] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a front extend hydraulic cylinder 138 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 19A – 19C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 806.5 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 571.5 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 75.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 85.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 40.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 18.4 mm ± 0.3 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0057] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a rear extend hydraulic cylinder 140 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 20A – 20C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 806.5 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 571.5 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 75.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 85.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 40.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 18.4 mm ± 0.3 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based

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equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0058] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a front extend hydraulic cylinder 142 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 21A – 21C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 993.6 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 724.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 75.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 88.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 40.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 19.4 mm ± 0.05 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

[0059] In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a rear extend hydraulic cylinder 144 used for various purposes where parts of a paving machine are moved relative to each other as shown in Figs. 22A – 22C, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 993.6 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 724.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 75.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 88.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 40.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 19.4 mm ± 0.05 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

Industrial Applicability

[0060] The disclosed hydraulic cylinders may be applicable to any paving machine where application of specific performance dimensions for stroke, pin-to-pin length, rod diameter, tube bore diameter, tube outer diameter, rod eye pin diameter, and trunnion cap pin diameter for each hydraulic cylinder are based at least in part on the results of structural and kinematic analysis of the various structural elements of a particular machine needed to perform certain tasks, such as adjusting a position of an auger relative to a floating screed and/or a hopper on a paving machine, raising and lowering an auger, hopper, portions of a screed, or other parts of the paving machine, steering the paving machine, and performing other tasks associated with a paving process. The specific performance dimensions for each hydraulic cylinder used on the particular machine may be determined, at least in part, from physics-based equations, and empirical and historical data, including fatigue analysis for the structural elements under load, the size of the particular machine and the environment where it will operate, the materials being applied by the machine, relative locations of linkage points at which the head end and rod end of each hydraulic cylinder will be pivotally connected, hydraulic system pressures, hoop stresses, shear stresses, compressive stresses, and tension stresses on the various components of each hydraulic cylinder, and other mechanical design considerations.

[0061] During operation of a paving machine, an operator may command a particular movement of one or more components of the machine relative to another component of the machine, or relative to the ground. For example, the operator may command the movement of an auger relative to a hopper and/or a floating screed, movement of portions of the screed, movement of other portions of the paving machine relative to each other or relative to a ground surface, steering of the paving machine, and other movements at a desired velocity or extent by way of an interface device. One or more corresponding signals indicative of the desired movement may be generated by the interface device and transmitted to an electronic controller, along with machine performance information, for example sensor data such a pressure data, position data, speed data, pump displacement data, and other data known in the art.

[0062] In response to the signals from the interface device, and based on the machine performance information, the controller may generate control signals directed to pumps, motors, and/or to valves that control the flow of hydraulic fluid to the head-end chamber on one side of the piston for each hydraulic cylinder and the rod-end chamber on the opposing side of the piston. In one exemplary implementation, the controller may generate a control signal that causes a pump of a first circuit to increase its displacement and discharge fluid into a right pump passage at a greater rate than fluid is discharged by the pump to a left pump passage. In addition, the controller may generate a control signal that causes a switching valve to move toward and/or remain in one of the two flow-passing positions. After fluid from the right pump passage passes into and through a right-travel motor, for example, or into a head-end chamber or a rod-end chamber of a hydraulic cylinder, the fluid from the motor, or from the head-end or rod-end chamber on the opposite side of the piston assembly in the hydraulic cylinder may return to the pump via a left pump passage. At this time, the speed of the right-travel motor, or of movement of the rod and piston assembly in the hydraulic cylinder, may be dependent on a discharge rate of the pump and on a restriction amount, if any, provided by a switching valve on the flow of fluid passing through right-travel motor, or into or out of the hydraulic cylinder. Movement of the right travel motor may be reversed by moving the switching valve to the other of the two flow-passing positions.

[0063] A first hydraulic cylinder may be moved simultaneous with and/or independent of movement of a second hydraulic cylinder. In particular, while a first hydraulic cylinder is receiving fluid from a pump, one or more metering valves may be moved to divert some of the fluid into a second hydraulic cylinder. At this same time, each metering valve may be moved to direct waste fluid from a hydraulic cylinder back to a pump. When a switching valve and the appropriate metering valves are fully open, the movements of the first and second hydraulic cylinders may be linked and dependent on the flow rate of fluid from the pump.

[0064] During some operations, the flow rate of fluid provided to individual hydraulic cylinders from their associated pumps may be insufficient to meet operator demands. During this situation, the controller may cause the valve element(s) of one or more corresponding combining valves to

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pass fluid from one fluid flow circuit to another fluid flow circuit, thereby increasing the flow rate of fluid available to a particular hydraulic cylinder. At this time, fluid discharging from some of the hydraulic cylinders may be returned to the pump of a desired fluid flow circuit via a combining valve. Flow sharing between other circuits via other combining valves may be implemented in a similar manner.

[0065] Flow sharing may also be selectively implemented when an amount of fluid discharged from one actuator exceeds a rate at which the corresponding pump can efficiently consume return fluid. Some of this discharging fluid may be redirected via metering valves back into a rod-end or head-end chamber of another hydraulic cylinder. This operation may be known as regeneration, and results in an efficiency improvement.

[0066] Flows provided by pumps on the machine may be substantially unrestricted during many operations such that significant energy is not unnecessarily wasted in the actuation process. Thus, embodiments of the disclosure may provide improved energy usage and conservation. In addition, the ability to combine fluid flows from different circuits to satisfy demands of individual actuators may allow for a reduction in the number of pumps required within the hydraulic system and/or a size and capacity of these pumps. These reductions may reduce pump losses, improve overall efficiency, improve packaging of the hydraulic system, and/or reduce a cost of the hydraulic system. The application of specific performance dimensions for stroke, pin-to-pin length, rod diameter, tube bore diameter, tube outer diameter, rod eye pin diameter, and trunnion cap pin diameter for each hydraulic cylinder based at least in part on the results of structural and kinematic analysis of the various structural elements of a particular paving machine needed to perform certain tasks associated with a paving process also improves the efficiency and quality of the paving operation, increases longevity of the machine, and reduces the occurrences of failures of machine components or the need for repairs or maintenance.

[0067] It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed hydraulic actuators and systems. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed hydraulic systems. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

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LIST OF ELEMENTS

TITLE: HYDRAULIC CYLINDER WITH SPECIFIC PERFORMANCE DIMENSIONS

FILE: 08350.2734-00000 (CAT: 21-0227US01)

102: Hydraulic Cylinder
104. Hydraulic Cylinder
104. Hydraulic Cylinder
106. Hydraulic Cylinder
108. Hydraulic Cylinder
110. Hydraulic Cylinder
112. Hydraulic Cylinder
114. Hydraulic Cylinder
116. Hydraulic Cylinder
118. Hydraulic Cylinder
120. Hydraulic Cylinder
122. Hydraulic Cylinder
124. Hydraulic Cylinder
126. Hydraulic Cylinder
128. Hydraulic Cylinder
130. Hydraulic Cylinder
131. Hydraulic Cylinder
132. Pin-to-Pin Dimension
134. Hydraulic Cylinder
136. Hydraulic Cylinder
138. Hydraulic Cylinder
140. Hydraulic Cylinder
144. Hydraulic Cylinder
222. Stroke Dimension
242. Trunnion Cap Bore Diameter
252. Rod Eye Bore Diameter
322. Tube

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324. Tube Bore Diameter
326. Tube Outer Diameter
332. Rod
334. Rod Diameter
342. Closed, Distal End of Tube
344. Proximal End of Rod
352. Head-End Chamber
354. Rod-End Chamber
420. Piston
520. Head Seal Assembly

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Claims

What is claimed is:

1. An actuator configured for actuating a first structural element on a paving machine relative to a second structural element on the paving machine, the actuator comprising:

a tube, the tube comprising a central, axially extending bore that is defined in the tube extending between a closed, distal end of the tube and an open, proximal end of the tube;

a rod slidably mounted within the tube, the rod being slidably supported at the proximal end of the tube by a head seal assembly;

a piston mounted at a distal end of the rod;

a piston retention assembly attached to the distal end of the rod and configured to retain the piston on the distal end of the rod;

a trunnion cap bore being defined through the closed, distal end of the tube and configured for receiving a trunnion pin adapted for pivotally connecting the distal end of the tube to the first structural element of the machine; and

a rod eye bore being defined through a proximal end of the rod and configured for receiving a rod eye pin adapted for pivotally connecting the proximal end of the rod to the second structural element of the machine; wherein

a retracted pin-to-pin dimension from a center of the trunnion cap bore to a center of the rod eye bore when the rod and piston are fully retracted into the tube with the distal end of the rod positioned adjacent the closed, distal end of the tube is equal to 993.6 mm ± 2.5 mm;

a stroke dimension from a first, fully retracted position of the piston adjacent the closed, distal end of the tube to a second, fully extended position of the piston in contact with the head seal assembly at the proximal end of the tube is equal to 724.0 mm ± 1.5 mm;

a diameter of the rod is equal to 40.0 mm ± 0.5 mm;

a diameter of the tube bore is equal to 75.0 mm ± 0.5 mm; and

an outer diameter of the tube is equal to 88.0 mm ± 0.5 mm.

2. The actuator of claim 1, wherein a diameter of the trunnion cap bore is equal to 19.4 mm ± 0.05 mm.

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3. The actuator of claim 1, wherein a diameter of the rod eye bore is equal to 19.4 mm ± 0.05 mm.

4. The actuator of claim 1, wherein the first structural element comprises an auger of the paving machine.

5. The actuator of claim 4, wherein the second structural element comprises a screed of the paving machine.

6. The actuator of claim 1, wherein the first structural element comprises a portion of a screed on the paving machine.

7. The actuator of claim 1, wherein the first structural element comprises a hopper on the paving machine.

8. The actuator of claim 1, wherein the first structural element comprises a frame or body of the paving machine and the second structural element comprises a screed of the paving machine.

9. The actuator of claim 1, wherein actuation of the first structural element relative to the second structural element results in at least one of a change in slope of a portion of the paving machine, a change in direction of movement of the paving machine, a change in tension between the first and second structural elements, or a change in distance between the first and second structural elements.

10. A paving machine comprising a plurality of structural elements and a plurality of hydraulic actuators each interconnecting two of the structural elements, wherein each hydraulic actuator is configured for actuating a first structural element on the paving machine relative to a second structural element on the paving machine, each hydraulic actuator comprising:

a tube, the tube comprising a central, axially extending bore that is defined in the tube extending between a closed, distal end of the tube and an open, proximal end of the tube;

a rod slidably mounted within the tube, the rod being slidably supported at the proximal end of the tube by a head seal assembly;

a piston mounted at a distal end of the rod;

a piston retention assembly attached to the distal end of the rod and configured to retain the piston on the distal end of the rod;

a trunnion cap bore being defined through the closed, distal end of the tube and configured for receiving a trunnion pin adapted for pivotally connecting the distal end of the tube to the first structural element of the machine; and

a rod eye bore being defined through a proximal end of the rod and configured for receiving a rod eye pin adapted for pivotally connecting the proximal end of the rod to the second structural element of the machine; wherein

a retracted pin-to-pin dimension from a center of the trunnion cap bore to a center of the rod eye bore when the rod and piston are fully retracted into the tube with the distal end of the rod positioned adjacent the closed, distal end of the tube is equal to 993.6 mm ± 2.5 mm;

a stroke dimension from a first, fully retracted position of the piston adjacent the closed, distal end of the tube to a second, fully extended position of the piston in contact with the head seal assembly at the proximal end of the tube is equal to 724.0 mm ± 1.5 mm;

a diameter of the rod is equal to 40.0 mm ± 0.5 mm;

a diameter of the tube bore is equal to 75.0 mm ± 0.5 mm; and

an outer diameter of the tube is equal to 88.0 mm ± 0.5 mm.

11. The paving machine of claim 10, wherein a diameter of the trunnion cap bore is equal to 19.4 mm ± 0.05 mm.

12. The paving machine of claim 10, wherein a diameter of the rod eye bore is equal to 19.4 mm ± 0.05 mm.

13. The paving machine of claim 10, wherein the first structural element comprises an auger of the paving machine.

14. The paving machine of claim 10, wherein the second structural element comprises a screed of the paving machine.

15. The paving machine of claim 10, wherein the first structural element comprises a portion of a screed on the paving machine.

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16. The paving machine of claim 10, wherein the first structural element comprises a hopper on the paving machine.

17. The paving machine of claim 10, wherein the first structural element comprises a frame or body of the paving machine and the second structural element comprises a screed of the paving machine.

18. The paving machine of claim 10, wherein actuation of the first structural element relative to the second structural element results in at least one of a change in slope of a portion of the paving machine, a change in direction of movement of the paving machine, a change in tension between the first and second structural elements, or a change in distance between the first and second structural elements.

19. A hydraulic cylinder configured for actuating a first structural element on a paving machine relative to a second structural element on the paving machine, the hydraulic cylinder comprising:

a tube, the tube comprising a central, axially extending bore that is defined in the tube extending between a closed, distal end of the tube and an open, proximal end of the tube;

a rod slidably mounted within the tube, the rod being slidably supported at the proximal end of the tube by a head seal assembly;

a piston mounted at a distal end of the rod;

a piston retention assembly attached to the distal end of the rod and configured to retain the piston on the distal end of the rod;

a trunnion cap bore being defined through the closed, distal end of the tube and configured for receiving a trunnion pin adapted for pivotally connecting the distal end of the tube to the first structural element of the machine; and

a rod eye bore being defined through a proximal end of the rod and configured for receiving a rod eye pin adapted for pivotally connecting the proximal end of the rod to the second structural element of the machine; wherein

a retracted pin-to-pin dimension from a center of the trunnion cap bore to a center of the rod eye bore when the rod and piston are fully retracted into the tube with the distal end of the rod positioned adjacent the closed, distal end of the tube is equal to 993.6 mm ± 2.5 mm;

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a stroke dimension from a first, fully retracted position of the piston adjacent the closed, distal end of the tube to a second, fully extended position of the piston in contact with the head seal assembly at the proximal end of the tube is equal to 724.0 mm ± 1.5 mm;

a diameter of the rod is equal to 40.0 mm ± 0.5 mm;

a diameter of the tube bore is equal to 75.0 mm ± 0.5 mm; and

an outer diameter of the tube is equal to 88.0 mm ± 0.5 mm.

20. The hydraulic cylinder of claim 19, wherein actuation of the first structural element relative to the second structural element results in at least one of a change in slope of a portion of the paving machine, a change in direction of movement of the paving machine, a change in tension between the first and second structural elements, or a change in distance between the first and second structural elements.

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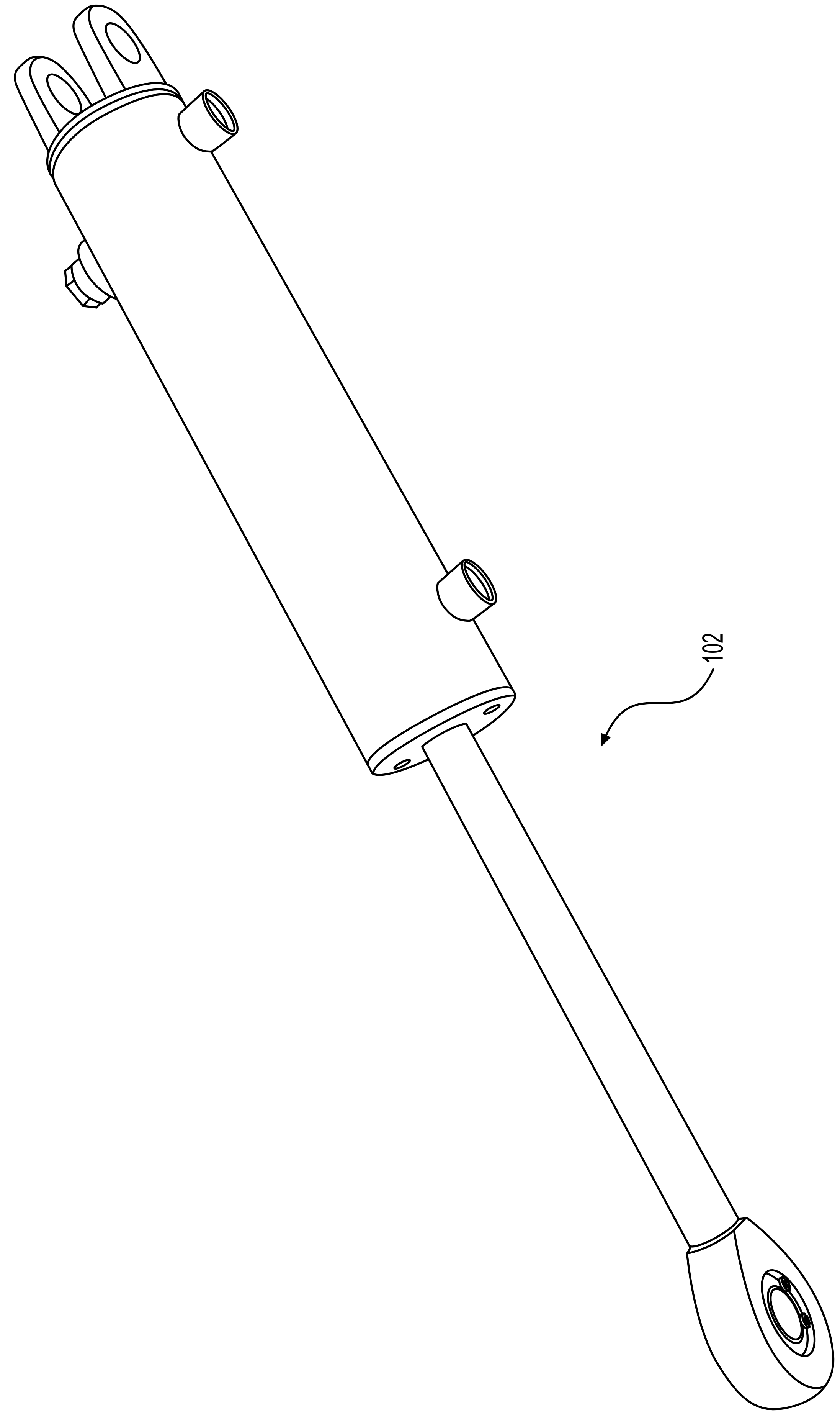

