(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 December 2007 (06.12.2007)

PCT

(10) International Publication Number
WO 2007/140166 A2

(51) International Patent Classification:
F01B 29/00 (2006.01)

(21) International Application Number:
PCT/US2007/069390

(22) International Filing Date: 21 May 2007 (21.05.2007)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
11/440,708 24 May 2006 (24.05.2006) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *without international search report and to be republished upon receipt of that report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) **Title:** LINEAR ACTUATOR ASSEMBLY

(57) **Abstract:** A linear actuator assembly having a cylinder body and an actuator rod slideably disposed in the cylinder body. The actuator rod has a forward end portion exterior of the cylinder body. An end plug is connected the cylinder body and closes an end portion of the cylinder body. A first retaining member is coupled to the actuator rod and is connectable to a first mounting portion to allow the actuator rod to pivot. A second retaining member removably engages the end plug and the rear end portion of the cylinder body. The second retaining member is connectable to the second mounting portion to allow the cylinder body to pivot about the second retaining member relative to the second mounting portion. The second retaining member retains the end plug within the rear end portion of the cylinder. The end plug can be removed from the cylinder body upon disengagement of the second retaining member from the end plug.

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LINEAR ACTUATOR ASSEMBLY

TECHNICAL FIELD

[0001] This application relates to actuators, and more particularly to linear actuator assemblies.

BACKGROUND

[0002] Conventional personnel lifts and other heavy equipment often use hydraulic or pneumatic linear actuators to control portions of the equipment. Figure 1 is an isometric view of a conventional hydraulic linear actuator of the type used with personnel lift equipment. The linear actuator 1 has a cylinder 2, a piston rod 3 that moves axially in and out of the cylinder, and rigid pivot mounts 4. The rigid pivot mounts are short sections of tube welded onto the cylinder and the rod and precision machined to accept bushings that are added during the assembly of the linear actuators. Other components of the linear actuator are welded together during the assembly process such that the linear actuator is referred to as having a welded construction.

[0003] This welded construction of the conventional linear actuator has several fabrication drawbacks or disadvantages. The welding process imparts internal material stresses that can cause distortion in the components being welded. For example, the cylinder tube may distort or warp to an out-of-round condition when subjected to the welding process. As a result, the internal bore of the cylinder tube may need to be re-machined, honed and/or polished, thereby adding to the cost of the assembly. Welds are also susceptible to stress corrosion cracking, which may result in leakage and loss of hydraulic fluid. The stress corrosion cracking also limits the repair options to those that do not involve re-welding the damaged area, because the heat from additional welding may damage internal bearings, bushings, or seals. The additional welding can also impart component distortion, which may result in binding or excessive wear during operation of the linear actuator. The welded construction also greatly limits the ability to substantially disassemble the linear actuator, or the ease with which it can be done, such as for maintenance, repair, or service of some of the components.

[0004] The linear actuator may also be susceptible to binding if great care is not taken during the manufacturing process to achieve proper alignment of the components. For example, each of the rigid pivot mounts welded to the cylinder and actuator rod is configured to receive a mounting pin that secures the linear actuator to the equipment, while allowing the cylinder and/or piston rod to pivot relative to the device to which the respective pivot mount is attached. The piston rod and the cylinder, however, only move linearly relative to each other. Accordingly, the rigid pivot mounts must be welded or otherwise securely connected in a perpendicular orientation relative to the cylinder and/or the piston rod.

[0005] Misalignment of the rigid pivot mounts and/or mating structure mounts can result in misalignment and binding between the cylinder and the piston rod during the rod's linear stroke. Such a construction process is labor-intensive, time-consuming, and requires relatively forgiving tolerances that accommodate for some misalignment during manufacturing. Failure to allow for misalignment may also result in the linear actuator assembly experiencing significant adverse physical stresses, resulting in poor performance, bearing and/or seal failure, and perhaps shortened component life.

[0006] Conventional linear actuators typically also utilize several bushings and bearing assemblies between moving components. For example, linear actuators typically include front and rear cylinder pivot bushings, and internal bearings in the cylinder, to facilitate axial movement of the actuator rod. Dual-direction actuators also typically utilize a front gland bushing to facilitate axial movement of the actuator rod relative to a front gland. These bushings and bearings are additional components that must be properly assembled in the linear actuator during the assembly process, thereby adding to the complexity and cost of manufacturing a conventional linear actuator. The bushings and bearings are also additional components that can be subjected to stresses and excessive wear if proper alignment is not maintained in the linear actuator.

[0007] Linear actuators often utilize complex couplers to try to compensate for some misalignment between the moving components of the linear actuator. For example, a conventional coupler can have a first part fixedly attached to an end of the actuator rod. A second part of the coupler is attached to the first part with a joint structure or other relatively complex mechanism that allows the second part to move relative to the first part to compensate for some misalignment in the linear actuator. These couplers add to the weight, complexity, required installation space and cost of manufacturing the linear actuators.