FIG. 1A

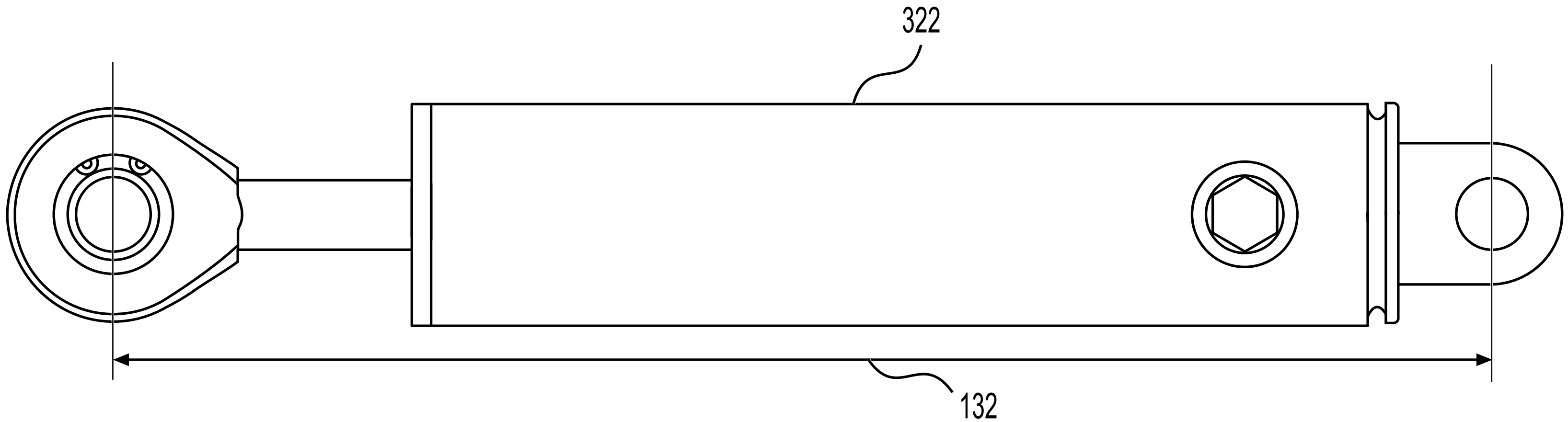

FIG. 1B

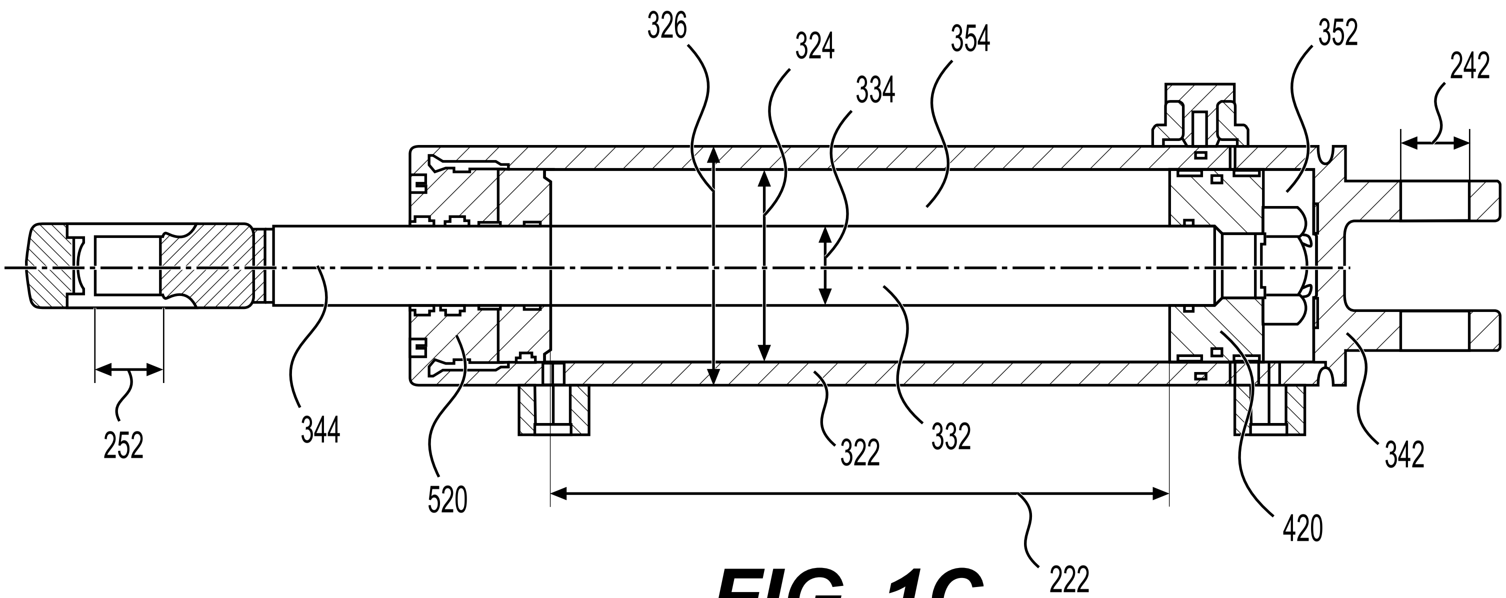

FIG. 1C

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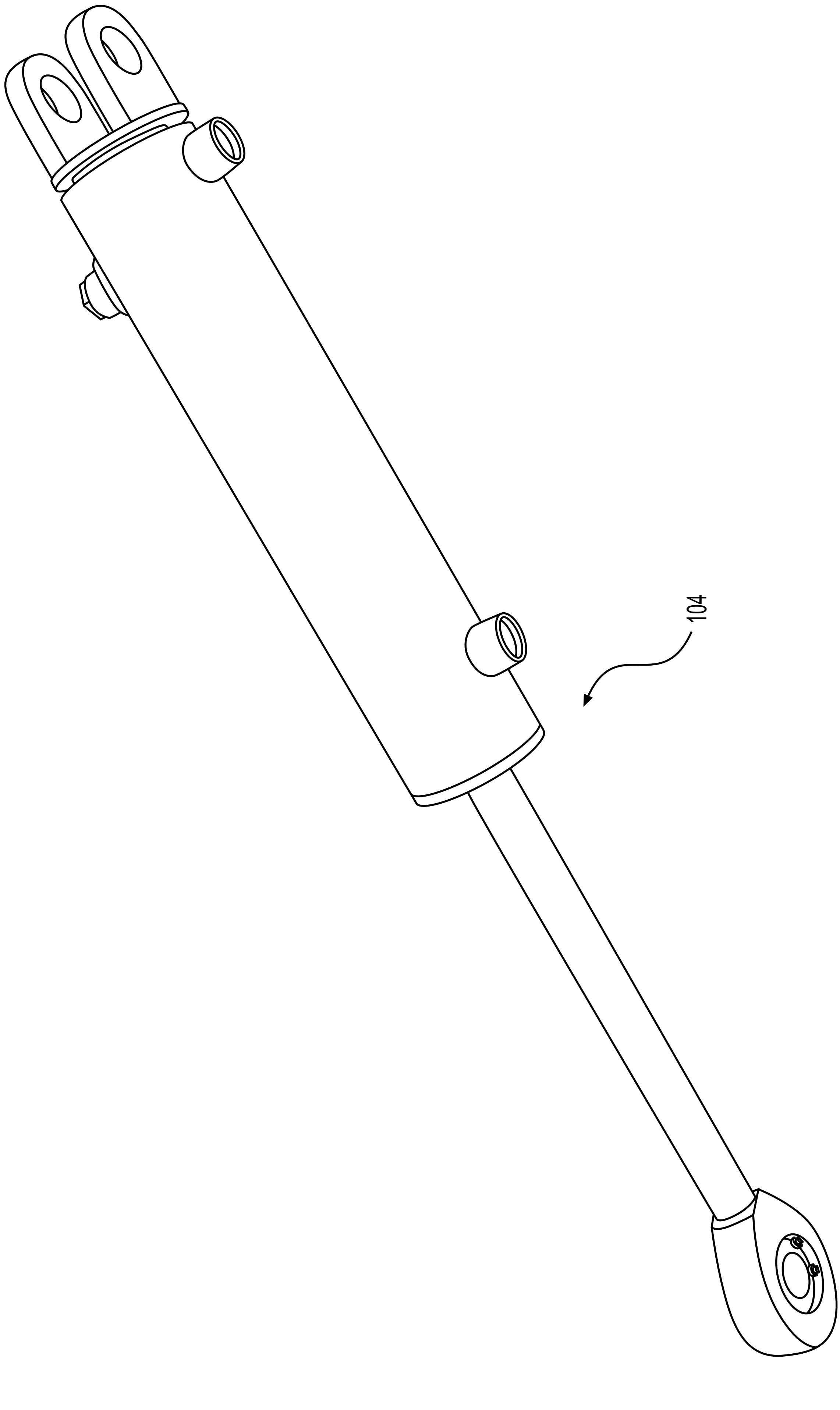

FIG. 2A

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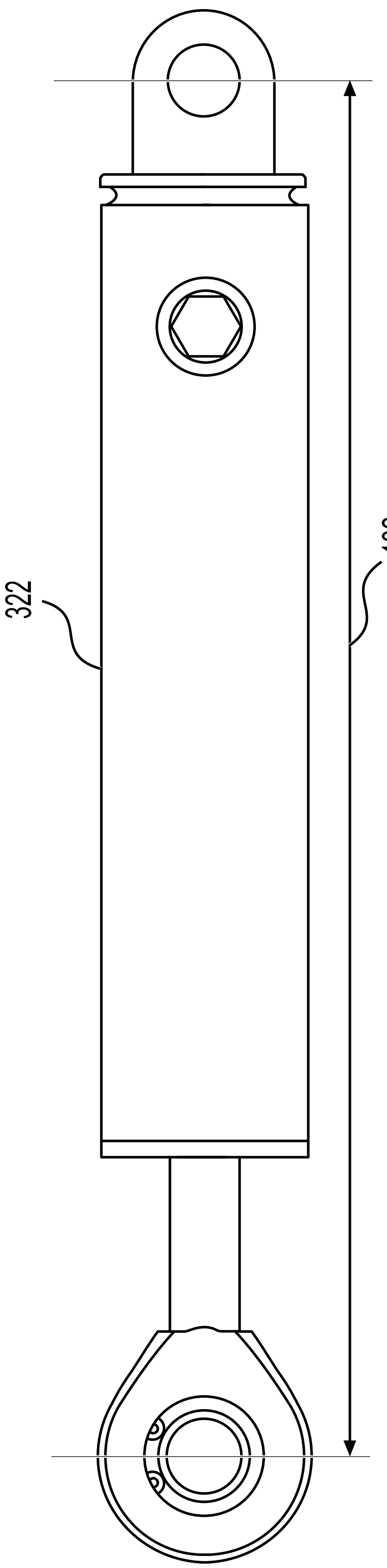

FIG. 2B

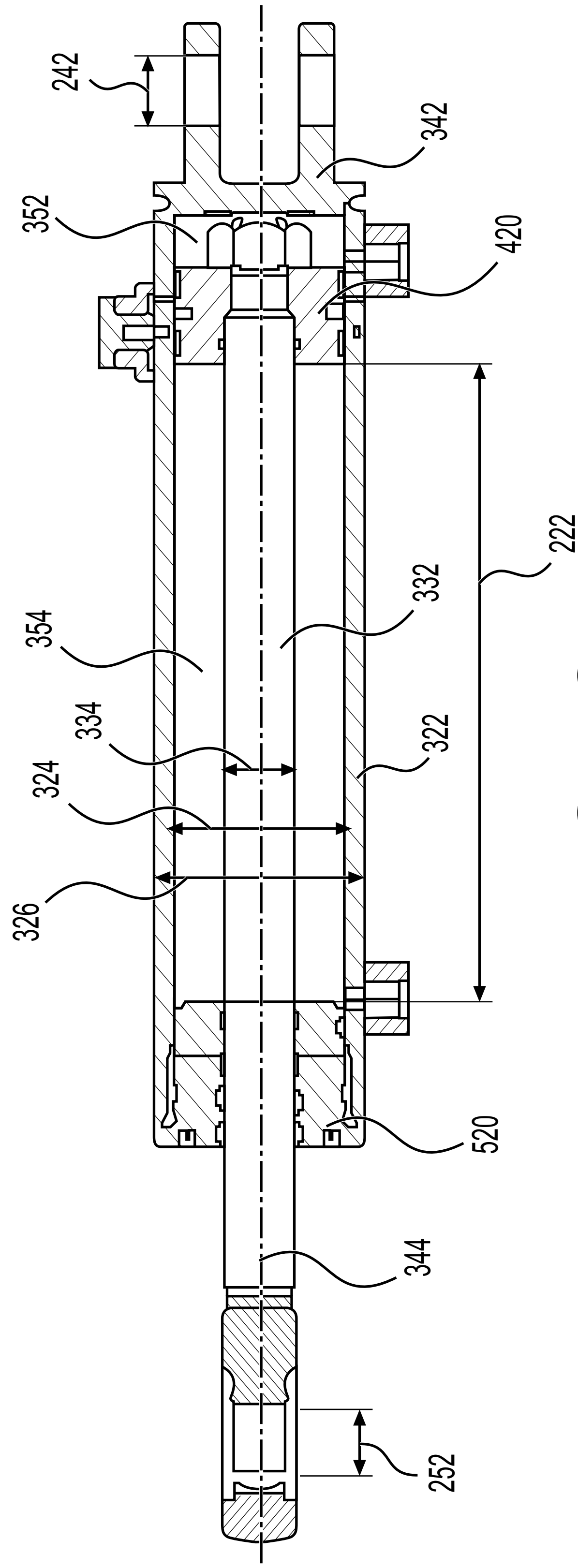

FIG. 2C

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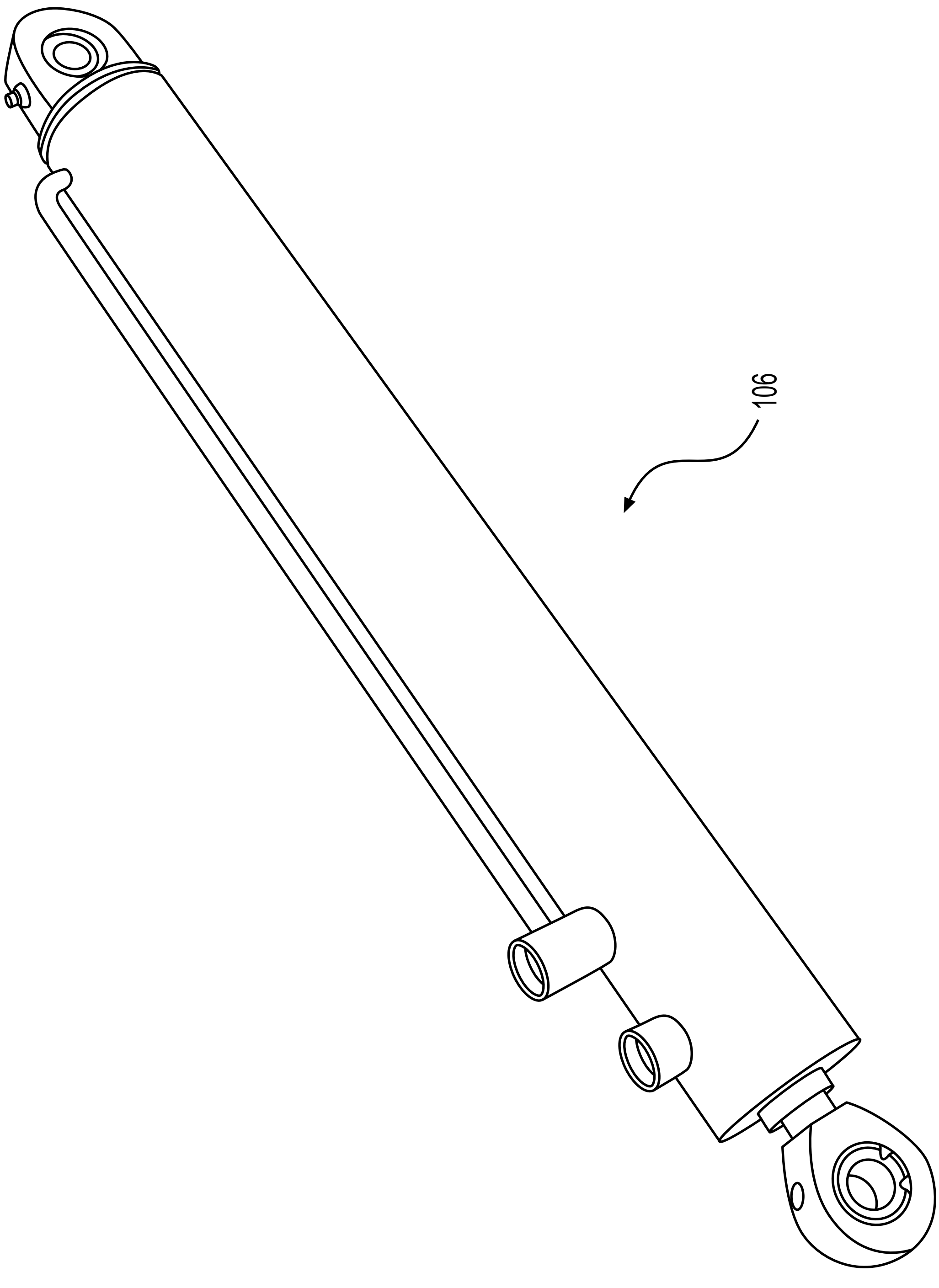

FIG. 3A

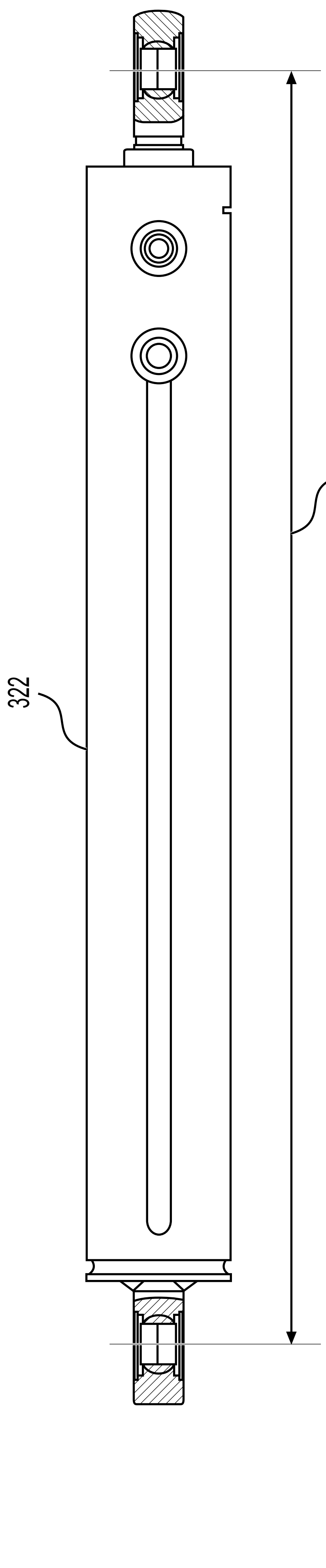

FIG. 3B

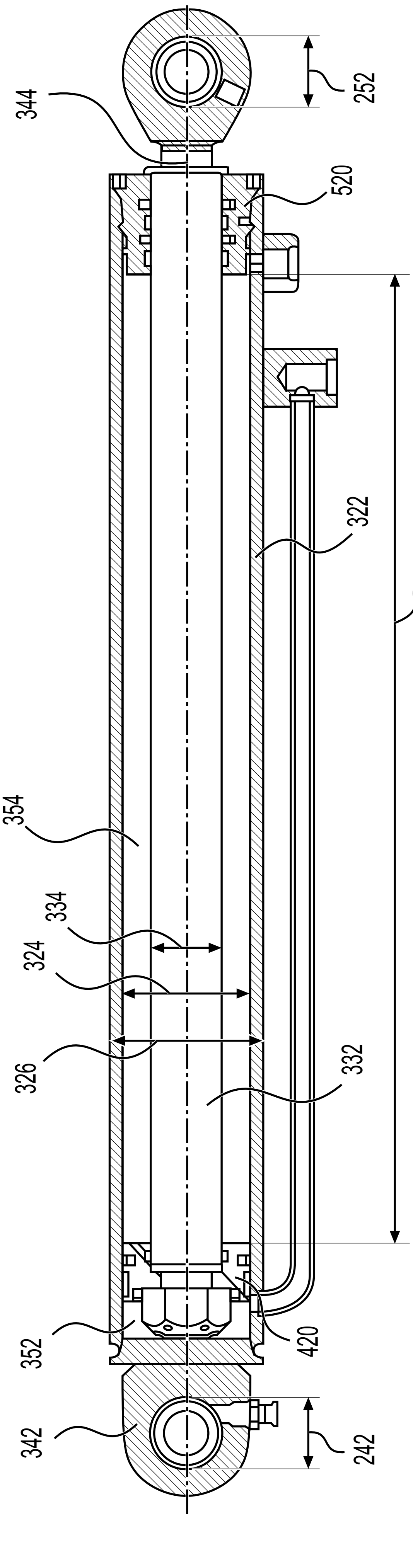

FIG. 3C

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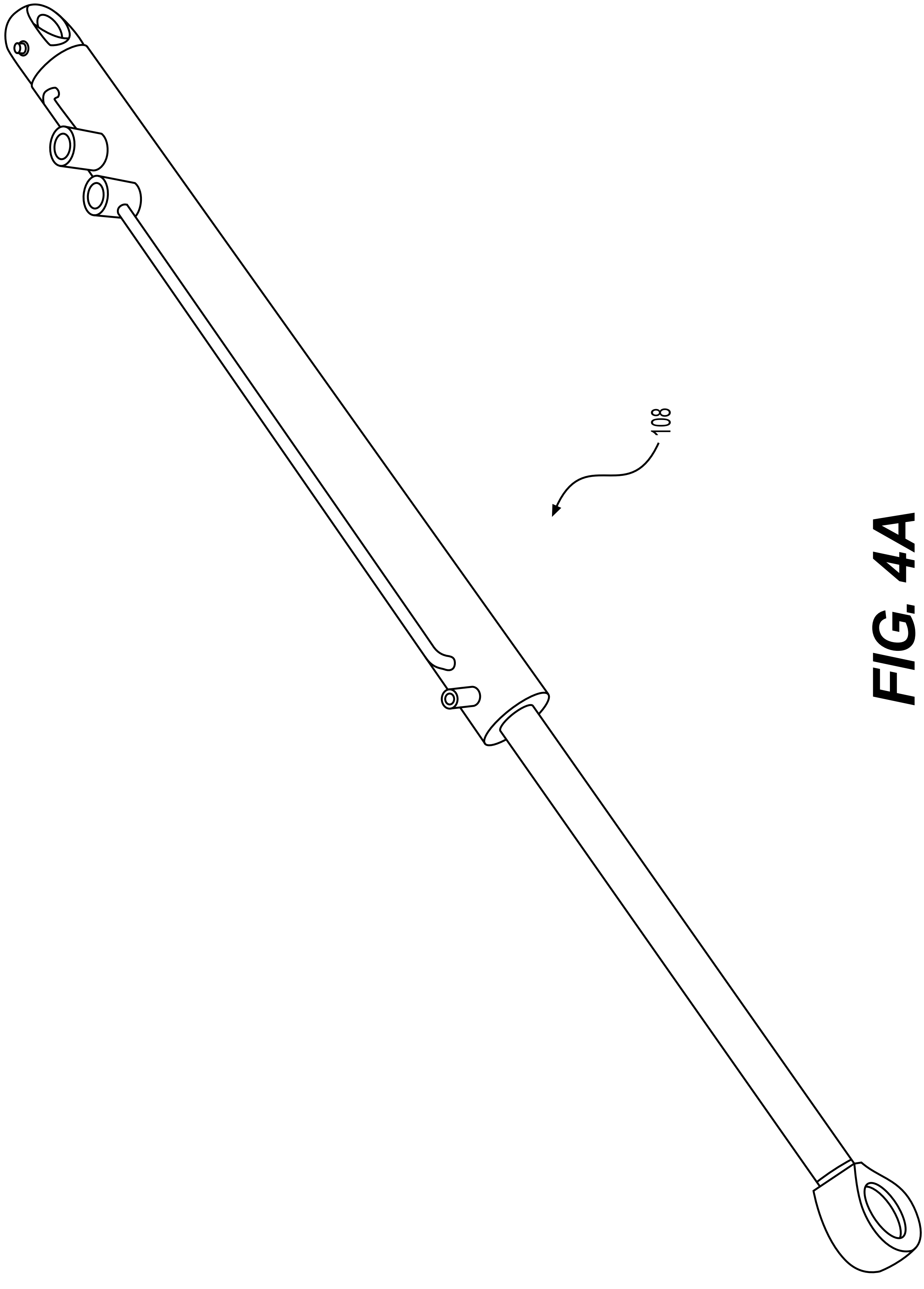