[0008] Conventional hydraulic and pneumatic linear actuators are also typically controlled by the flow of fluid to and from the actuators via conduits. The flow rate, direction, pressure, etc., of the fluid is typically controlled by a plurality of valves in a manifold or otherwise mounted remotely from the linear actuator. However, this valve arrangement has drawbacks. The greater the distance between the control valve or valves and the actuator, the slower will be the actuators' motion response. This is due to the compressibility of the fluid contained within the conduits that connect the valves to the actuator. For example, when an operator activates one or more valves to control the fluid that moves the linear actuator there is a proportional time delay till the actuator actually moves.

[0009] Another drawback of the valve manifold arrangement is its complexity. If one of several linear actuators is not operating correctly, due to a control valve problem, the process to identify the malfunctioning valve among many within a single manifold block can be problematic and time consuming, which increases the amount of time that the vehicle or other unit is out of service. Accordingly, there is a need for an improved linear actuator assembly.

SUMMARY

[0010] The present invention provides a linear actuator assembly that overcomes drawbacks experienced in the prior art and provides additional benefits. In one embodiment, a linear actuator assembly is connectable to first and second mounting portions. The linear actuator assembly comprises a cylinder body having an interior area and a rear end portion positionable adjacent to the second mounting portion. An actuator rod is slideably disposed in the cylinder body. The actuator rod has a forward end portion exterior of the cylinder body and is positionable adjacent to the first mounting portion. An end plug closes the rear end portion of the cylinder body.

[0011] A first retaining member is coupled to the forward end portion of the actuator rod and is connectable to the first mounting portion to allow the actuator rod to pivot about the first retaining member relative to the first mounting portion. A second retaining member removably engages the end plug and the rear end portion of the cylinder body. The second retaining member is connectable to the second mounting portion to allow the cylinder body to pivot about the second retaining member relative to the second mounting portion. The second retaining member retains the end plug within the rear end portion of the cylinder. The end plug can be slideably removed from the cylinder body upon disengagement of the second retaining member from the end plug.

[0012] Another embodiment provides an a linear actuator assembly connectable to first and second mounting portions, the first mounting portion being moveable relative to the second mounting portion. The assembly has a cylinder body with an interior area and a rear end portion positionable adjacent to the second mounting portion. An actuator rod is moveably disposed in the cylinder body. The actuator rod has a forward end portion exterior of the cylinder body and positionable adjacent to the first mounting portion. An end plug is connected to the rear end portion of the cylinder body. The end plug has a weldless interface with the cylinder body and closes the rear end portion of the cylinder body. A first retaining member is coupled to the forward end portion of the actuator rod and is connectable to the first mounting portion to allow the actuator rod to pivot about the first retaining member relative to the first mounting portion. A second retaining member removably engages the end plug and is connectable to the second mounting portion to allow the cylinder body to pivot about the second retaining member relative to the second mounting portion, wherein the end plug can be removed from the cylinder body.

[0013] Another embodiment provides an articulatable assembly, comprising first and second members articulatable relative to each other. The first member has a first mounting portion and the second member has a second mounting portion. An actuator assembly is connected to the first and second members. The actuator assembly comprises a cylinder body having an interior area, and a shaft disposed in the cylinder body. The shaft has a free end portion exterior of the cylinder body. An end plug is removably connected to the cylinder body and plugs a portion of the interior area.

[0014] A first retaining member is coupled to the free end portion of the shaft and connected to the first mounting portion. The first retaining member is configured to allow the shaft to pivot relative to the first mounting portion about a longitudinal axis of the first retaining member. A second retaining member removably retains the end plug in the portion of the cylinder body. The second retaining member is connected to the second mounting portion and is configured to allow the cylinder body to pivot relative to the second mounting portion about a longitudinal axis of the second retaining member. The end plug can be removed from the portion of the cylinder body upon disengaging the second retaining member from the end plug. The foregoing and other aspects of the invention will now be described in more detail with reference to the accompanying drawings. This Summary section is provided to introduce in a simplified manner aspects and features further described below in the Detailed Description section and illustrated in the figures. This Summary section is not intended to limit the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Figure 1 is an isometric view of a conventional hydraulic linear actuator assembly.

[0016] Figure 2 is an isometric view of a linear actuator assembly in accordance with an embodiment of the present invention.

[0017] Figure 3 is an isometric view of the linear actuator assembly of Figure 2 shown with spacers and mounting pins.

[0018] Figure 4 is a cross-sectional view of the linear actuator assembly of Figure 2 taken substantially along lines 4-4.

[0019] Figure 5 is an isometric view of a piston rod shown removed from the linear actuator assembly of Figure 2.

[0020] Figure 6 is an enlarged cross-sectional view of a front end portion of the linear actuator assembly of Figure 4.

[0021] Figure 7 is a side elevation view of a front end portion of a linear actuator assembly in accordance with another embodiment.

[0022] Figure 8 is a cross-sectional view of the front end portion of the linear actuator assembly taken substantially along lines 8-8 of Figure 7.

[0023] Figure 9A is an enlarged cross-sectional view of a rear end portion of the linear actuator assembly of Figure 4 with an internal valve in a closed position.

[0024] Figure 9B is an isometric view of a rear end portion of a linear actuator assembly in accordance with another embodiment.

[0025] Figure 9C is a cross-sectional view of the rear end portion of the linear actuator assembly taken substantially along lines 9C-9C.

[0026] Figure 9D is an isometric view of the end plug shown removed from the cylinder of the linear actuator assembly of Figure 9B.

[0027] Figure 10 is an enlarged side elevation view of an end plug shown removed from the linear actuator assembly of Figure 9.

[0028] Figure 11 is an isometric view of a poppet of an internal valve shown removed from the end plug of the linear actuator assembly of Figure 10.

[0029] Figure 12 is a cross-sectional view of the rear end portion of the linear actuator assembly of Figure 9 with the internal valve in an open position.

[0030] Figure 13 is an isometric view of a linear actuator assembly in accordance with another embodiment of the present invention.

[0031] Figure 14 is a cross-sectional view of the linear actuator assembly of Figure 13 taken substantially along lines 14-14.

[0032] Figure 15 is an enlarged cross-sectional view of the forward portion of the linear actuator assembly of Figure 14.

[0033] Figure 16 is a cross-sectional view of a linear actuator assembly with formed-in-place seals in accordance with another embodiment of the present invention.

[0034] Figure 17 is an isometric view of a vehicle having at least one linear actuator assembly in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0035] Embodiments of the present invention include linear actuator assemblies, including hydraulic linear actuators and pneumatic linear actuators, along with methods for using the actuators. Several specific details of the invention are set forth in the following detailed description and in Figures 2-17 to provide a thorough understanding of embodiments of the invention. One skilled in the art, however, will understand that the present invention may have additional embodiments, and that other embodiments of the invention may be practiced without one or more of the specific features described below. In other instances, well-known structures, materials, or operations are not shown or described in order to avoid obscuring aspects of the invention.

[0036] Figure 2 is an isometric view of a linear actuator assembly 10 in accordance with an embodiment of the present invention. The linear actuator assembly 10 is a ram-style actuator having an actuator rod 12 slideably disposed at least partially within a cylinder 14. The actuator rod is shown in a retracted position and is movable relative to the cylinder between extended and retracted positions. The cylinder is sealably closed without the use of welding at its rear end portion 16 by an end plug 90. A valve system 20 extends through the rear end portion of the cylinder and one or more valves 22 may be disposed in the end plug. The valves are configured to control the flow of a driving fluid, such as hydraulic or pneumatic fluid, that controls the movement of the actuator rod relative to the cylinder between the extended and retracted positions.

[0037] The linear actuator assembly 10 of the illustrated embodiment is configured such that neither the cylinder nor the actuator rod is subjected to welding during the manufacturing and/or assembly process. In other words, none of the components are welded together during the assembly of the linear actuator. Accordingly, the linear actuator assembly can be of non-welded construction. This non-welded construction provides significant benefits. By not welding the components together, the components are not subject to distortion, warping, or other side effects of welding. Thus, the cylinder and/or actuator rod do not require secondary machining, honing, or polishing to correct for the side effects of welding in an effort to maintain proper alignment and operation of the components of the assembly. Post assembly distortion due to retained weld stress is eliminated. The non-welded construction is significantly less labor-intensive, thereby significantly reducing the manufacturing cost of the linear actuator assembly. Other, non-metallic materials can also be employed. This construction can also allow the assembly to be easily and quickly disassembled and/or reassembled as needed for service and maintenance. As discussed in greater detail below, the linear actuator assembly is configured so that it has fewer parts, is much easier to assemble and disassemble, is lighter, has a lower profile, and is easier to maintain and/or repair than a conventional linear actuator assembly. The linear actuator assembly is also configured so that the cylinder and the actuator rod are automatically held together and in alignment upon mounting the assembly via the mounting pins to a structure (e.g., a lift assembly) that will be moved via the actuator assembly. Accordingly, additional components used to hold conventional linear actuator assemblies together are eliminated, thereby reducing the complexity, weight, size, and cost of the linear actuator assembly.

[0038] The linear actuator assembly 10 of the illustrated embodiment also includes an aperture 24 that extends through the rearward end of the cylinder and through the end plug substantially perpendicular to the linear actuator's longitudinal axis 32. The aperture pivotably receives a mounting pin 26 (shown in phantom lines) that securely mounts to a portion of the equipment or device onto which the linear actuator assembly is mounted. The opposite end of the linear actuator assembly includes an aperture 28 extending through a front end portion 30 of the actuator rod substantially perpendicular to the linear actuator assembly's longitudinal axis. The aperture in the actuator rod pivotably receives another mounting pin 26 that attaches the front end of the linear actuator assembly to another portion of the equipment or device onto which the linear actuator assembly is mounted. The perpendicular orientation of the apertures 24 and 28 relative to the longitudinal axes of the cylinder and the actuator rod is relatively easy to achieve during the manufacture of the components, thereby substantially avoiding the risk of binding due to misalignment of the cylinder and/or the actuator rod.