FIG. 4A

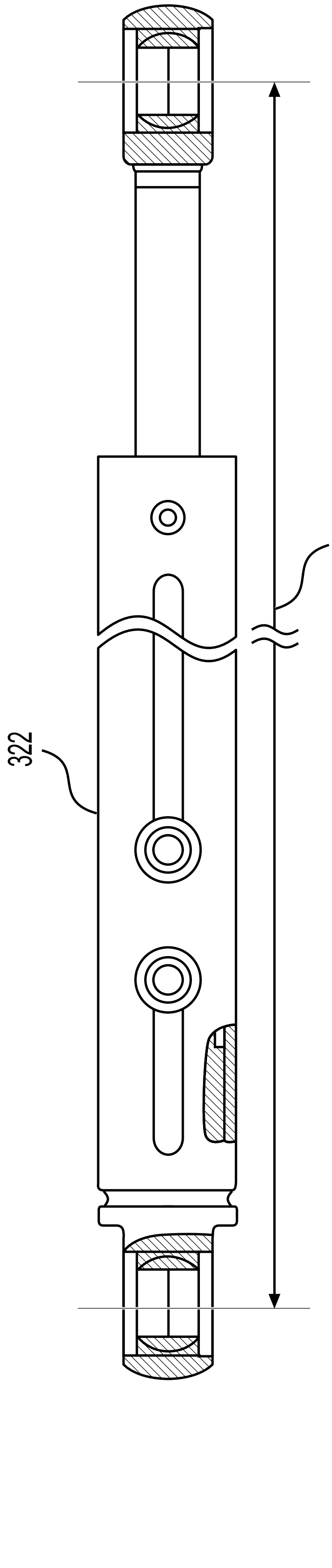

FIG. 4B

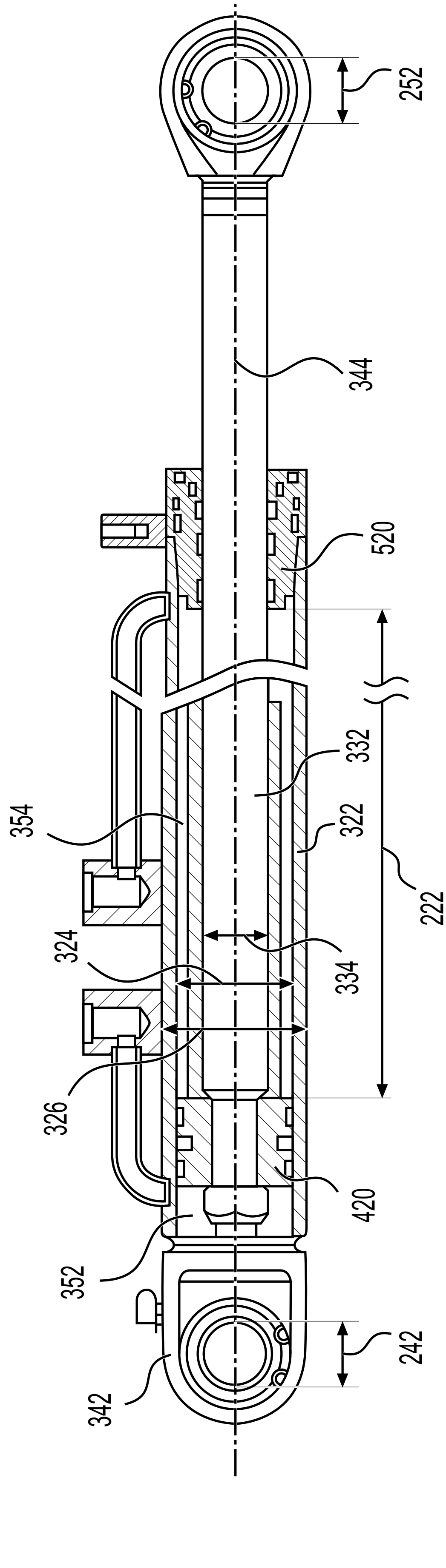

FIG. 4C

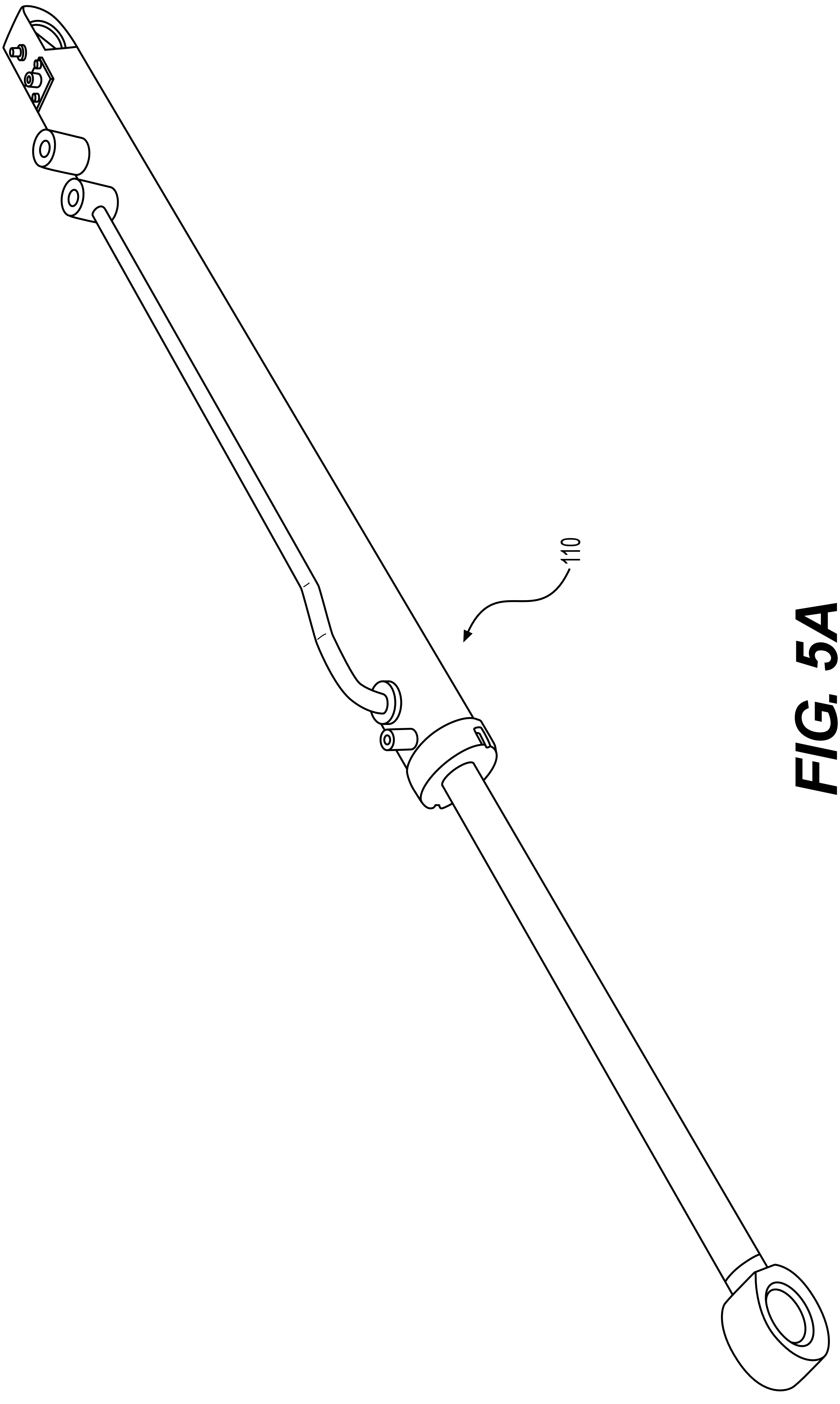

FIG. 5A

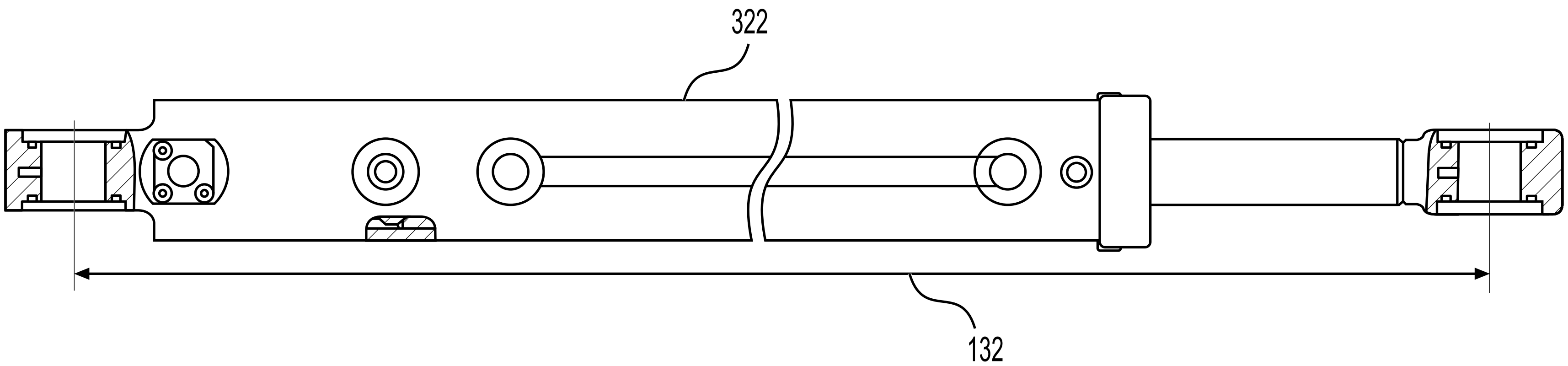

FIG. 5B

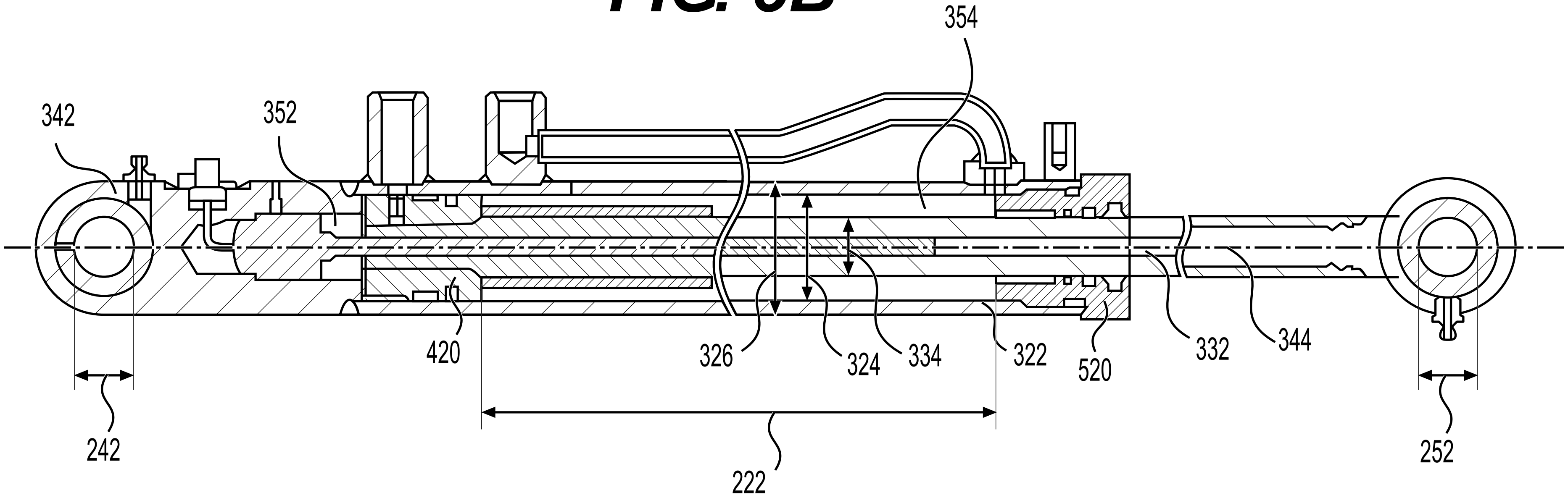

FIG. 5C

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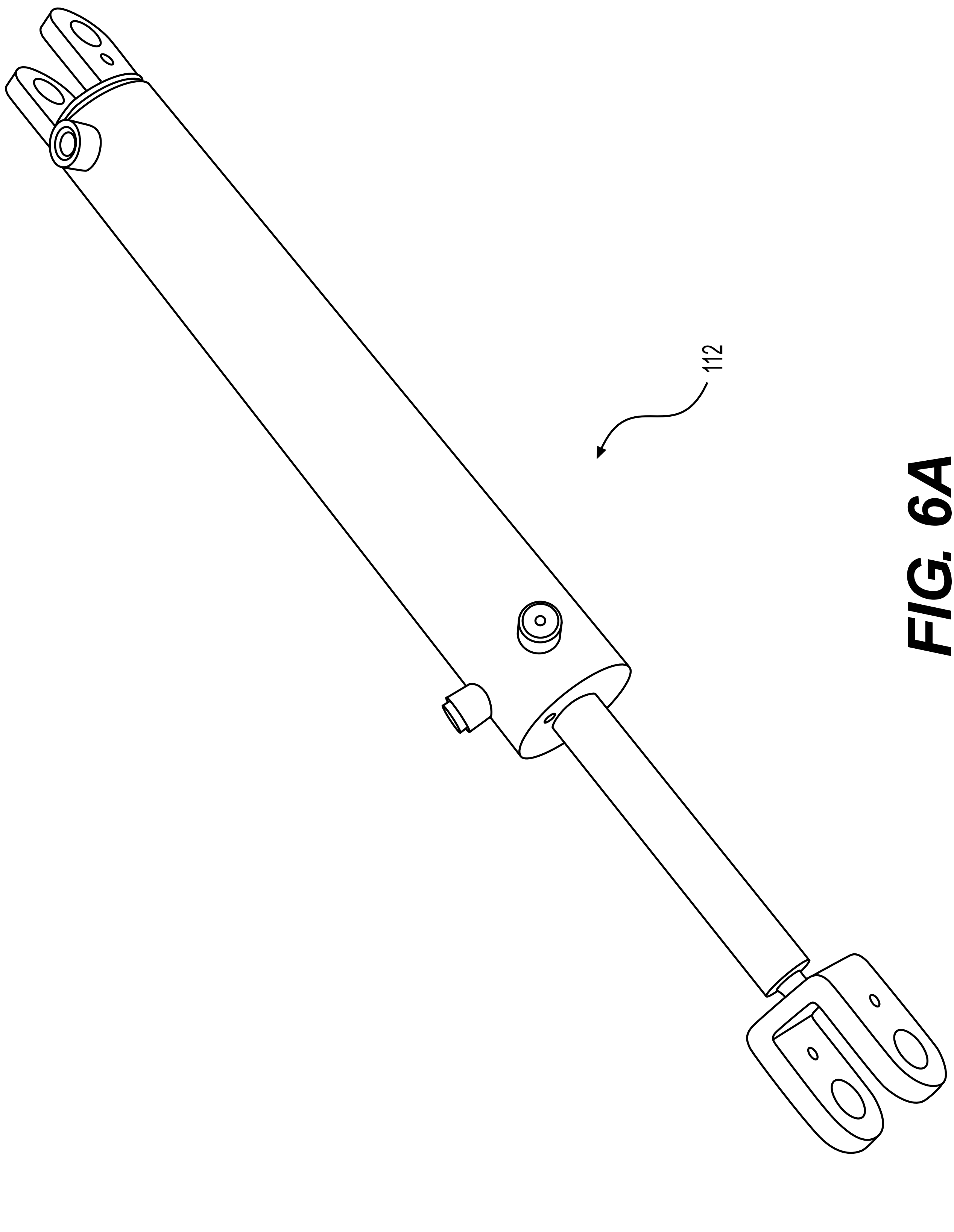

FIG. 6A

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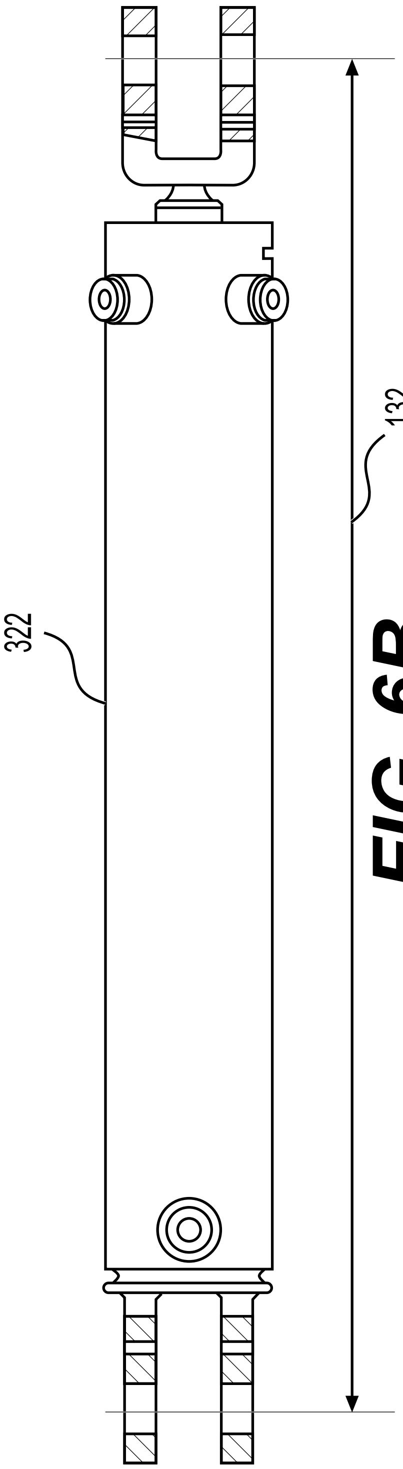

FIG. 6B

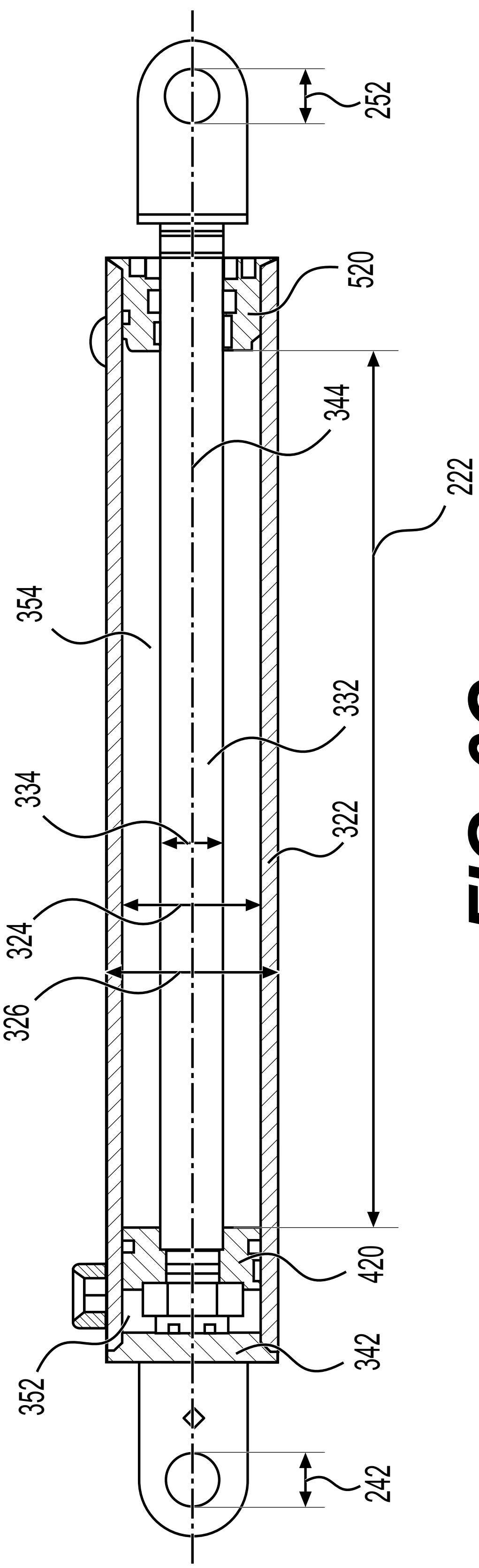

FIG. 6C

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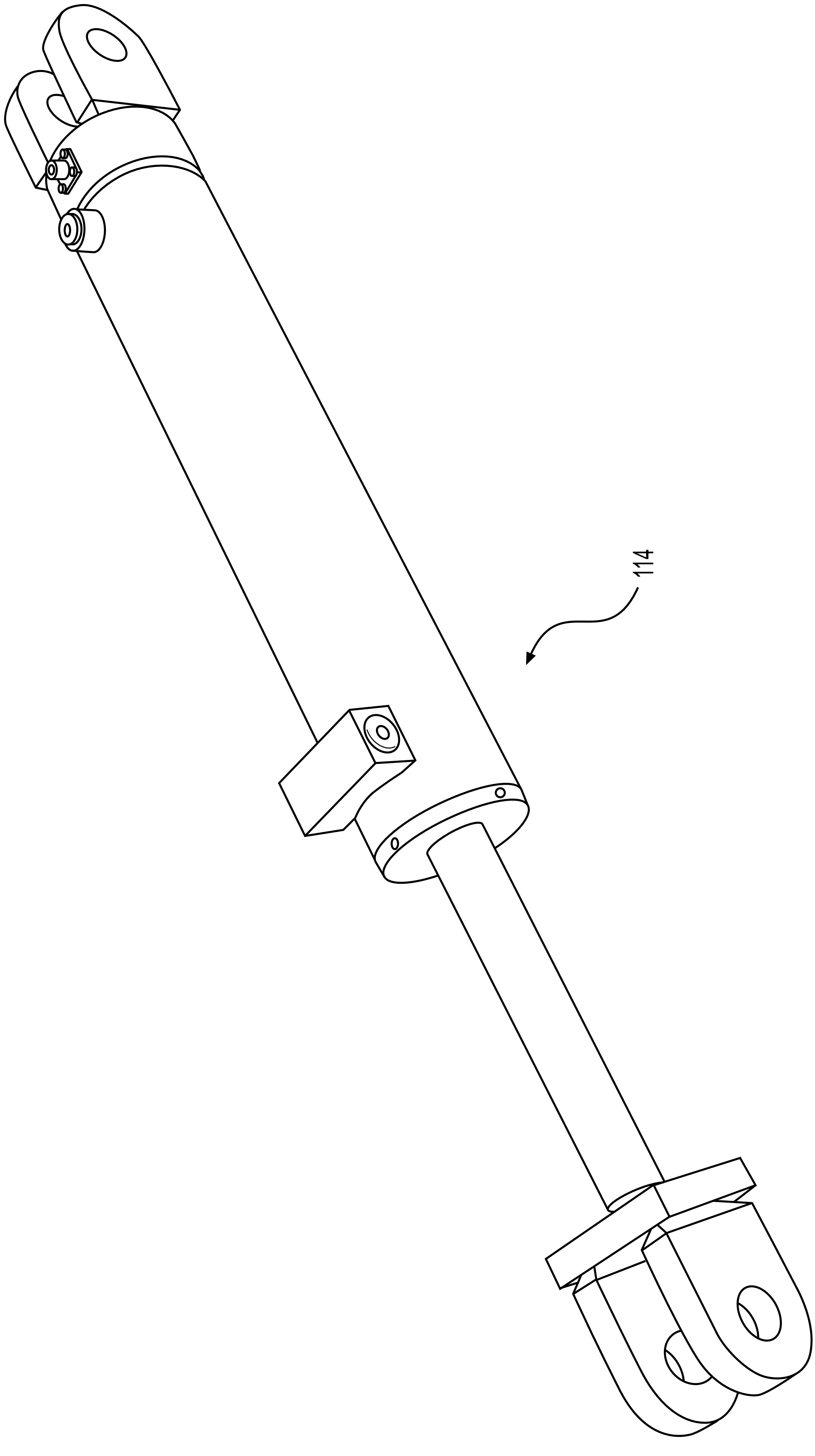