[0039] In one embodiment illustrated in Figure 3, the linear actuator assembly 10 can include front spacers 34 that extend over the forward mounting pin 26 and are positioned adjacent to the front end portion 30 of the actuator rod 12. Rear spacers 36 can also be provided that extend over the rear mounting pin and are positioned on opposite sides of the rear end portion of the cylinder. The front and rear spacers of the illustrated embodiment are shaped and sized so a conventional U-joint (not shown) used on equipment can be mounted to the forward and rear mounting pins and properly oriented relative to the front and rear portions of the linear actuator assembly. The spacers prevent unwanted lateral motion of the linear actuator assembly relative to the conventional U-joint. In other embodiments, different sized spacers can be used for fitting the linear actuator assembly into place on a selected piece of equipment or device. In other embodiments, as shown in Figure 2, spacers are not provided when not needed.

[0040] Figure 4 is a cross-sectional view taken substantially along line 4-4 of Figure 2 showing the actuator rod 12 in the retracted position relative to the cylinder 14. The cylinder of the illustrated embodiment is a tubular member having a front end portion 38 opposite the rear end portion 16. The cylinder has an interior area 40 defined by an inner surface 42, which has a substantially constant inner diameter (ID). The cylinder is sized such that, when the actuator rod is in the fully retracted position, as shown in Figure 4, a front end 44 of the actuator rod is exterior of the cylinder's interior area. The inner diameter of the cylinder substantially corresponds to the outer diameter (OD) of the actuator rod such that the actuator rod can slide along the inner surface of the cylinder as the actuator rod moves axially between the retracted and extended positions.

[0041] The cylinder of the illustrated embodiment is constructed of a machined and polished metal tube capable of withstanding the pressures generated by the driving fluid within the interior area without any substantive or plastic deformation of the tube's cylindrical shape. The cylinder can be machined or otherwise formed to provide a straight, round, and smooth inside surface. As indicated above, the linear actuator assembly is constructed so that none of the actuator's components are welded to the cylinder, thereby avoiding the heat, warping, distortion, or other drawbacks experienced by the prior art. The cylinder of the illustrated embodiment can be made of steel, alloys, or other suitably durable material.

[0042] Figure 5 is an isometric view of the actuator rod 12 shown removed from the linear actuator assembly 10 of Figure 4. The illustrated actuator rod is a rigid member, such as a metal rod, having a substantially constant outer diameter, such that the actuator rod's outer surface 46 slides along the inner surface of the cylinder (Figure 4), and the inner surface of aperture 56 pivots about the external surface of pin 26. The actuator rod of the illustrated embodiment has a bearing surface coating 46 that slides against the inner surface of the cylinder (Figure 4), and the outer surface of pivot pin 26 (Figure 5) without substantial frictional losses. In the illustrated embodiment, the bearing surface coating 46 is provided by coating a steel rod and rod aperture 56 with a lubricious material 48, such as an electroless nickel plus thirty percent Teflon (i.e., PTFE) impregnation. In another embodiment, the inside surface of the cylinder 14 (Figure 4) and the exterior surface of pivot pin 26 (Figure 5) may be provided with a coating of the lubricious material, and in yet another embodiment, the actuator rod 12, pivot pin 26 and the cylinder 14 can be provided with a coating of the lubricious material. The coating provides corrosion protection and provides a low friction bearing surface along the length of the actuator rod that remains within the cylinder. Accordingly, the linear actuator assembly of the illustrated embodiment is a bearingless assembly, because additional bearing components are not used between the actuator rod and the cylinder while still allowing for smooth, efficient, and effective axial movement of the actuator rod within the cylinder 14 (Figure 4), and pivotal motion between rod aperture 56 and pivot pin 26 (Figure 5) under working loads.

[0043] While the above embodiments use a coating impregnated or otherwise applied to the outside of a shaft (e.g., the actuator rod), or the inside of the cylinder, or both, other coating materials, impregnation processes, or materials of the rod can be used to achieve the low friction engagement between a shaft and the cylinder, thereby eliminating the need for additional bearing assemblies. This bearingless linear actuator assembly 10 has a reduced exterior size because a smaller diameter cylinder can be used with the actuator rod, thereby providing a "low profile" linear actuator assembly. Further, since a substantive surface length of rod 12 is always in slideable contact with the inner surface 42 of cylinder 14, as seen in Figure 4, a maximum length of bearing surface to rod diameter ratio is maintained. This low profile linear actuator assembly also has fewer components, is lighter weight, and is significantly simpler to manufacture, and as a result, is a less expensive actuator assembly.

[0044] As best seen in Figure 4, a rear end 50 of the actuator rod 12 that remains in the cylinder 14 has a seal 54 mounted in an annular groove 52. The seal is configured to maintain a fluid-tight seal under the fluid pressures in the cylinder's fluid chamber. The seal slideably and sealably engages the inner surface of the cylinder. In one embodiment, the seal is a Parker Hannifin PolyPak™ seal, although other seals can be used to prevent the pressurized hydraulic or other driving fluid from moving forwardly past the rear end of the rod. In one embodiment, the seal is pressed into the annular groove during assembly before the actuator rod is inserted into the cylinder. In another embodiment, the seal can be a "formed-in-place" seal, such as a thermoplastic or other sealant that can be injected or otherwise disposed into the annular groove after the actuator rod is positioned in the cylinder and allowed to cure.

[0045] The front end 44 of the actuator rod includes an aperture 56 that receives a mounting pin (shown in phantom lines) that mounts to the device carrying the linear actuator assembly. The mounting pin allows the actuator rod to pivot relative to the mounting pin and/or the device, so that the actuator rod and the cylinder remain axially aligned as the actuator rod is moved between the extended and retracted positions. In this configuration the front mounting pin has dual functions. The mounting pin acts as a retaining pin that holds the actuator rod in place relative to the device carrying the linear actuator and relative to the cylinder. The mounting pin also acts as a pivot mount that pivotally connects the front of the linear actuator assembly to the device. In one embodiment, the surface defining the aperture 56 in the front end of the actuator rod is coated or otherwise treated with a lubricious material, such as the electroless nickel coating discussed above. In another embodiment, at least a portion of the mounting pin is provided with the lubricious coating that engages the mounting pin to provide the low friction interface between the mounting pin and the actuator rod. This arrangement eliminates the need for front pivot bushings, thereby further reducing the complexity and cost of the linear actuator assembly.

[0046] Figure 6 is an enlarged cross-sectional view of the front end portion of the linear actuator assembly 10 of Figure 4. In the illustrated embodiment, the cylinder 14 has an interior annular groove 58, and a seal 60 is retained in the annular groove. The seal 60 slideably and sealably engages the outer surface 46 of the actuator rod as the actuator rod moves between the extended and retracted positions. The seal 60 can be positioned in the annular groove during assembly before the actuator rod is inserted into the cylinder. In other embodiments, the seal 60 can be a "formed-in-place" seal, such a thermoplastic or other sealant, that can be injected or otherwise disposed into the annular groove after the actuator rod is positioned in the cylinder and allowed to cure. In the event some fluid leaks forwardly past the seal 54 (Figure 4) over time, the front seal 60 blocks any of the leaked fluid from exiting out a front end 66 of the cylinder 14. In the illustrated embodiment, the seal 60 is a resilient, flexible quad-ring, although other seals can be used. One of the benefits of being able to use such a seal 60 at the front end portion is that the cylinder can be a relatively thin-walled cylinder, thereby providing a low-profile, durable assembly.

[0047] In the illustrated embodiment, an overflow port 62 is provided in the cylinder just rearward of the annular groove. A return tube 64 (shown in phantom lines) can be connected to the overflow port to return any of the leaked hydraulic or other driving fluid back to the fluid reservoir. The return tube and the overflow port help ensure that any fluid that makes its way to the front end 66 of the cylinder is not forced past the seal 60.

[0048] The front end of the cylinder also has a bored interior recess 68, and a scraper ring 70 is retained in the recess. The scraper ring has an angled leading edge portion 72 that rides along the outer surface of the actuator rod to scrape off any dirt, debris, or the like that may have gotten onto the rod when it was in the extended or partially extended position. The scraper ring of the illustrated embodiment is constructed of a hard, durable plastic material that will not damage or degrade the outer surface 46 of the actuator rod. Other suitable materials can be used for the scraper ring in other embodiments.

[0049] Figure 7 is a side elevation view of the front end portion of the linear actuator assembly 10 in accordance with another embodiment. Figure 8 is a cross-sectional view of the front end portion of the linear actuator assembly taken substantially along line 8-8 of Figure 7. The linear actuator assembly 10 of this embodiment has an external shaft seal assembly 74 attached to the front end 66 of the cylinder. As best seen in Figure 8, the external shaft seal assembly of the illustrated embodiment has a retaining member 82 connected to a seal portion 78 and to a scraper portion 76. Other embodiments of the seal assembly can include the seal portion and the retaining member without the scraper portion. The retaining member is configured so it fits over and securely attaches to the end of the cylinder along the cylinder's exterior surface so that the seal portion and the scraper portion are coaxially aligned with the cylinder and securely held adjacent to the end of the cylinder. Unlike conventional shaft seals, the external shaft seal can be assembled to smaller housing features. The retaining member of the illustrated embodiment is a "press-on" retainer that is securely press fit onto an exterior mounting surface of the cylinder, although other means of attachment may be employed. Accordingly, when installed, the inner diameter of the seal assembly substantially corresponds to the outer diameter of the exterior mounting surface of the cylinder.