FIG. 7A

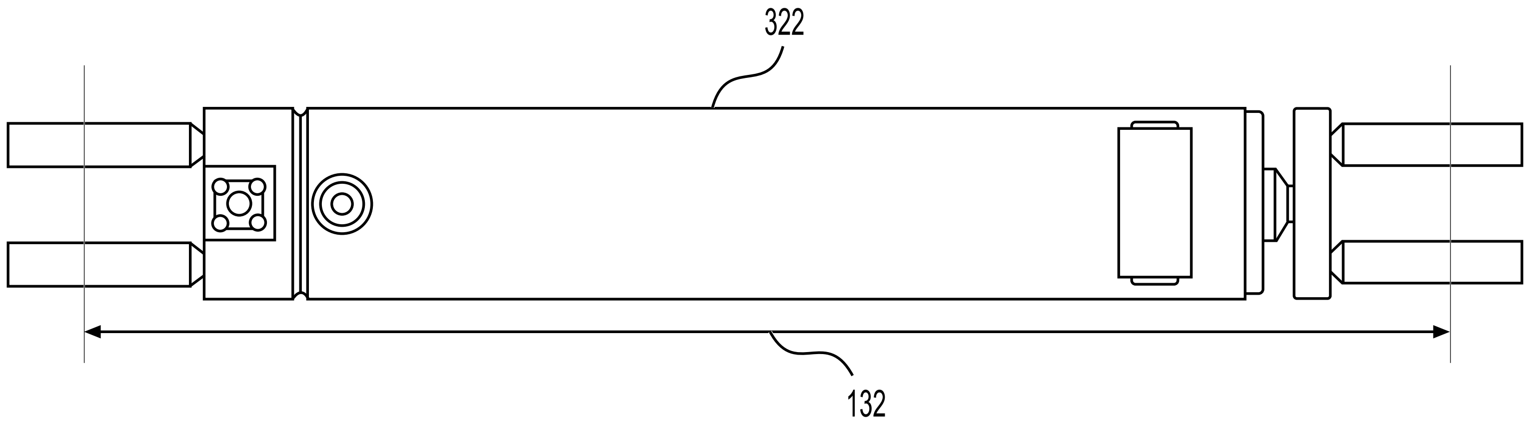

FIG. 7B

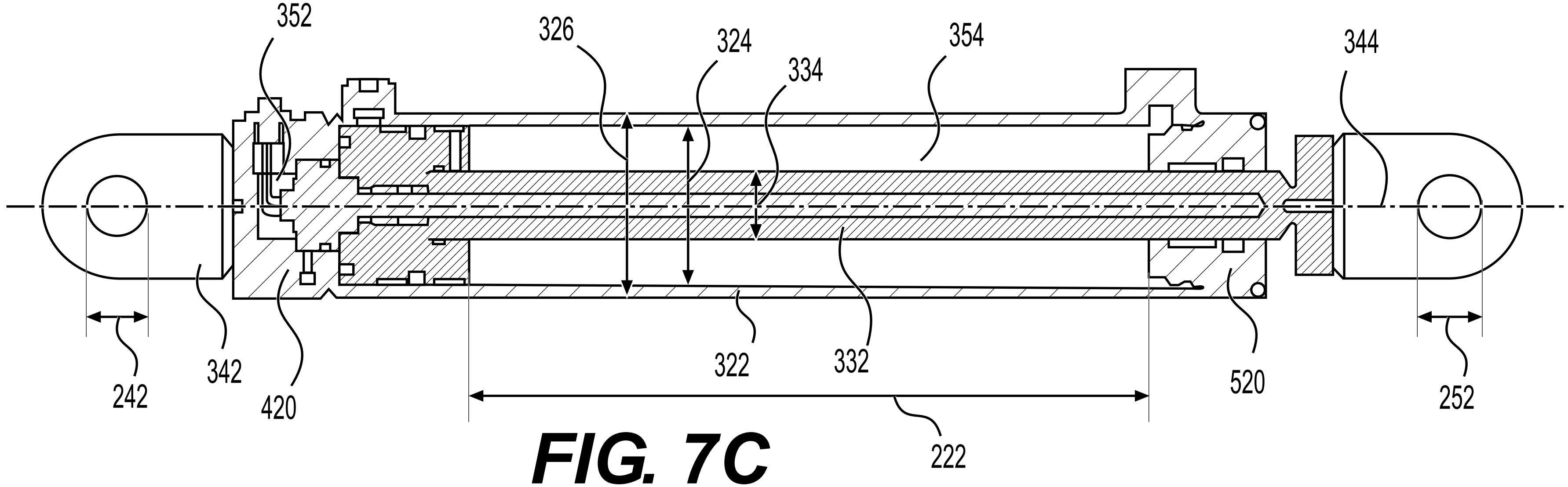

FIG. 7C

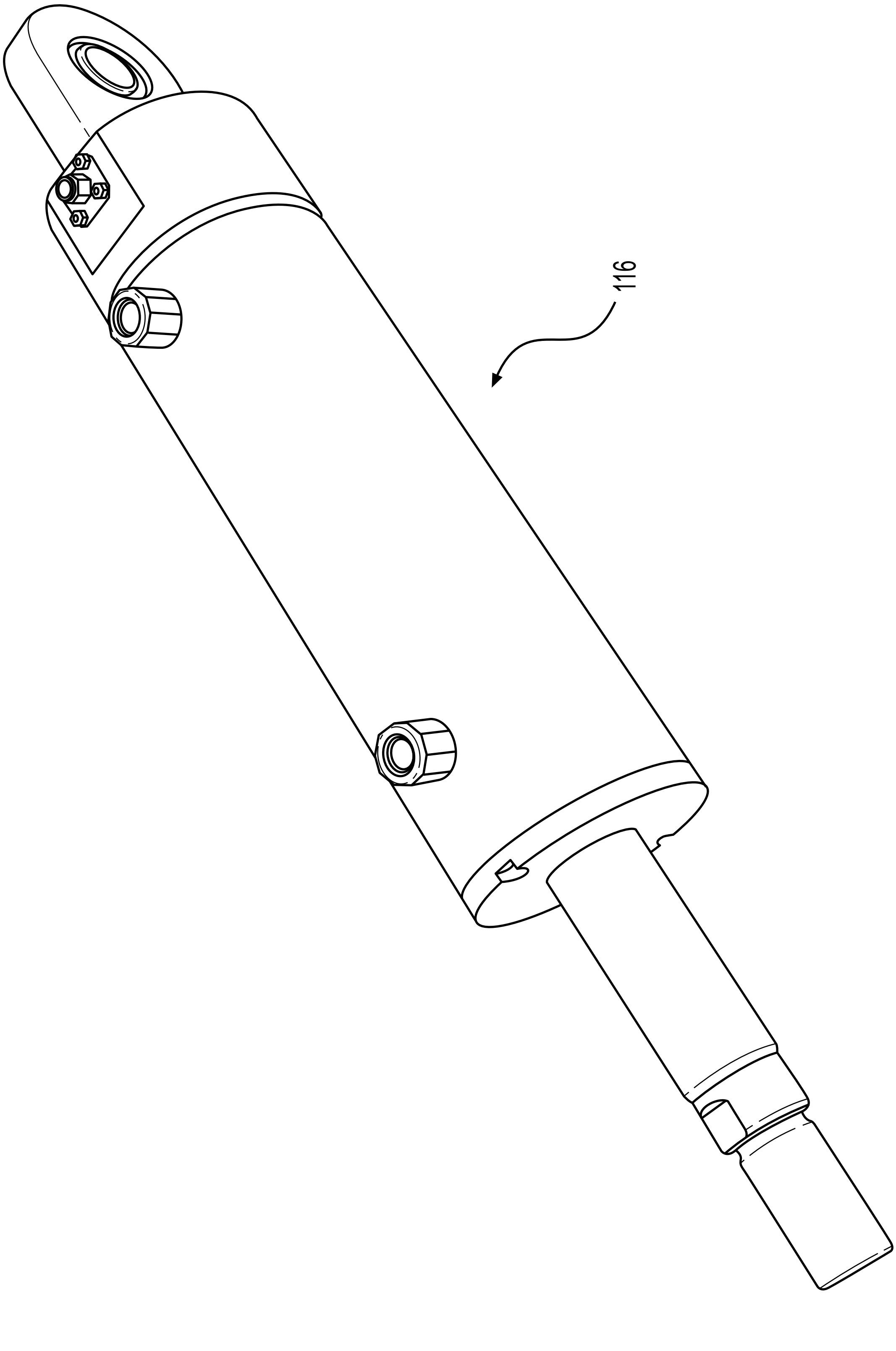

FIG. 8A

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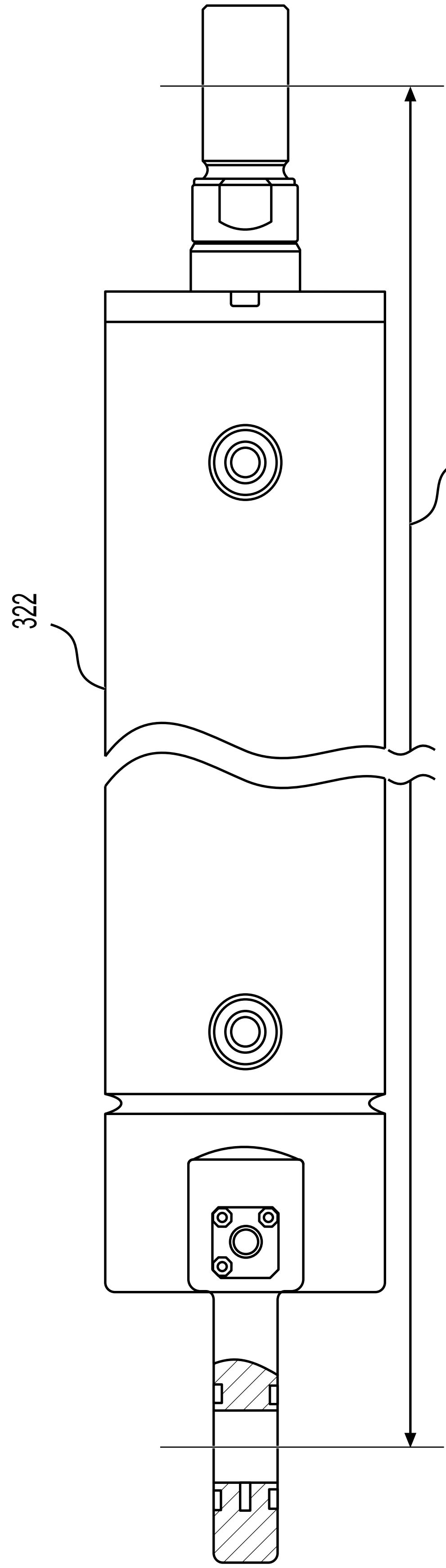

FIG. 8B

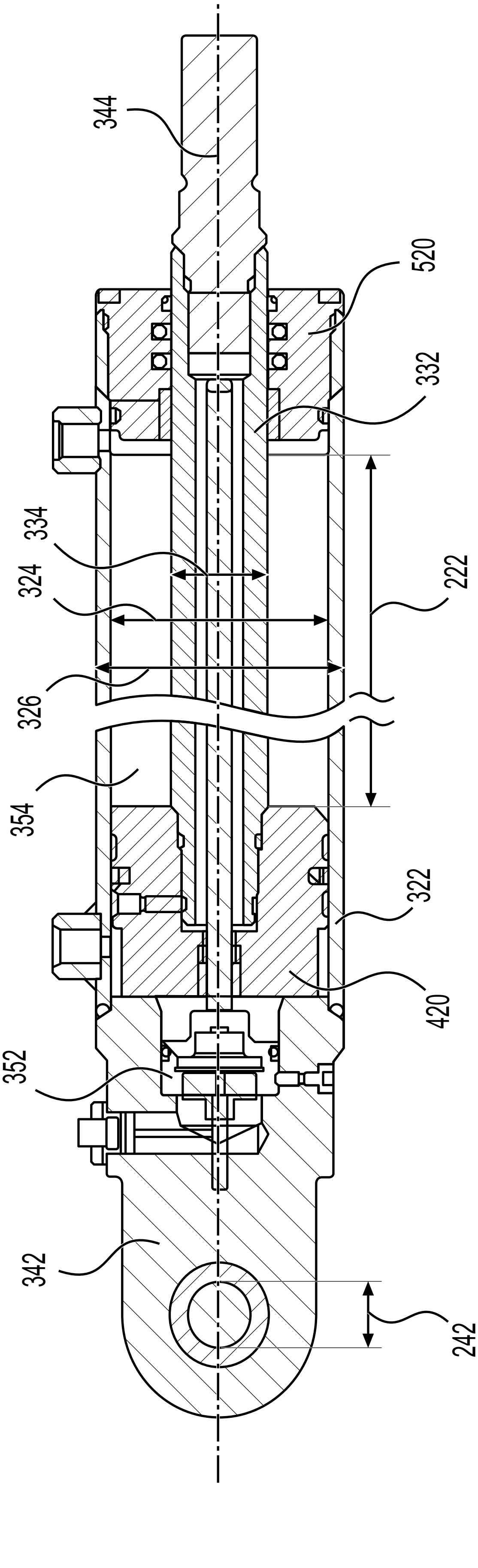

FIG. 8C

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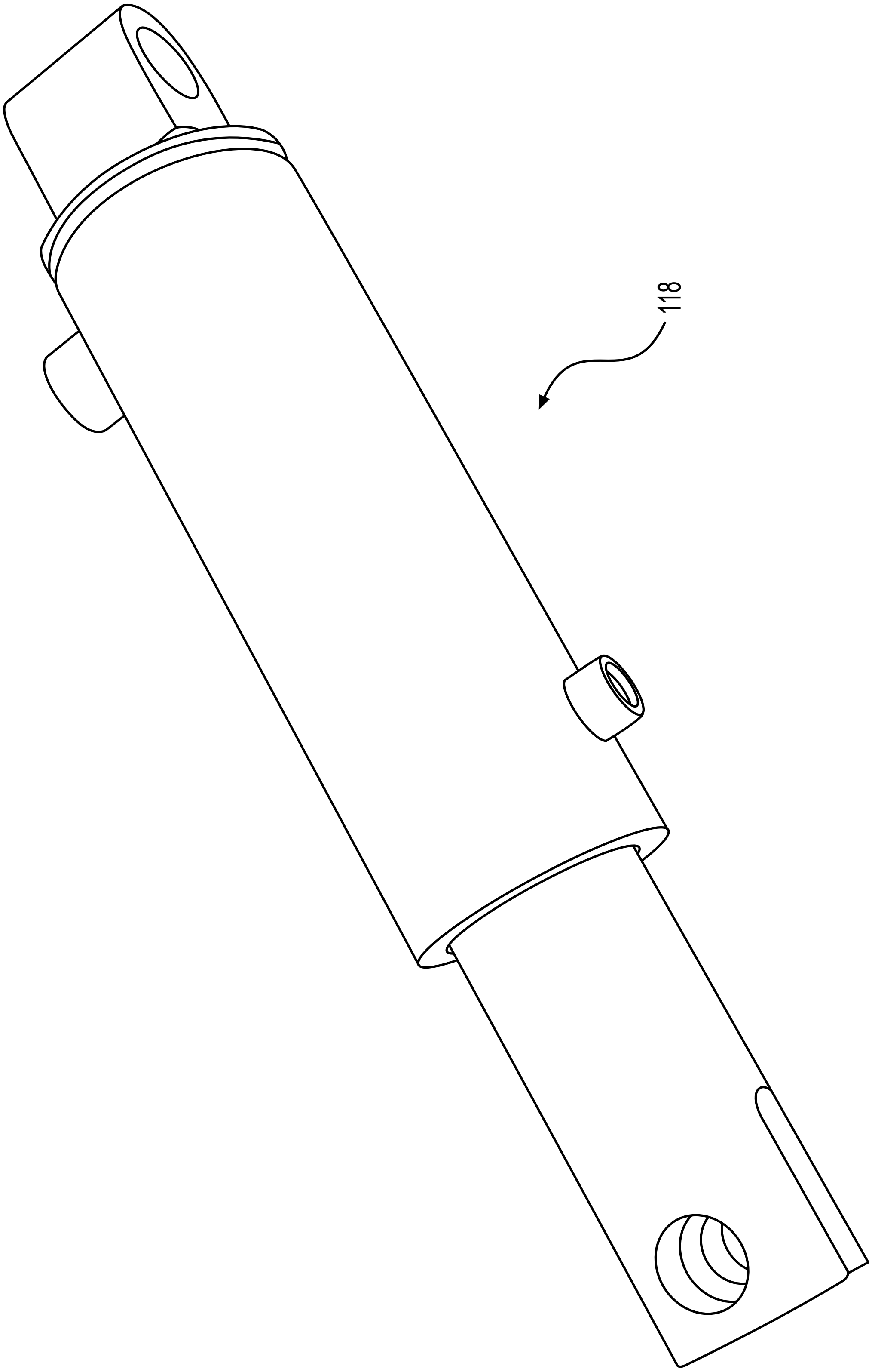

FIG. 9A

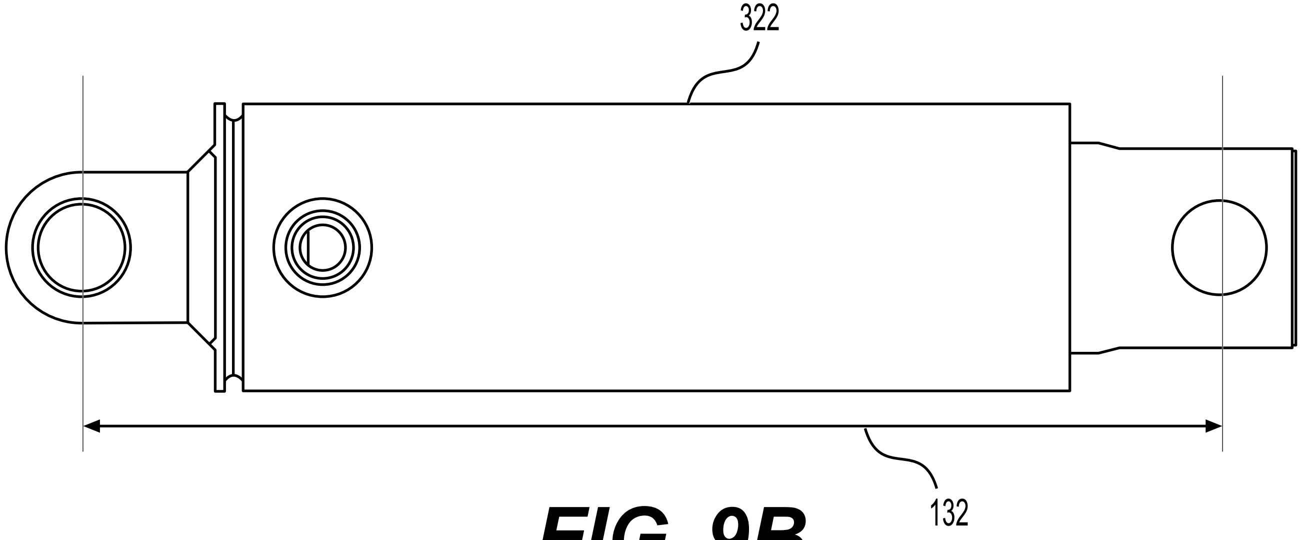

FIG. 9B

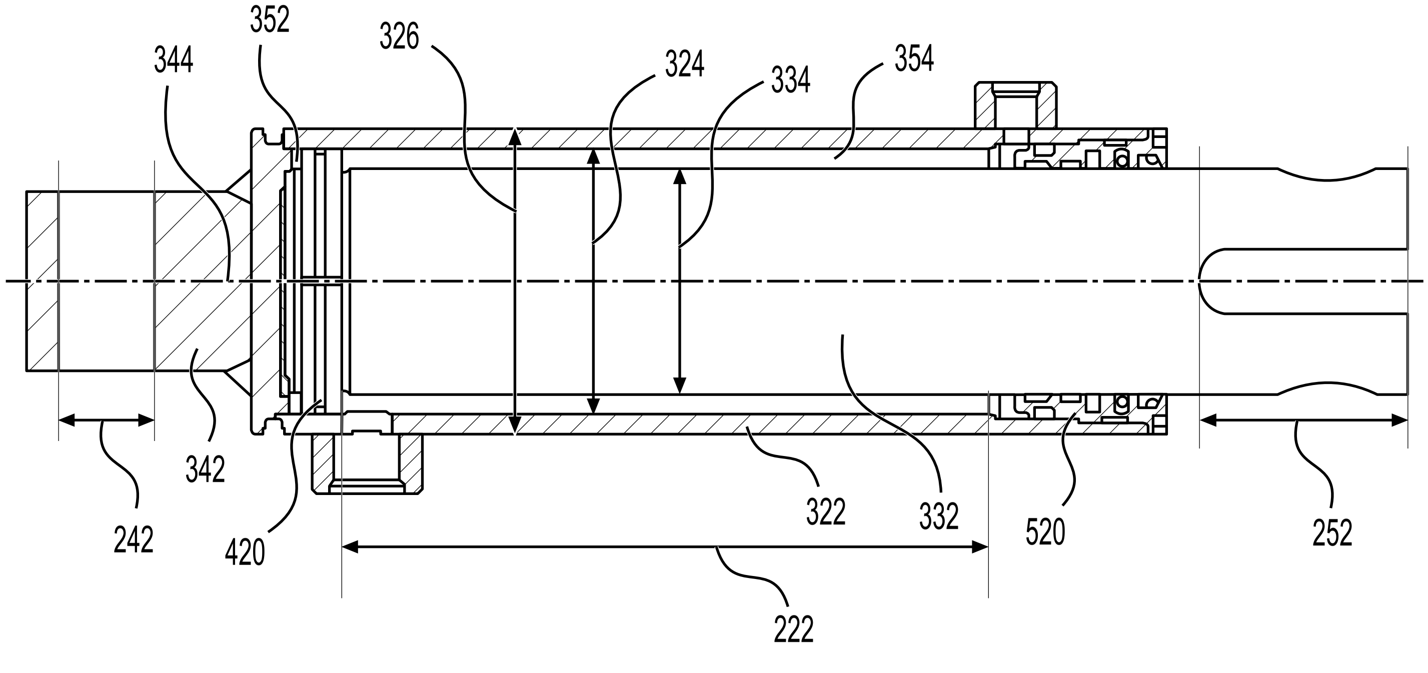

FIG. 9C

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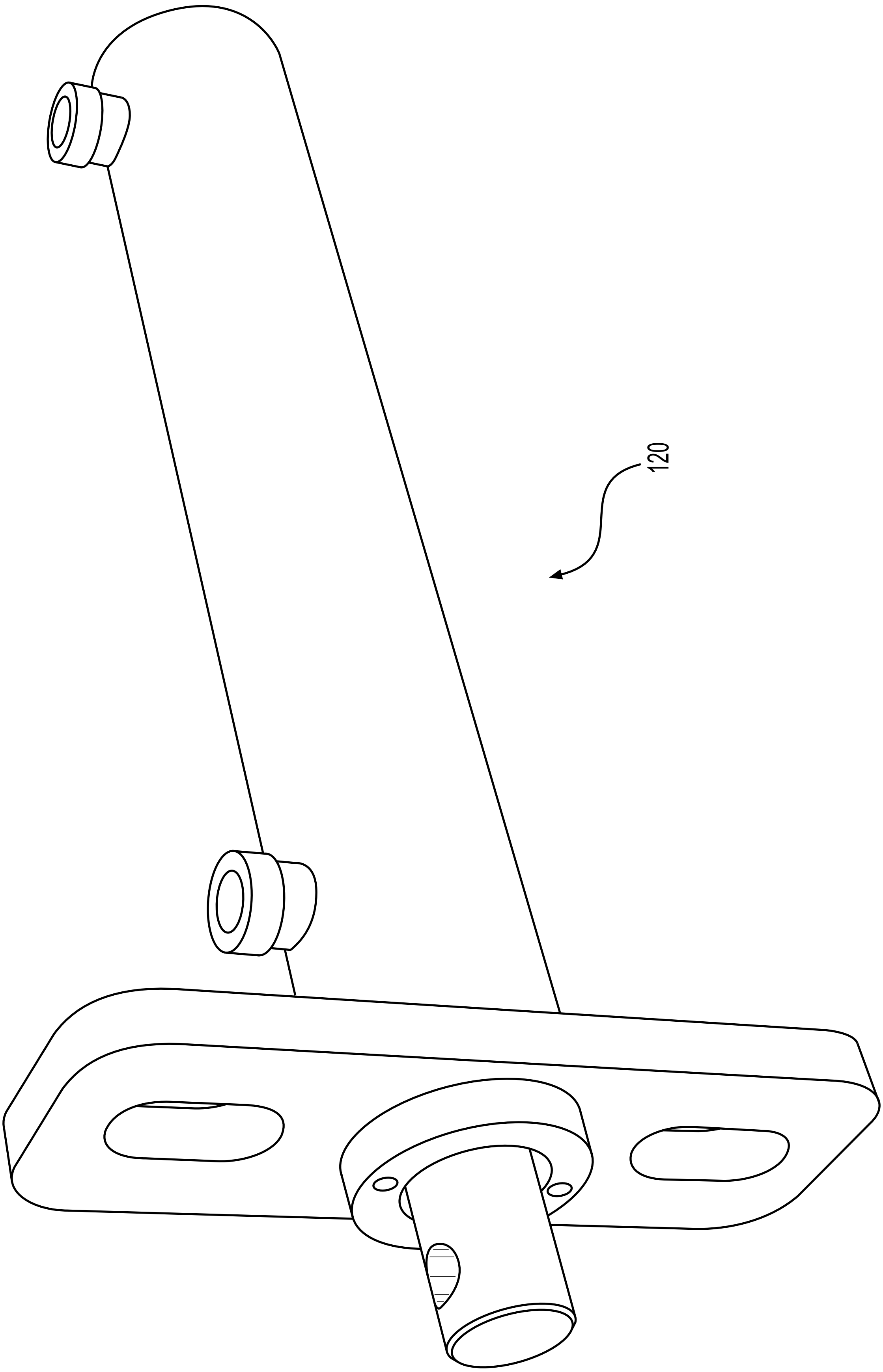

FIG. 10A

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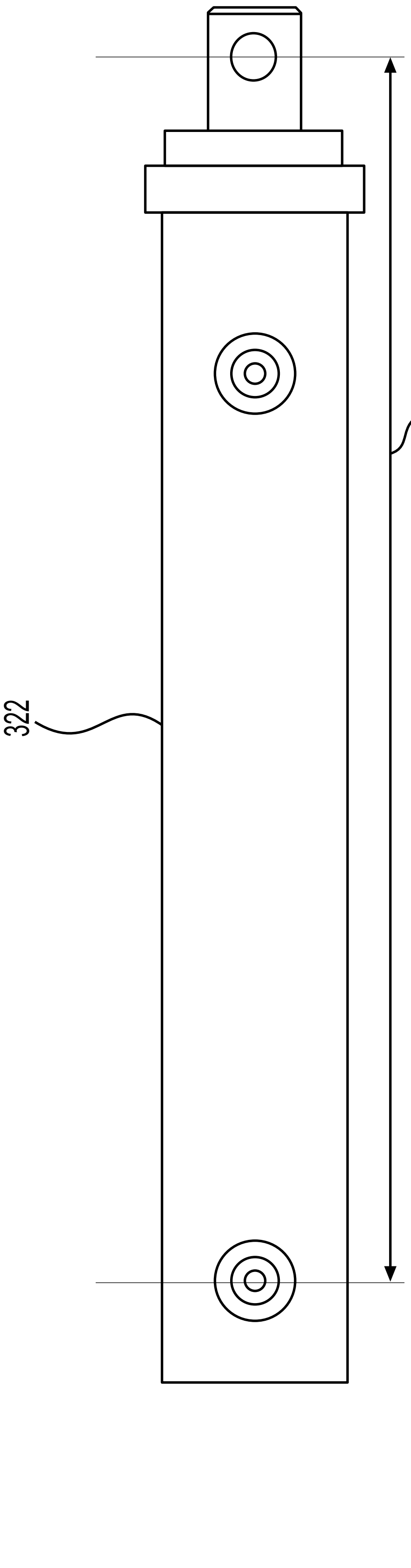

FIG. 10B

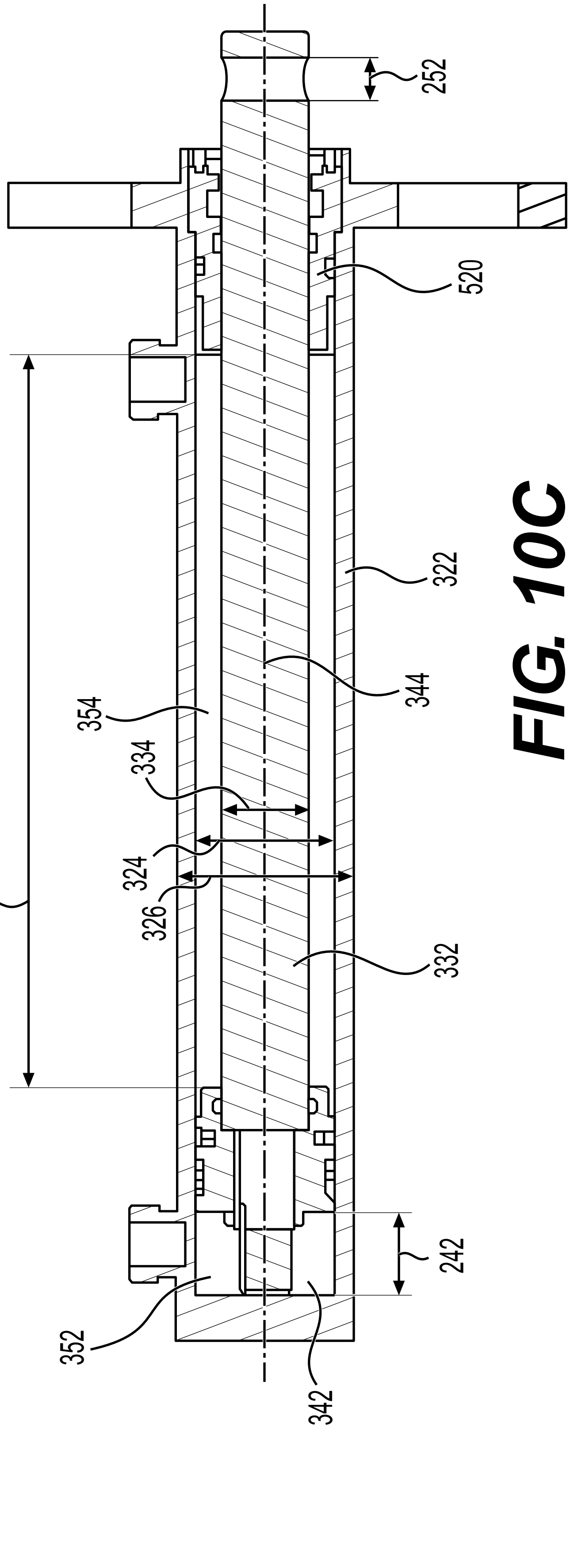

FIG. 10C

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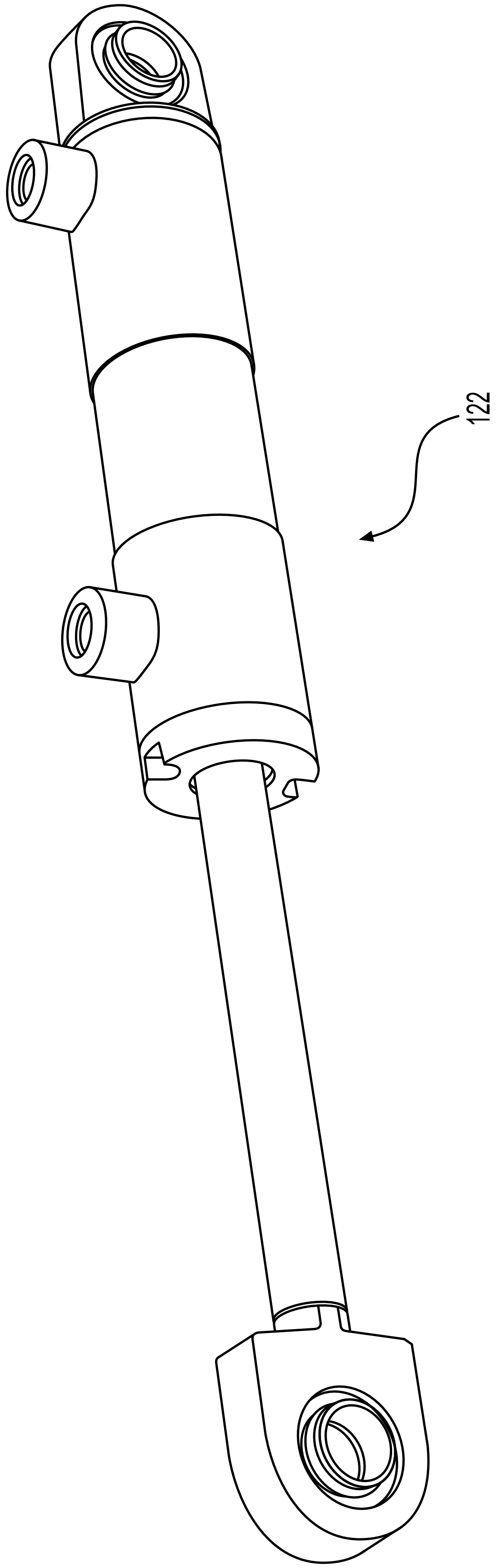

FIG. 11A

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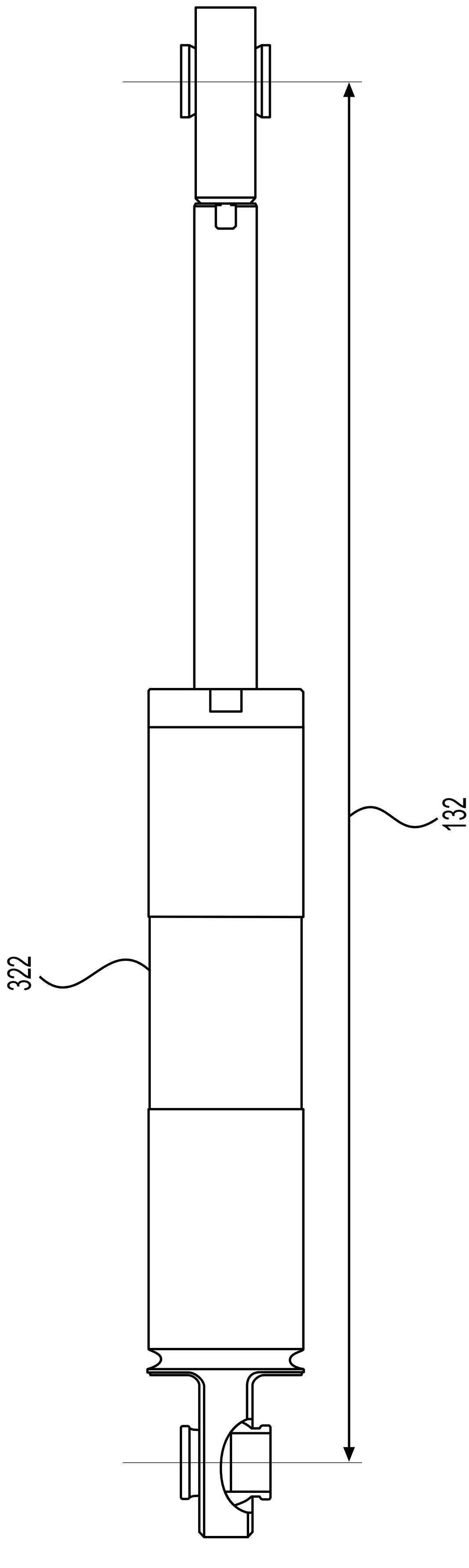

FIG. 11B

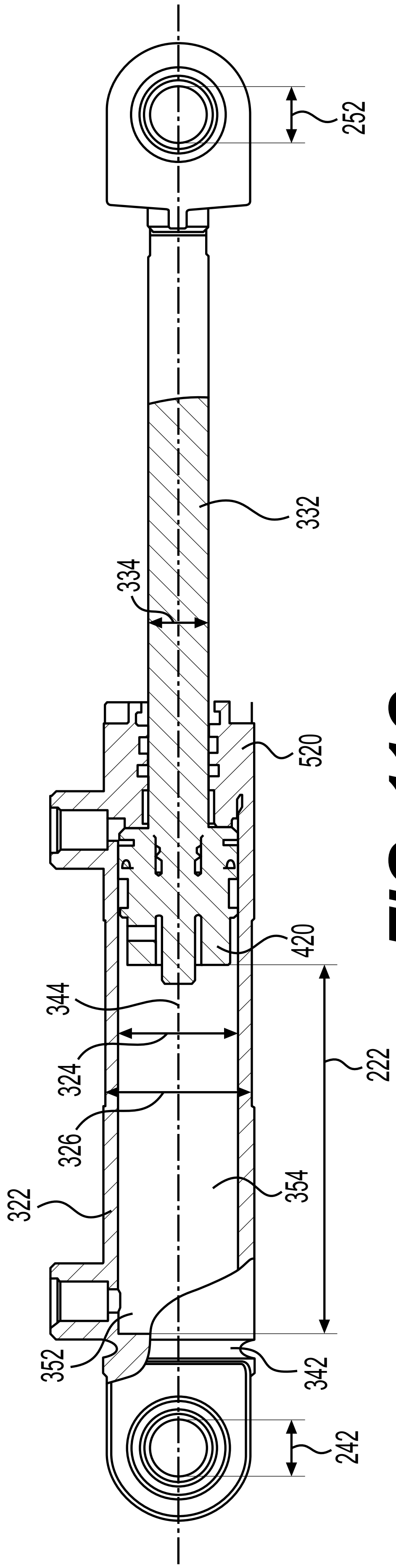

FIG. 11C

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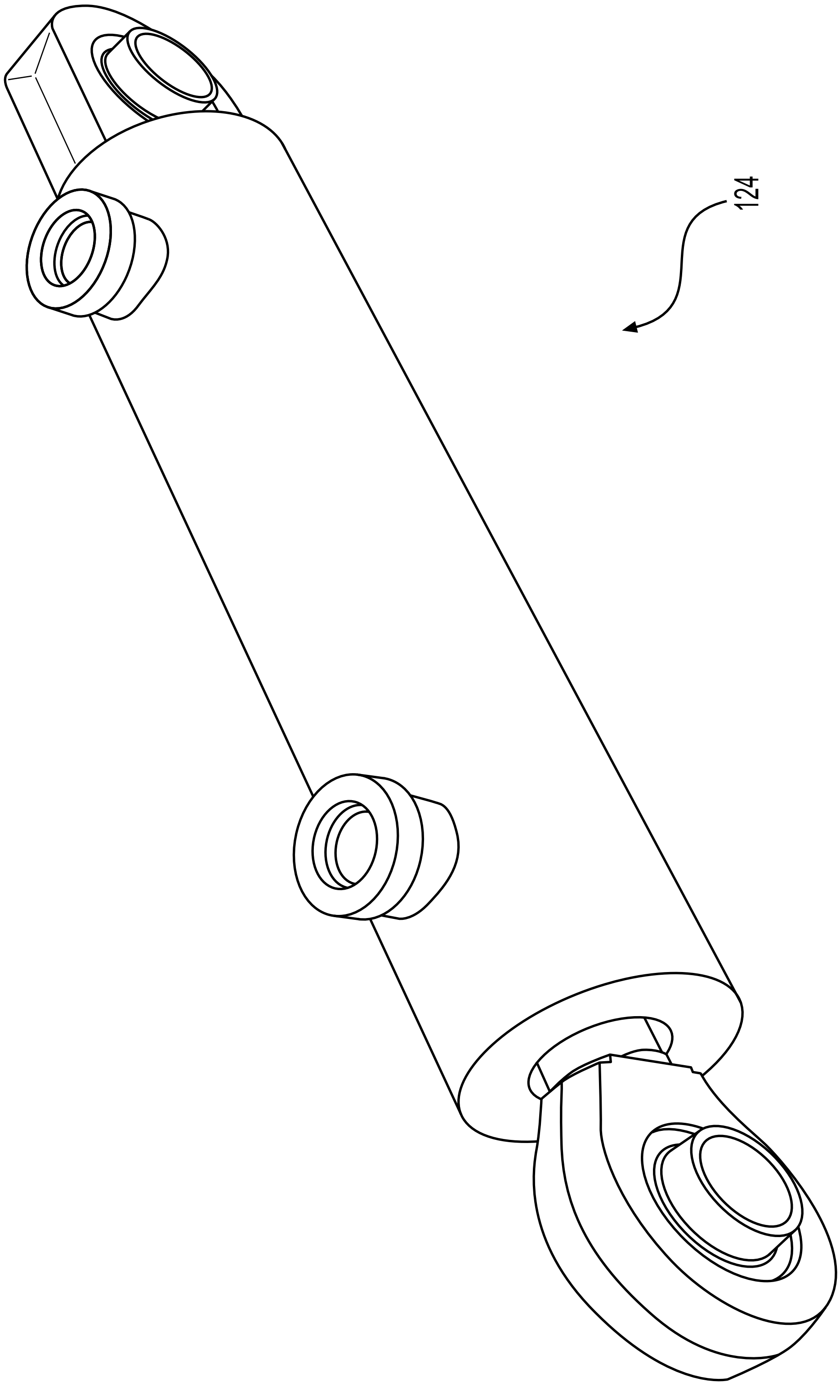

FIG. 12A

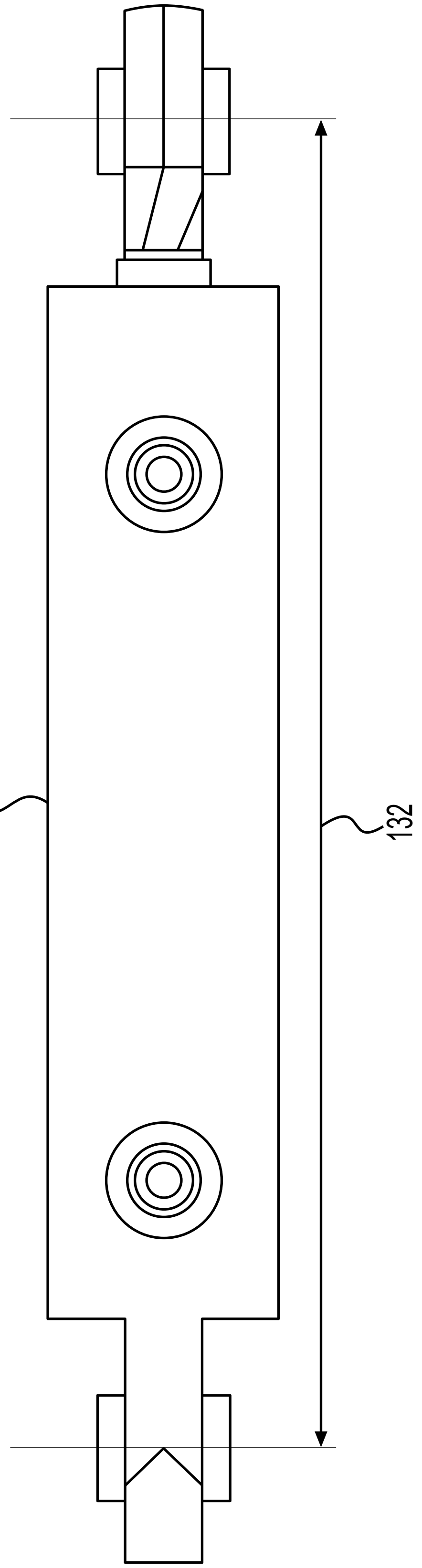

FIG. 12B

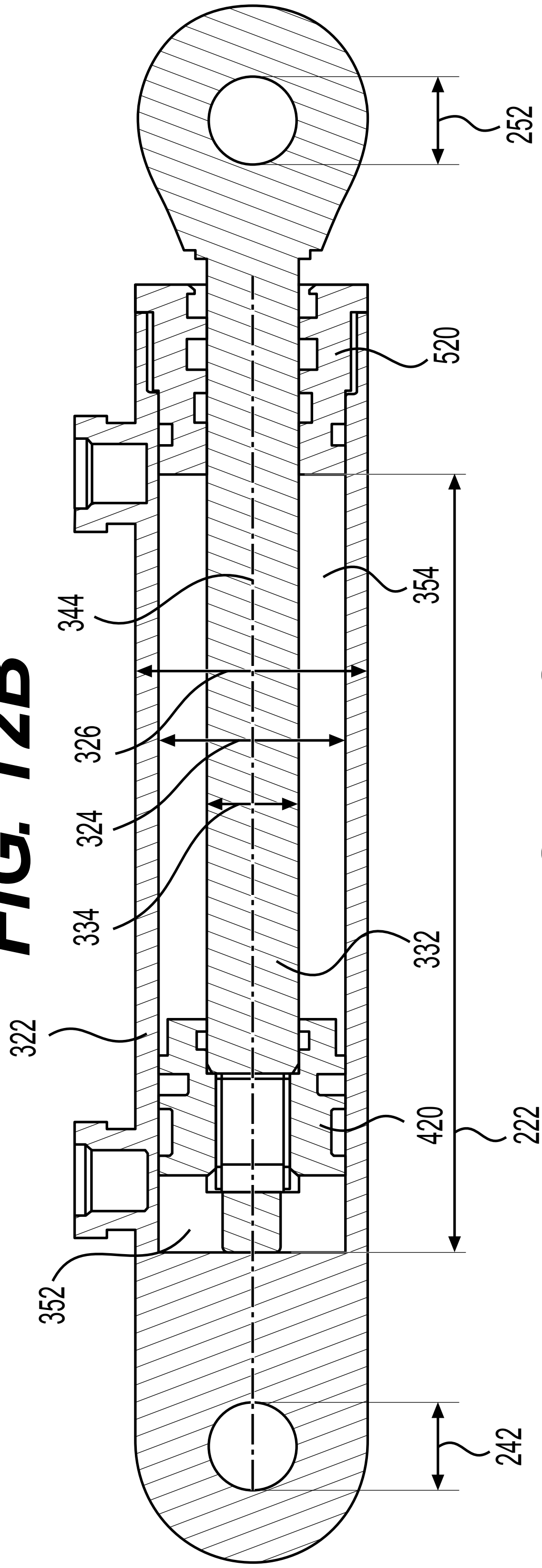

FIG. 12C

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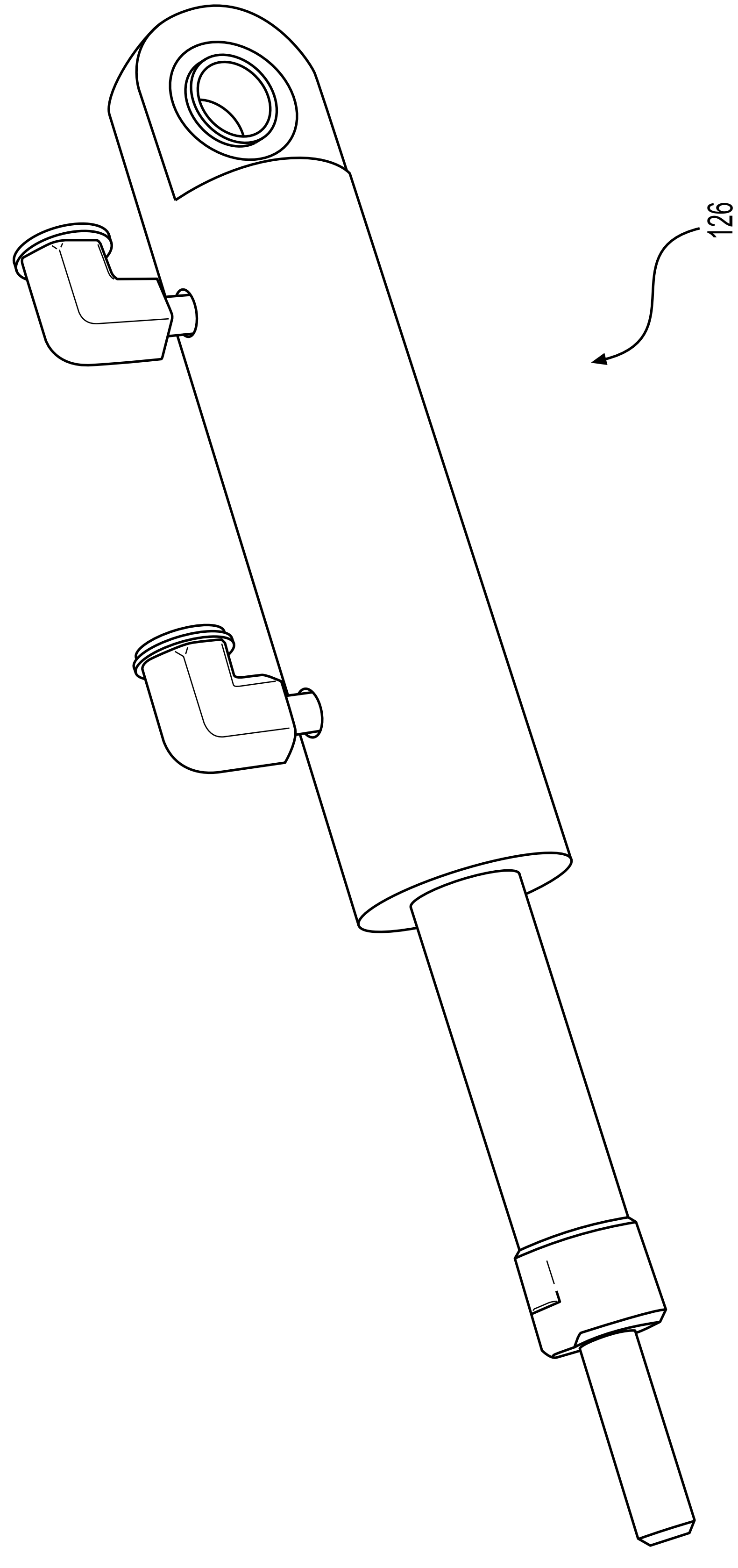