[0050] In the illustrated embodiment, the scraper portion includes a scraper edge 80 positioned forward of the seal portion 78. The scraper portion is a hard plastic ring with an inner diameter that corresponds to the outer diameter of the actuator rod. The seal portion is a spring-loaded lip seal biased radially inwardly to sealably engage the outer surface of the actuator rod. Other embodiments may be used. The press-on retaining member of the illustrated embodiment is an annular sheet metal cap that securely retains the scraper portion and seal portion in position such that the seal assembly can be installed on the end of the cylinder in a single manufacturing step. The seal assembly with the press-on retaining member is attached to the outside of the cylinder and holds the seal portion immediately adjacent to the end of the cylinder, thereby avoiding the need for an internal bore or groove machined into the inside surface of the cylinder.

[0051] In the illustrated embodiments, the frictional engagement of the external shaft seal assembly's press fit connection is such that welds, additional fastening devices or securing mechanisms are not needed. As a result, the seal assembly can be installed on the cylinder fairly quickly and easily. The seal assembly can also be pulled off of the end of the cylinder for repair or maintenance. A replacement seal can be quickly installed if needed by press fitting it on the exterior of the cylinder, thereby minimizing the amount of time the actuator assembly is out of service. The retaining member of other embodiments can be configured to engage a recess, detent, threads, or other retaining feature provided on the outer surface at the end of the cylinder.

[0052] One of the benefits of this seal assembly arrangement is that the seal assembly allows a larger outside diameter seal to be used at the front end of the cylinder without requiring that the cylinder have a thicker wall section to accommodate the seal. In the illustrated embodiment, the seal has a thickness approximately the same (or slightly less than) the thickness of the thin-walled cylinder, thereby maintaining a low profile of the assembly. Other embodiments can use a seal portion having a different thickness. A further benefit of the seal assembly is that it mounts to an external housing feature, so the entire assembly, or portions of the assembly, can be replaced quickly and easily without having to disassemble any other portion of the linear actuator. Another benefit is that the external shaft seal assembly saves space and reduces the weight of the components to which it is affixed.

[0053] The external shaft seal assembly is described in connection with the cylinder of the linear actuator assembly. The seal assembly can also be connected to other structures to create a substantially fluid tight seal against a shaft. As an example, the seal assembly with the seal portion and the retaining member can be used with bearing assemblies, pumps, motors, gear boxes, rods, cylinders or other shaft structures. The seal assembly attaches to the exterior of a structure and securely holds the seal portion (and scraper portion if provided) immediately adjacent to the end of the structure and in engagement with the shaft. Accordingly, a wide range of seal portions could be used without requiring a bore or internal groove within the inside surface of the structure. Accordingly, the structure and shaft assembly can have a lower profile (e.g. a reduced outer diameter) because the wall thickness of the structure does not have to accommodate the internal bore or groove.

[0054] Figure 9A is an enlarged cross-sectional view of the rear end portion of the linear actuator assembly of Figure 4. In the illustrated embodiment, an end plug 90 is positioned within the interior area 40 of the cylinder 14. The end plug 90 can be positioned at least partially within the cylinder, or it can be exterior of the cylinder. Figure 10 is an enlarged side elevation view of the end plug shown removed from the cylinder of Figure 9A. The end plug of the illustrated embodiment is a generally cylindrical member having an outer diameter that approximately corresponds to the inner diameter of the cylinder, such that an outer surface 92 of the end plug frictionally engages the inner surface 42 of the cylinder in a slip or press fit configuration. The illustrated end plug fits snugly into the end of the cylinder such that a rear face 94 of the end plug is substantially co-planar with a rear edge 96 of the cylinder.

[0055] The end plug has an aperture 98 coaxially aligned with an aperture 100 of substantially the same size formed in the cylinder. In the illustrated embodiment, the end plug is securely retained in the cylinder by the friction fit and then by the mounting pin that extends therethrough. No additional structures, fasteners, or securing devices are needed to retain the end plug in position in the cylinder. This configuration of the end plug with the cylinder and the mounting pin has a reduced number of parts, is lighter weight, and is easier and faster to assemble, thereby reducing the manufacturing cost of the linear actuator assembly.

[0056] In this arrangement, the rear mounting pin has dual functions. The mounting pin acts as a retaining pin that holds the end plug in place within the cylinder. The retaining pin function also holds the rear end portion of the cylinder in place relative to the actuator rod. The mounting pin also acts as a pivot mount that pivotally connects the rear of the linear actuator assembly to the device carrying the linear actuator assembly. This arrangement eliminates the need to weld the end plug into place. Accordingly, the cylinder is not subjected to welding and the distortion or warping that can be caused by the heat of welding thereby eliminating the need for re-machining, honing, polishing and other post welding processes to compensate for residual induced stresses. This arrangement also permits easy and complete disassembly and reassembly for service or maintenance.

[0057] The arrangement of the mounting pins with the linear actuator assembly also acts to operatively hold the cylinder and the actuator rod in position and together when they are mounted on the device carrying the linear actuator assembly. When the mounting pins are removed, the actuator rod and cylinder can be pulled apart from each other. The other components of the linear actuator can then be accessed, disassembled, removed, or replaced.