FIG. 13A

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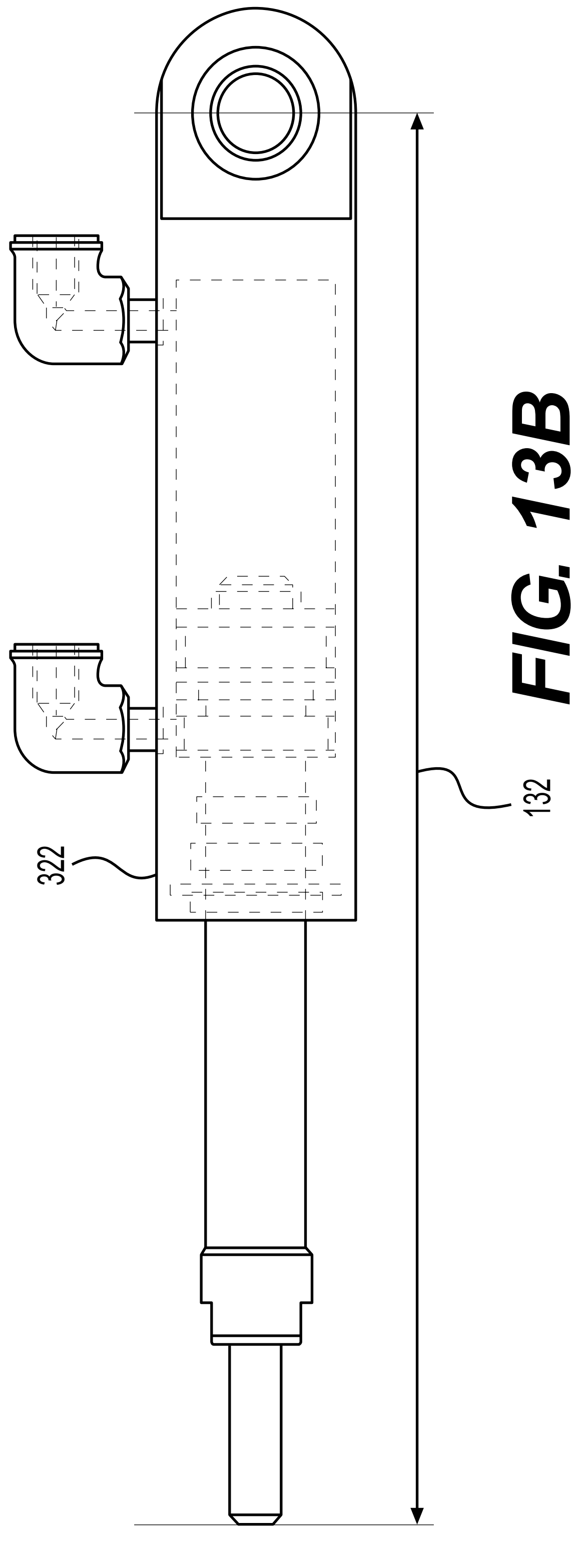

FIG. 13B

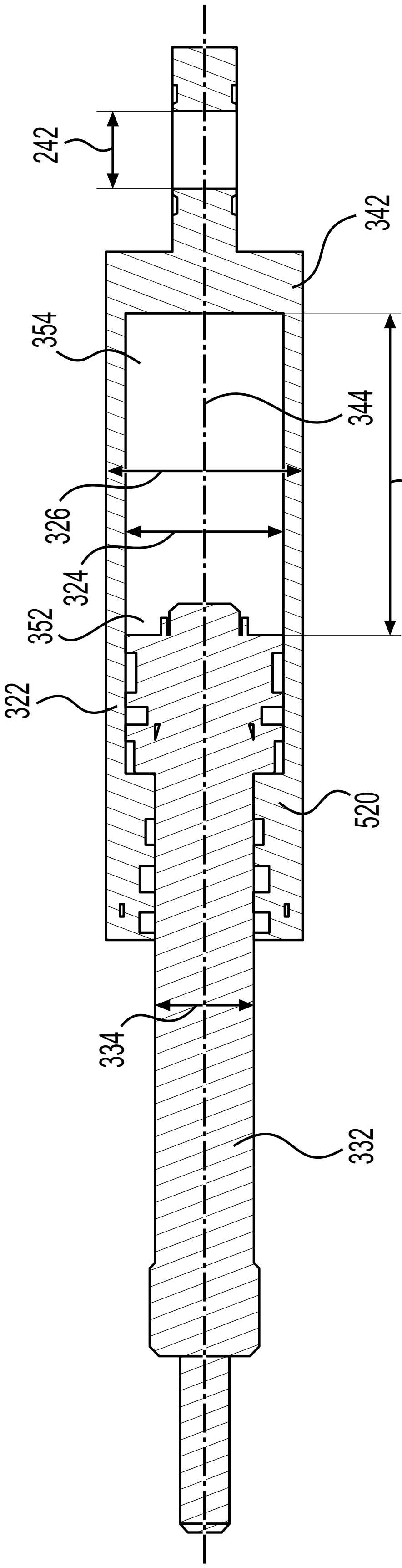

FIG. 13C

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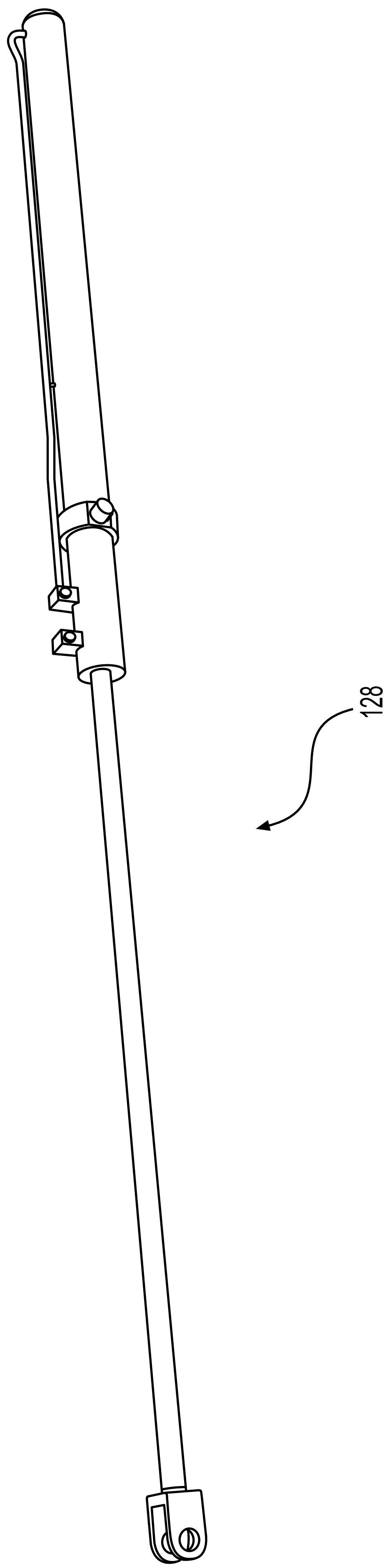

FIG. 14A

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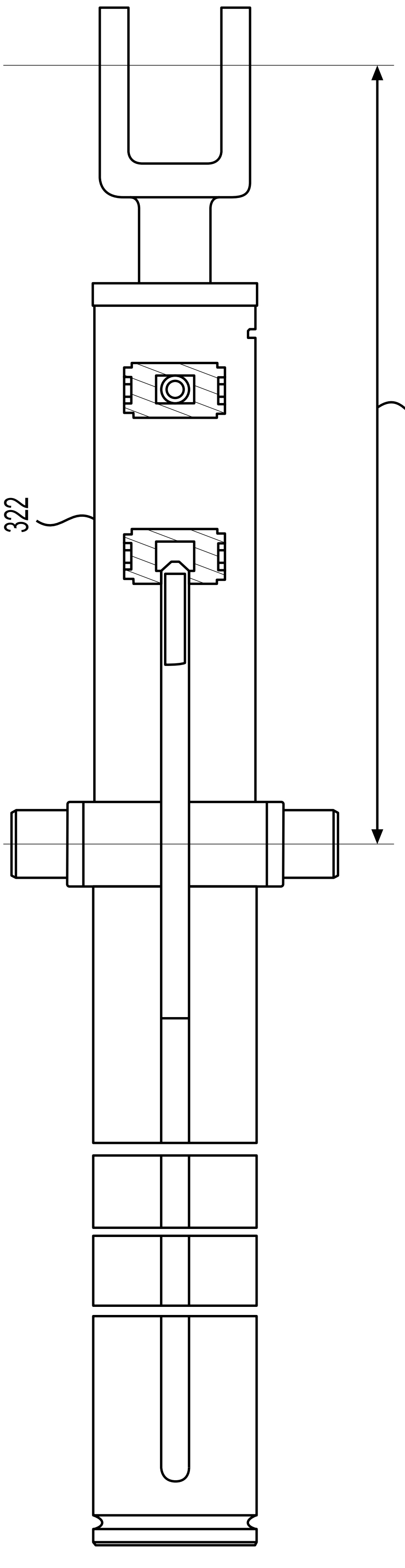

FIG. 14B

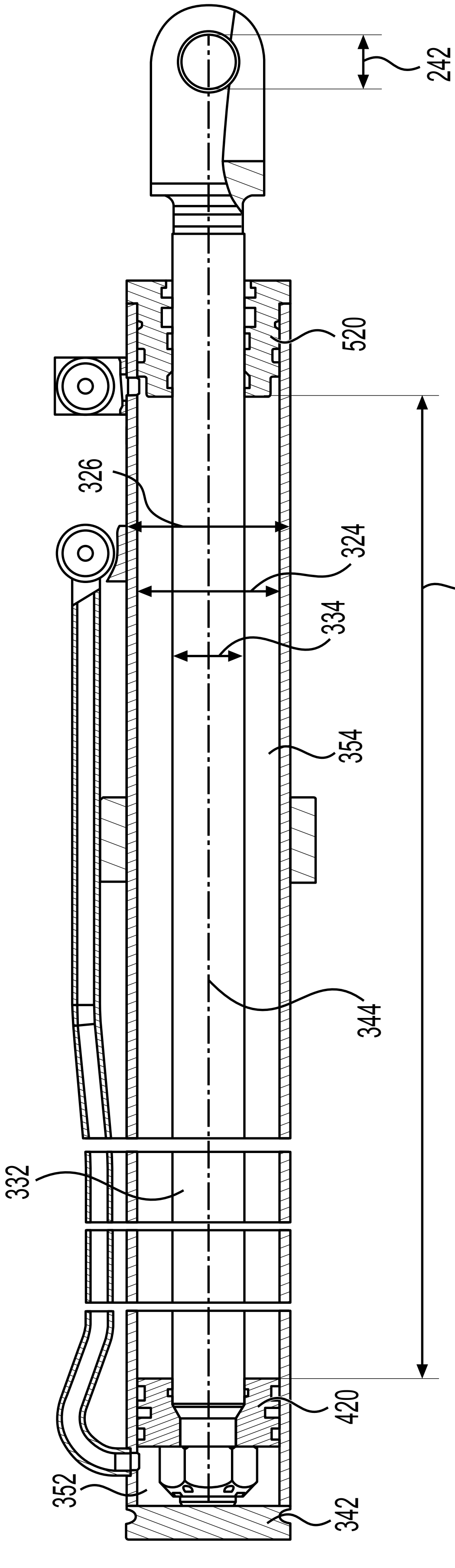

FIG. 14C

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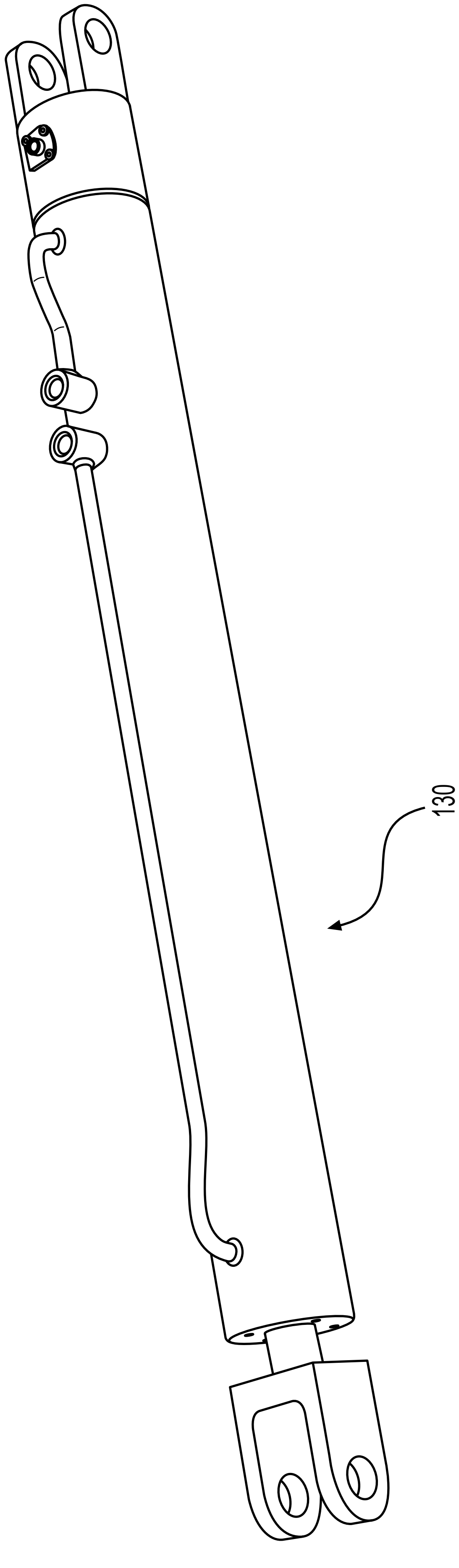

FIG. 15A

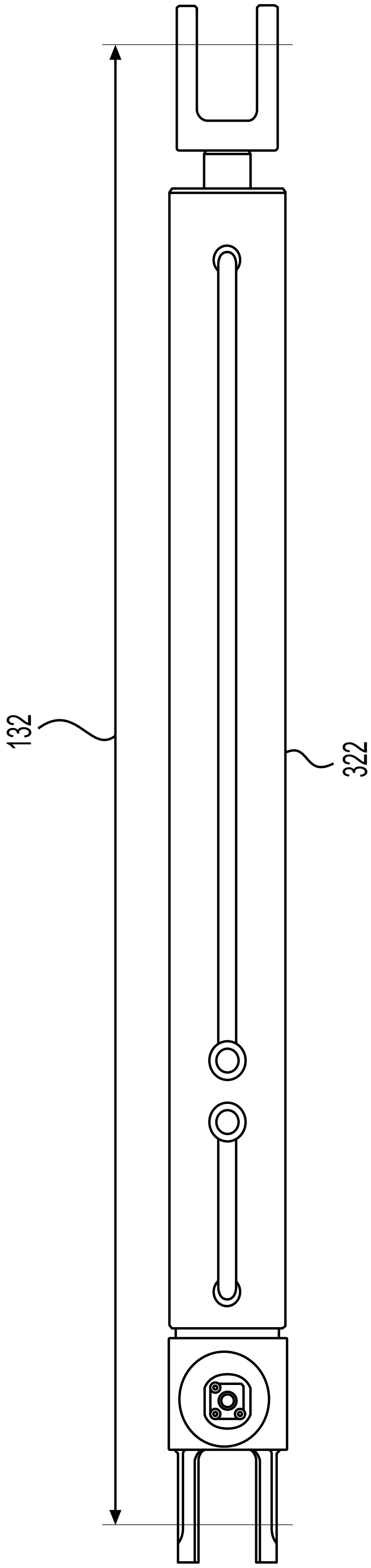

FIG. 15B

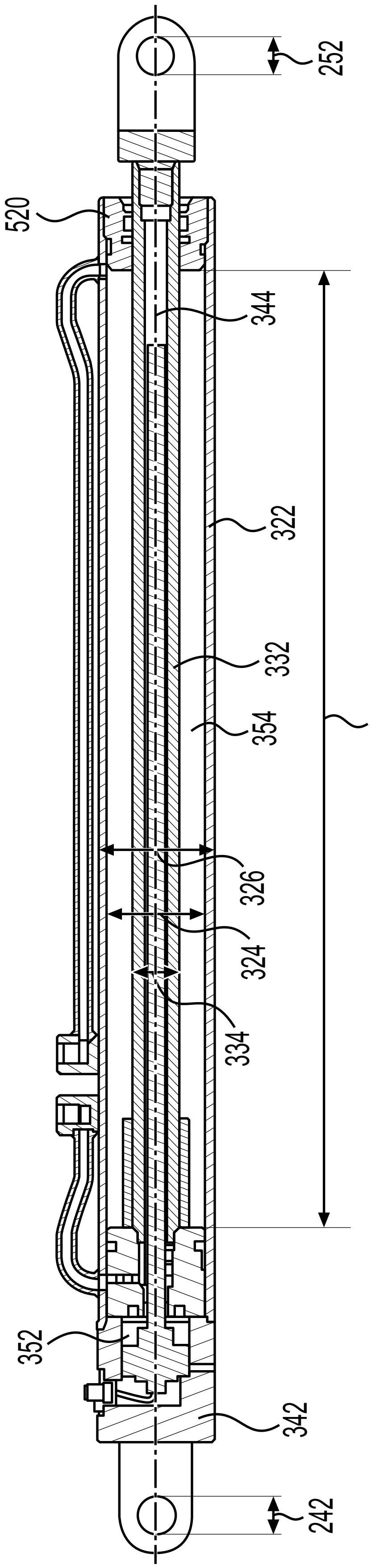

FIG. 15C

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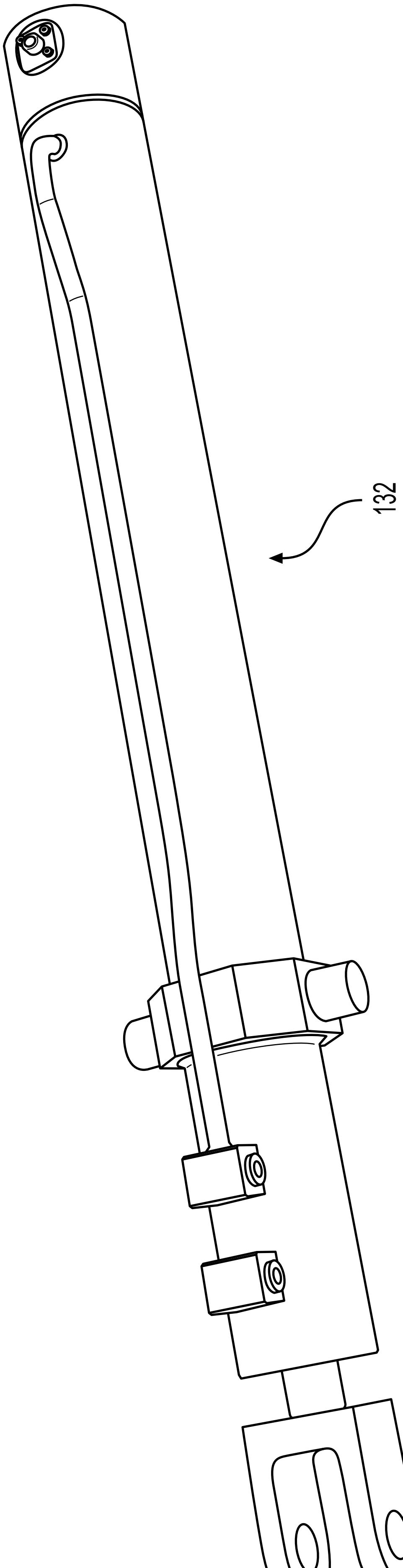