[0058] The aligned apertures 98 and 100 pivotably receive a mounting pin 26 (shown in phantom lines) to allow the rear end portion of the linear actuator assembly to pivot relative to the device carrying the linear actuator assembly. The interior surface of the end plug defining the aperture can be coated with a lubricious material to facilitate the pivoting movement of the mounting pin as the actuator rod moves between the extended and retracted positions. In yet another embodiment, the mounting pin can be provided with a lubricious material or coating thereon so as to provide a low friction interface between the end plug and the mounting pin. In another embodiment, both the end plug and the mounting pin can be provided with the lubricious material or coating. This configuration eliminates the need for rear cylinder bushings while providing a corrosion resistant, low friction interface. Accordingly, the linear actuator assembly has fewer parts, is less complex, easier to assemble and less expensive to manufacture than the prior art.

[0059] As best seen in Figure 9A, a forward portion 102 of the end plug is spaced apart from the rear end portion 50 of the actuator rod to define a fluid chamber 108 that contains the driving fluid used to drive the actuator rod. The front end portion of the end plug includes an annular groove 104 that contains a seal 106. The seal sealably engages the inner surface 42 of the cylinder to prevent the pressurized driving fluid from moving rearwardly past the seal. In the illustrated embodiment, the seal 106 is a Parker Hannifin PolyPak™ seal, although other seals could be used in other embodiments. The seal 106 could also be a "formed-in-place" seal, such as a thermoplastic or other sealant, that can be injected or otherwise disposed into the annular groove after the end plug is positioned in the cylinder.

[0060] The fluid chamber 108 is in fluid communication with a hydraulic or pneumatic power source via a passageway 110 extending through the end plug. The end plug contains valves in the passageway that control fluid flow into or out of the fluid chamber 108 (Figure 9A). The passageway of the illustrated embodiment includes a first portion 112 formed by a contoured through hole that extends substantially perpendicular to the end plug's longitudinal axis. A second portion 114 of the passageway extends forwardly from the first portion parallel with the end plug's longitudinal axis and terminates at a port 111 in fluid communication with the fluid chamber. Each of the first and second portions of the passageway may contain a valve or valves that control the flow of hydraulic or other driving fluid to and from the fluid chamber (Figure 9A).

[0061] In the illustrated embodiment, the first portion of the passageway is aligned with apertures in the cylinder and includes a connection port 116 that removably and sealably retains a connection fitting 118. The connection fitting is coupled to a fluid line 120 that carries the fluid to and from a power source (Figure 4). In the illustrated embodiment, the hydraulic power source includes a tank 121 or other fluid reservoir, a pump 129 and a valve assembly 123. Referring back to Figure 9A, the connection fitting 118 can have external threads that engage internal threads within the connection port. An O-ring seal 119 is provided to prevent leakage of the fluid between the connection fitting and the connection port. The connection fitting sealably engages a lower portion of a valve assembly 122 that extends into the end plug through the passageway's first portion opposite the connection port. The valve assembly has a controllable valve member 126 disposed in the first portion of the passageway. The valve member is adjustable to control the flow rate of fluid through the end plug and into or out of the fluid chamber. By providing control valves within the linear actuator, response time is greatly improved, as compared to actuators of the prior art, where controls valves are some distance away from the actuator. This is because response time is adversely affected by the compressibility of the fluid volume contained within the fluid conduits, between the control valves and the actuator, and the elasticity of the conduits themselves. Accordingly, this valve arrangement substantially eliminates lost motion and/or actuator function delay due to fluid compressibility and conduit elasticity.

[0062] In the illustrated embodiment, the valve assembly is a solenoid valve assembly, although other valve assemblies could be used in other embodiments. The lower portion of the valve assembly of the illustrated embodiment has external threads that engage internal threads within the end plug. Accordingly, the valve assembly can be easily and quickly attached to the cylinder and the end plug, thereby reducing the manufacturing cost of the linear actuator assembly.

[0063] As indicated above, the illustrated actuator is a ram-type actuator, wherein the fluid is driven into the fluid chamber 108 through the passageway 110 in the end plug, and the fluid drives the actuator rod forwardly toward the extended position. The actuator rod returns under the force of gravity along a return stroke back toward the retracted position, so long as the valve assembly allows for the reverse flow of the hydraulic fluid back through the connection fitting and the fluid line. The speed of the actuator rod on the return stroke is limited by a restrictor valve assembly 134 positioned within the second portion of the passageway in the end plug. The restrictor valve assembly allows the full flow into the fluid chamber, while restricting the flow of fluid out of the fluid chamber, thereby restricting the speed at which the actuator rod can return to the retracted position.

[0064] The restrictor valve assembly illustrated in Figure 9A is contained in an enlarged valve chamber 136 of the passageway's second portion forward of a narrower passageway segment 115 that connects to the passageway's first portion. The restrictor valve assembly includes a valve poppet 138 axially movable within the valve chamber, and a biasing member 140 is positioned within the valve chamber. The biasing member engages the poppet to urge the poppet rearwardly toward a closed position. In the closed position the poppet is in sealable engagement with a shoulder 142 defined at the transition between the valve chamber and the narrower passageway segment. In the illustrated embodiment, the biasing member is a coil spring, although other biasing devices can be used in other embodiments. A spring clip 144 is mounted in the forward area of the valve chamber and positioned to provide a surface against which the biasing member can press to react the biasing force exerted against the poppet 138.