FIG. 16A

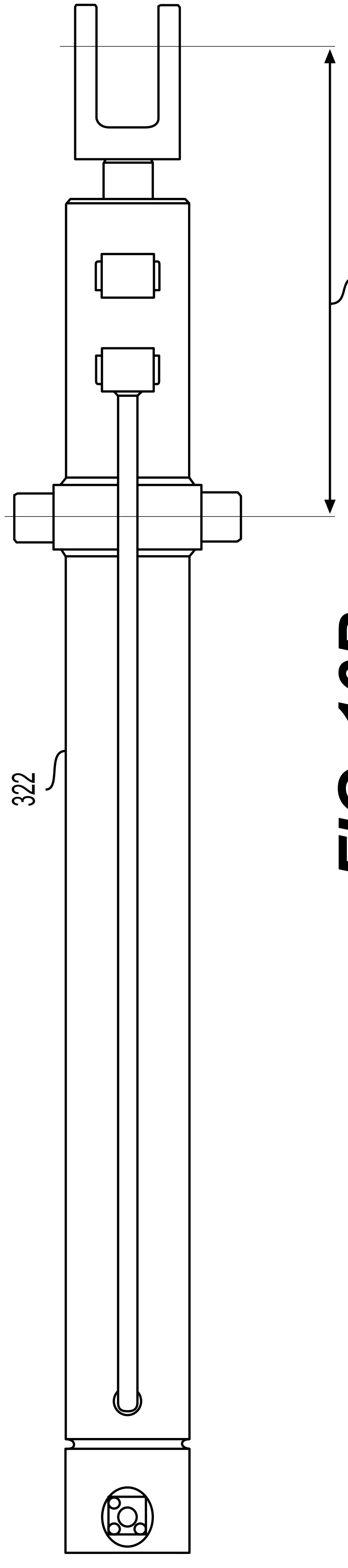

FIG. 16B

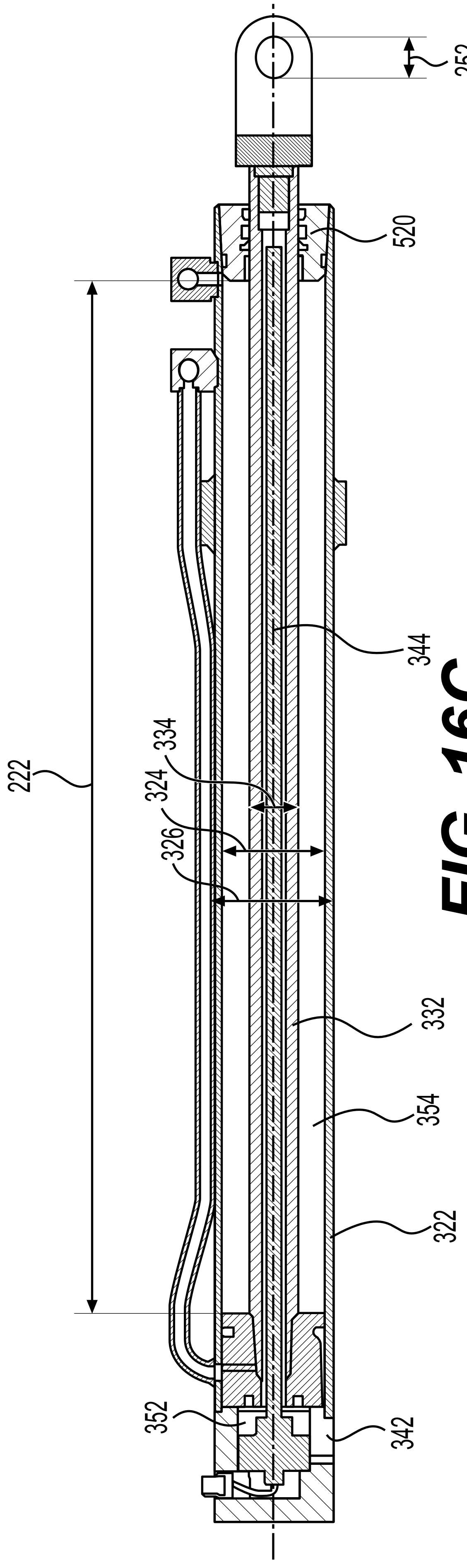

FIG. 16C

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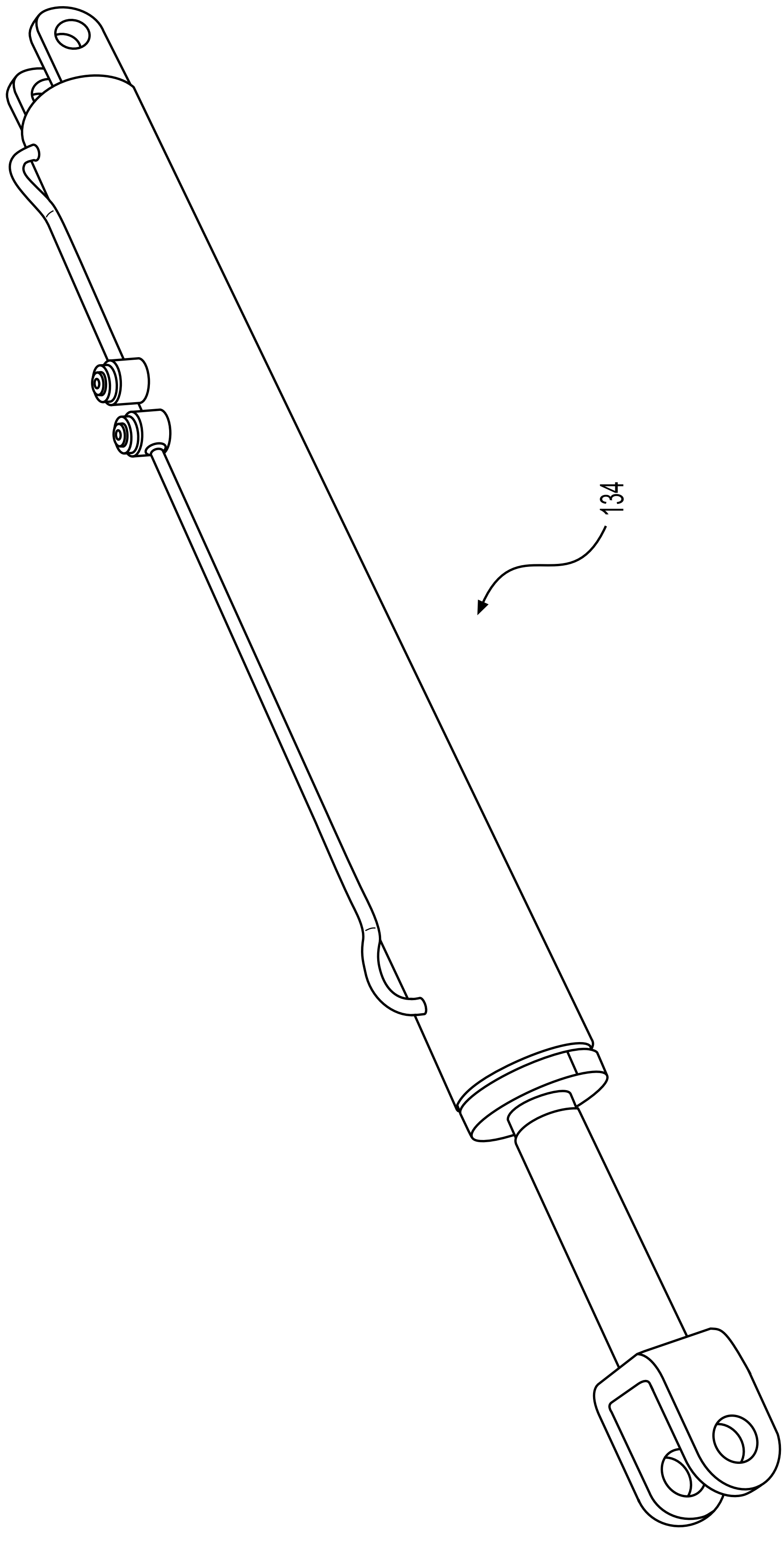

FIG. 17A

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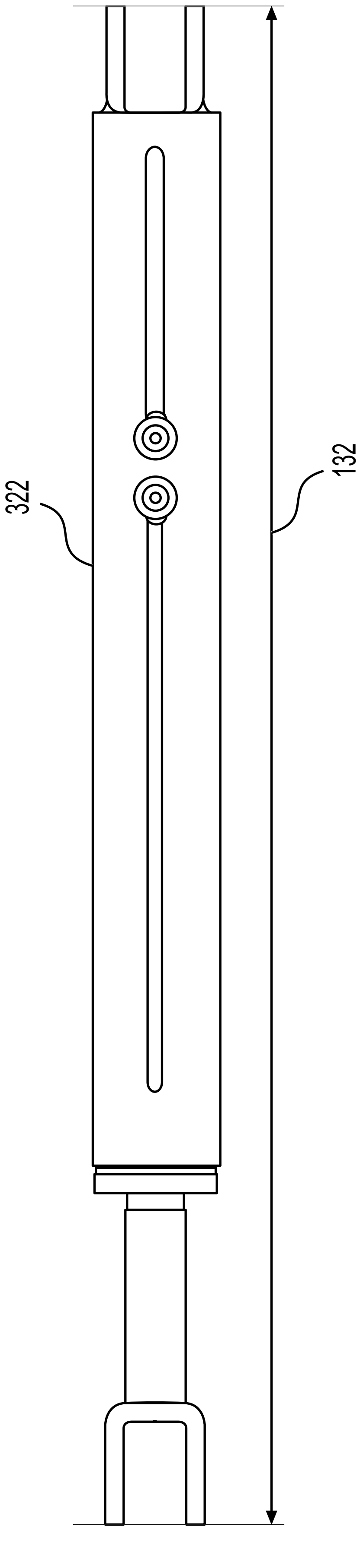

FIG. 17B

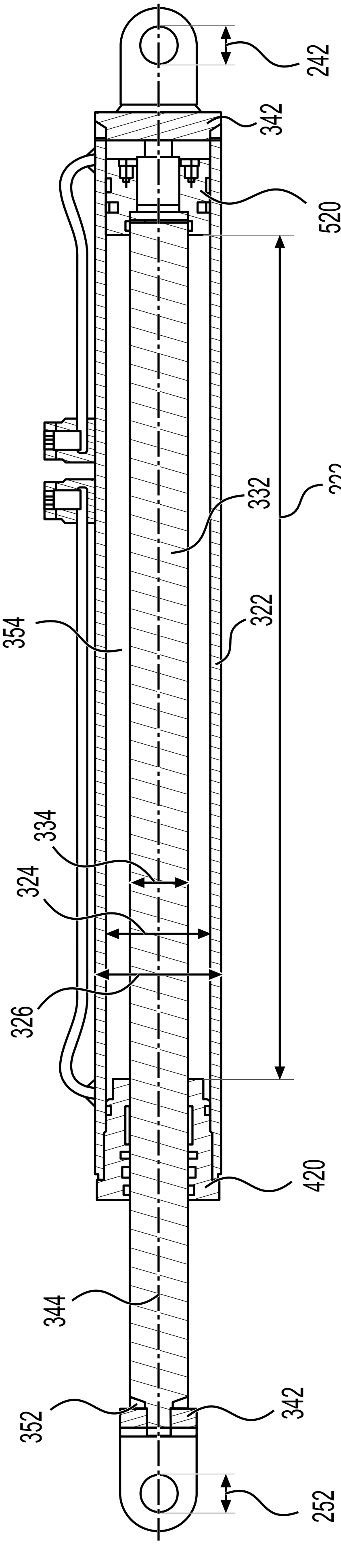

FIG. 17C

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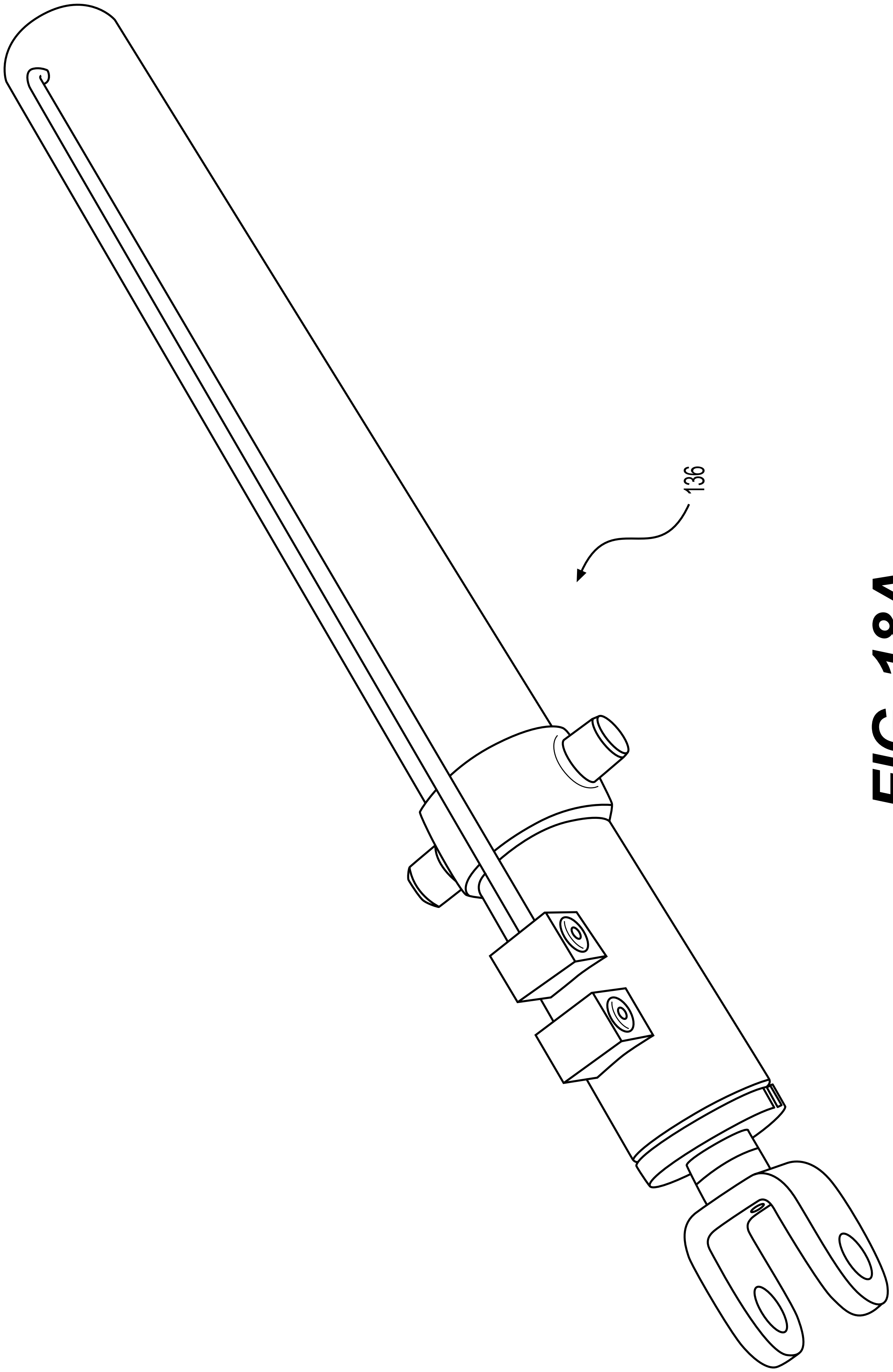

FIG. 18A

20211102510 12 May 2021

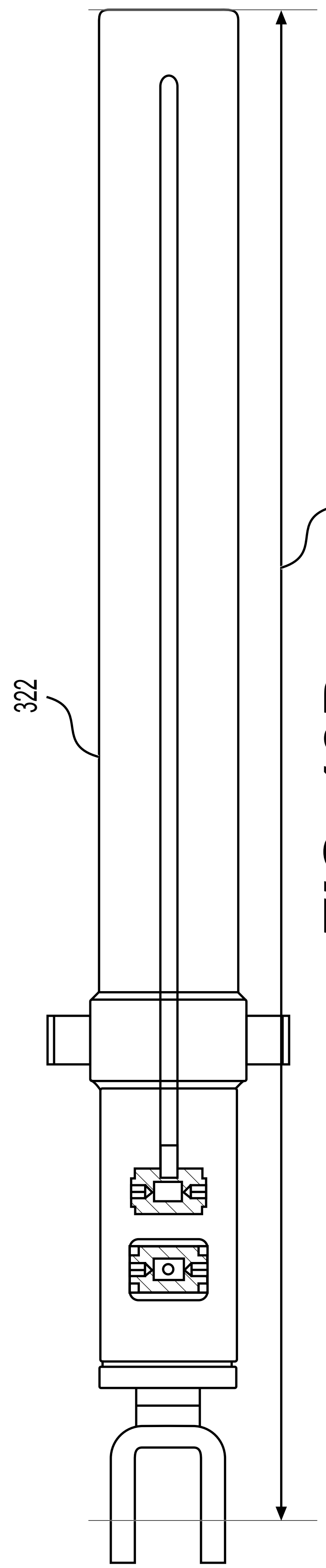

FIG. 18B

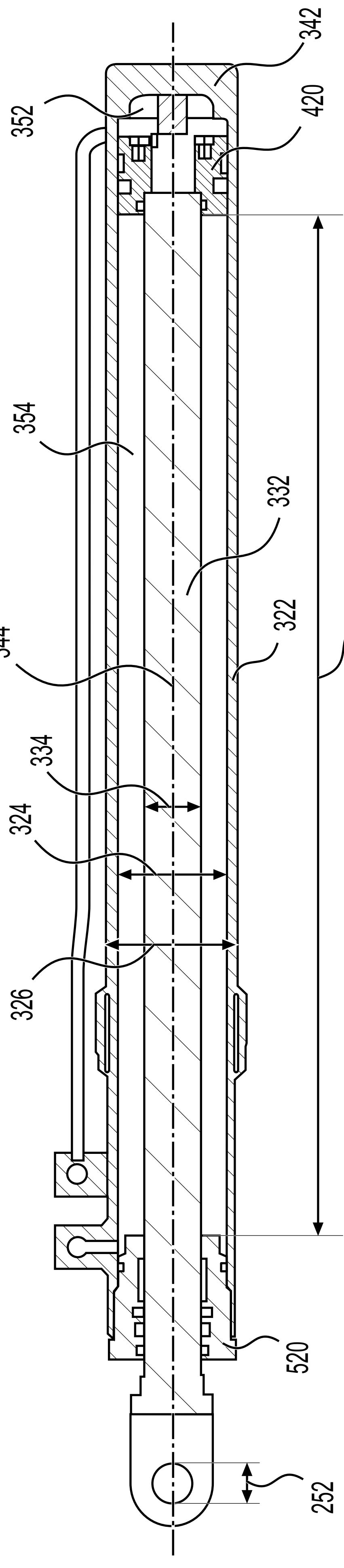

FIG. 18C

2021102510 12 May 2021

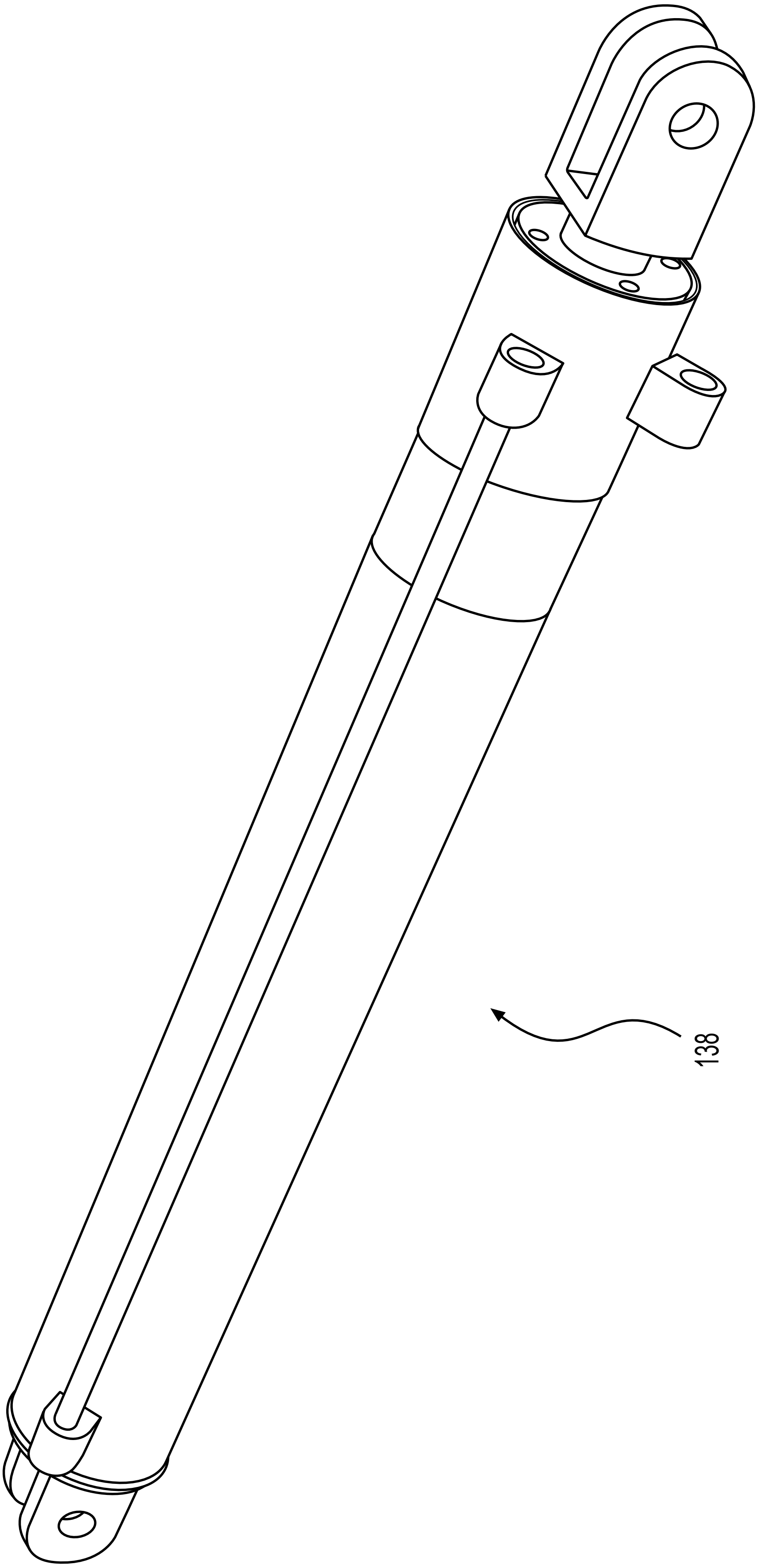

FIG. 19A

20211102510 12 May 2021

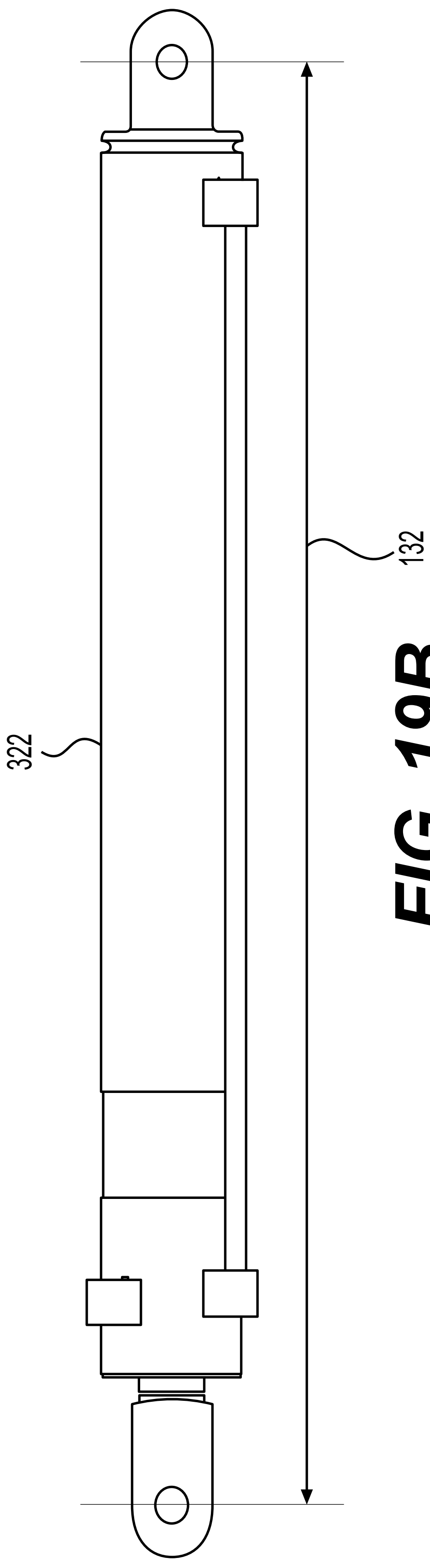

FIG. 19B

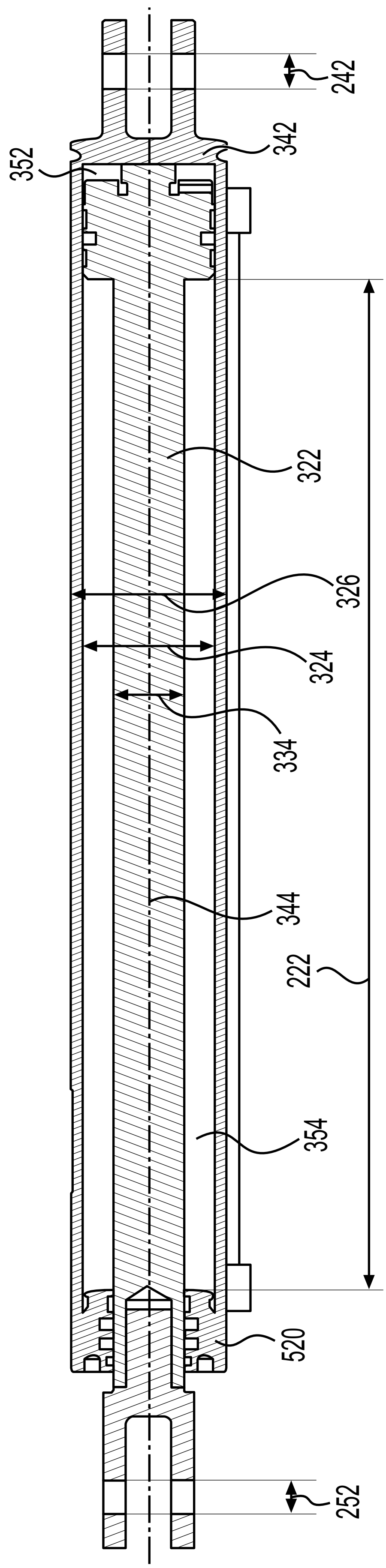

FIG. 19C

20211102510 12 May 2021

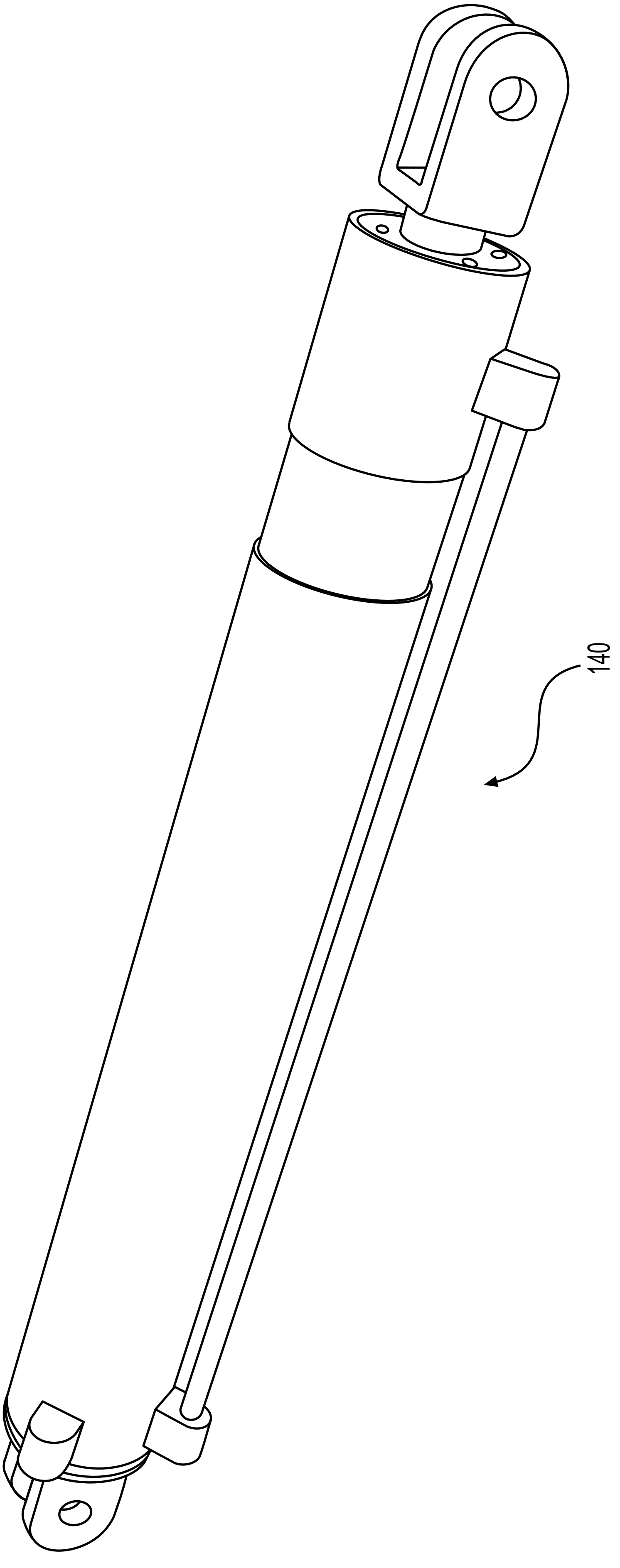

FIG. 20A

20211102510 12 May 2021

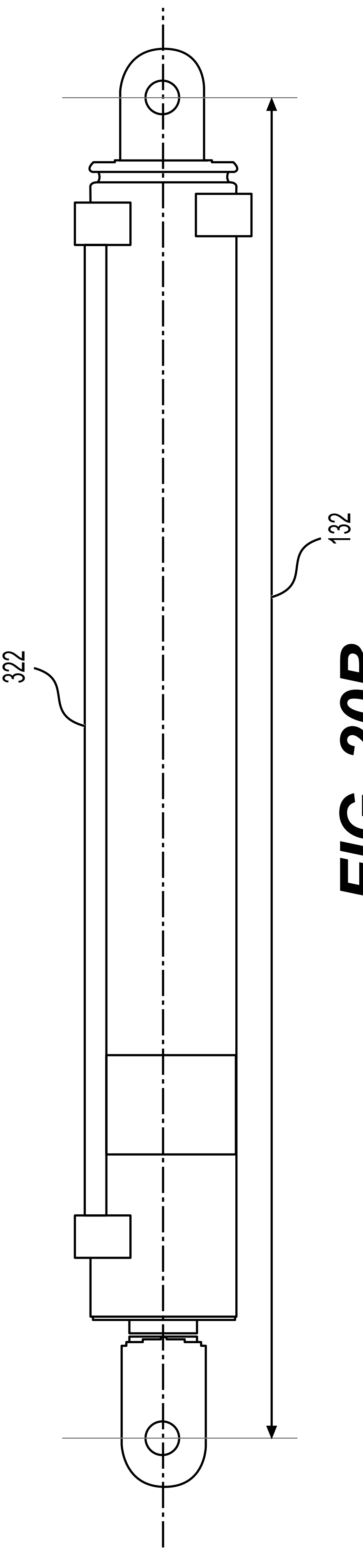

FIG. 20B

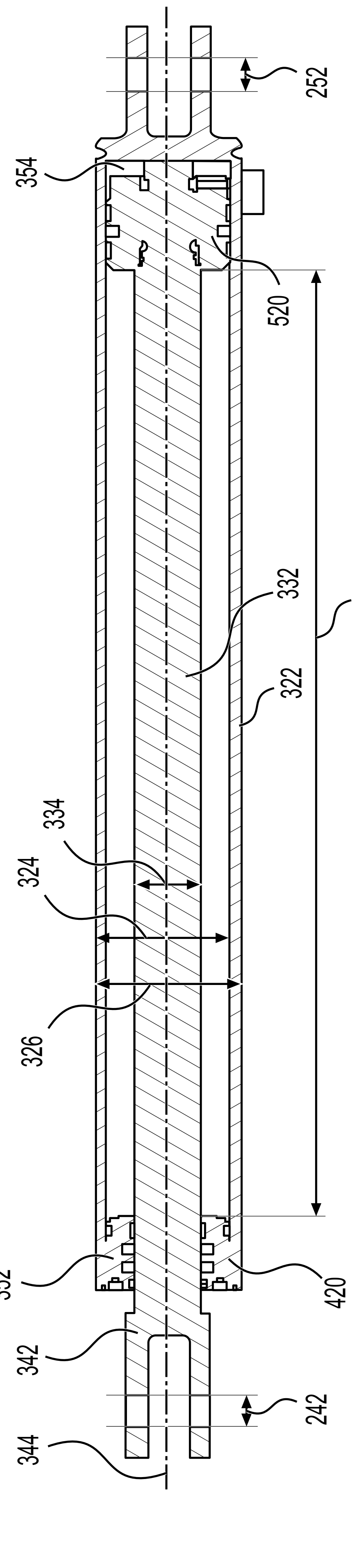

FIG. 20C

20211102510 12 May 2021

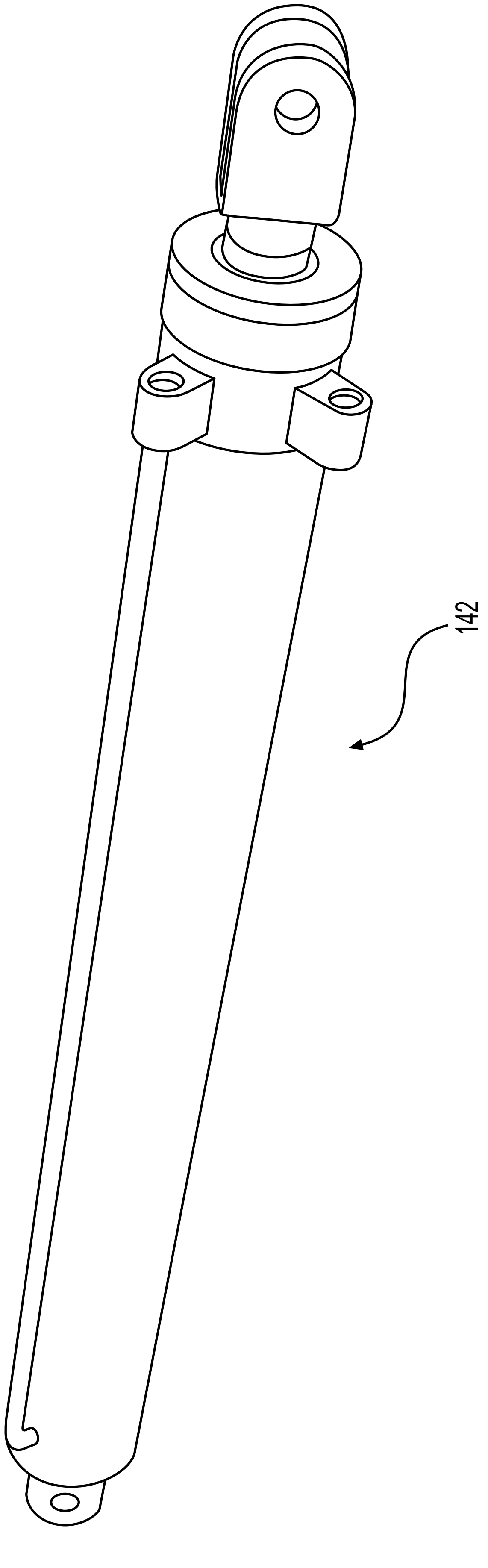

FIG. 21A

20211102510 12 May 2021

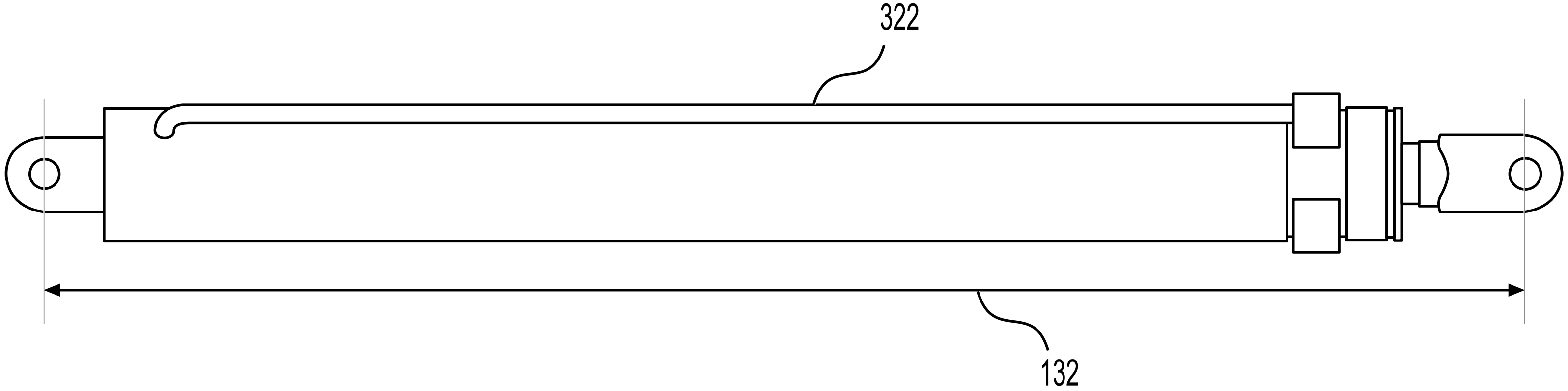

FIG. 21B

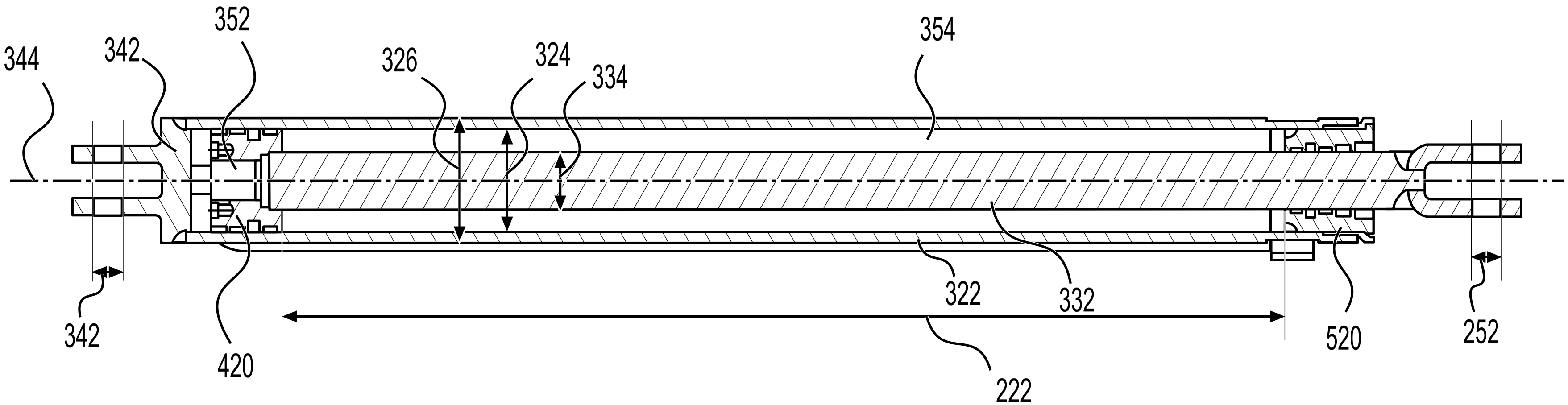

FIG. 21C

20211102510 12 May 2021

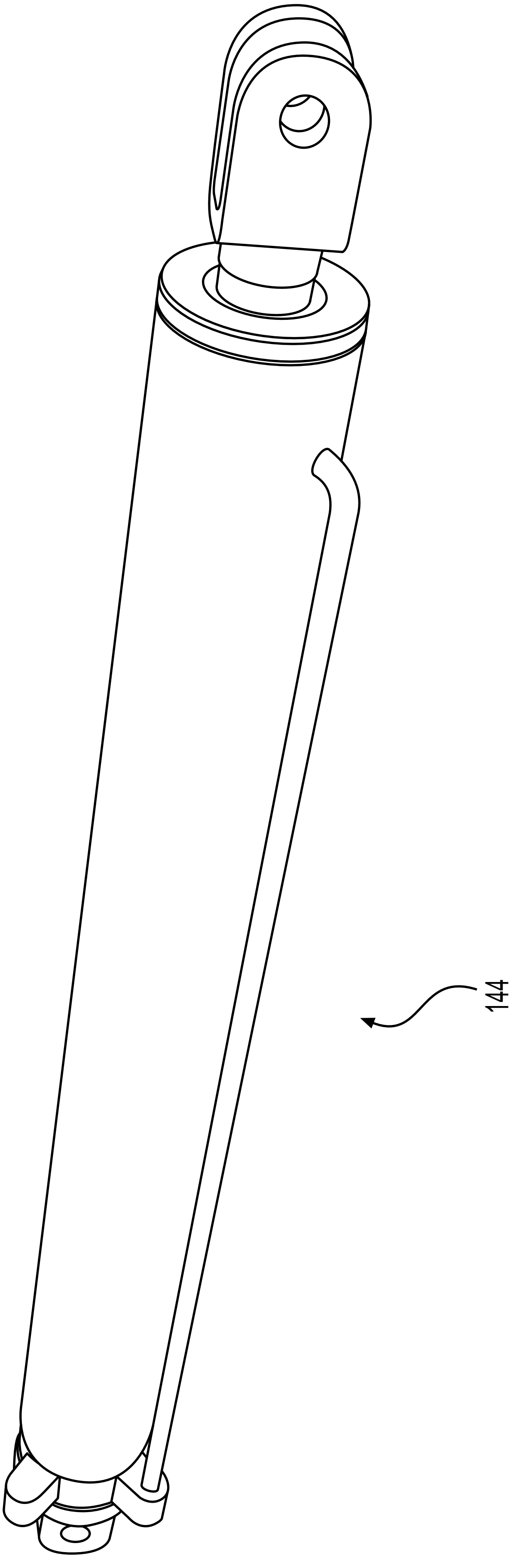

FIG. 22A

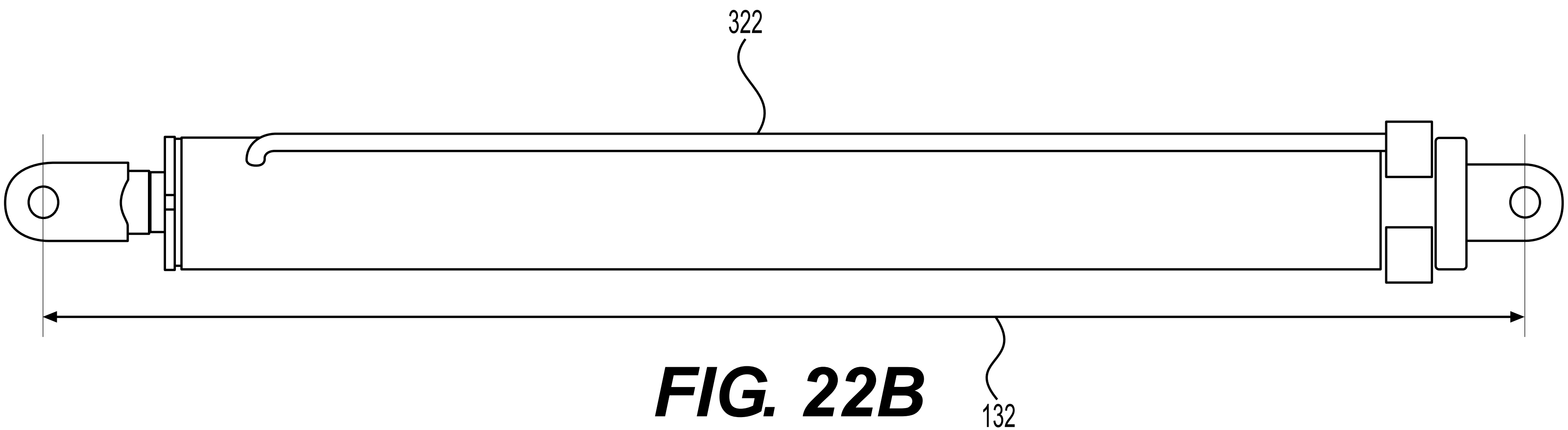

FIG. 22B

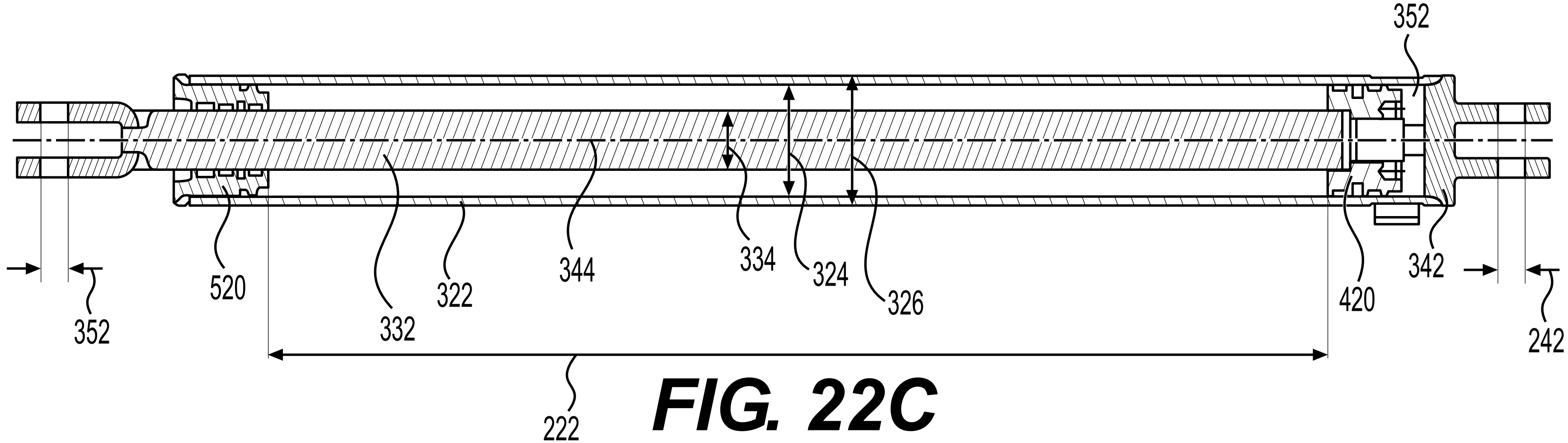

FIG. 22C