[0065] Figure 11 is an enlarged isometric view of the poppet 138 of the restrictor valve assembly shown removed from the end plug of Figure 9A. The poppet has a central orifice 146 therethrough that allows a small flow of fluid to pass through the poppet even when the poppet is in the closed position. The outer portions of the poppet include four outer flow path portions 148 around the perimeter. The flow path portions are symmetrically disposed around the poppet. In the illustrated embodiment, the flow path portions have an arcuate shape and each flow path portion is opposite another one of the flow path portions. The poppet in other embodiments can have other shapes and configurations.

[0066] The poppet of the illustrated embodiment has a maximum diameter slightly less than the inner diameter of the valve chamber (Figure 9A) such that the poppet can move axially within the valve chamber between closed and open positions. The distance between the opposing flow path portions, however, is greater than the diameter of the narrower passageway segment of the flow path's second portion. Accordingly, when the poppet is in a closed position (Figure 9A) and pressed against the shoulder, the flow path portions are radially outward of the opening to the narrower passageway segment, so fluid cannot flow rearwardly around the flow path portions and into the narrower passageway segment. The only flow of fluid rearwardly from the fluid chamber 108 through the restrictor valve is through the small central orifice in the poppet and into the narrower passageway segment. Accordingly, the small central orifice in the poppet limits the rearward flow of fluid, thereby limiting the speed at which the actuator rod can return toward its retracted position.

[0067] Figure 12 is a cross-sectional view of the rear end portion of the linear actuator assembly with the restrictor valve assembly 134 in the open position. As the hydraulic fluid is directed forwardly through the passageway's second portion, the fluid presses forwardly against the poppet 138 so as to compress the biasing member 140 and move the poppet away from the shoulder 142. The poppet's flow path portions allow a flow of the fluid to pass through the valve chamber and around the poppet toward the fluid chamber 108. The two pairs of opposing flow path portions are configured such that the poppet is hydraulically balanced as the fluid flows around the symmetrically disposed flow path portions, so the poppet maintains axial alignment within the valve chamber while moving to or from the open position. As a result, the restrictor valve assembly provides a simple valve mechanism that effectively and accurately controls flow of the fluid into and out of the fluid chamber, thereby controlling the position and speed of the actuator rod's movement relative to the cylinder.

[0068] Referring back to Figure 4, Pump 129 draws fluid from reservoir 121 and delivers the fluid via conduit 125 to valve (or valves) 123 through conduit 120 to linear actuator 10, while blocking any connection to conduit 127. This fluid from conduit 120, extends rod 12. To retract rod 12, via gravity or some other mechanical force, valve (or valves) 123 blocks fluid from pump 129, while opening a connection between conduits 120 and 127 back to tank 121. The valves 123 can be contained in a manifold assembly on a vehicle carrying the linear actuator assembly. In one embodiment, the valves 123 can be configured to control, as an example, fluid pressure, flow rate, and/or flow direction of the driving fluid. The valve manifold assembly on the vehicle can be mounted remote from the linear actuator assembly and coupled thereto by the fluid lines. The valves 123 are coupled to a control system that includes a controller, such as a joystick, that an operator can use to control the valves, thereby controlling the resulting movement of the linear actuator assembly.

[0069] Figure 9B is an isometric view of a rear end portion of a linear actuator assembly in accordance with another embodiment. Figure 9C is a cross-sectional view of the rear end portion of the linear actuator assembly taken substantially along lines 9C-9C of Figure 9B. Figure 9D is an isometric view of the end plug shown removed from the cylinder of the linear actuator assembly of Figure 9C. The end plug 900 is similar to the end plug 90 discussed above except the plurality of control valves 902 are contained in the end plug or connected to the end plug and contained within the cylinder adjacent to the end plug. The control valves are configured to control at least fluid pressure, flow rate, and direction. Accordingly, all of the valves used to control movement of the linear actuator assembly are contained in the end plug or in the cylinder adjacent to the end plug.

[0070] In the illustrated embodiment, the valves 902 are coupled to a fluid supply line 904 and a fluid return line 906, both of which are coupled to a remote tank 908. In the case where the linear actuator is a pneumatic device, line 904 would be coupled to a compressed air power source, and line 906 would be coupled to an exhaust. The fluid supply line 904 is connected to an inlet fitting 910 that extends into the end plug and sealably engages a first portion 914 of a valve housing 912 (Figure 9C) within the end plug. The first portion of the valve housing is in fluid communication with the fluid chamber 108 via the second portion 114 of the fluid passageway discussed above. The fluid return line is connected to a return line fitting 916 that extends into the end plug and sealably engages a second portion 918 of the valve housing (Figure 9C). The second portion of the valve housing is also in fluid communication with the fluid chamber via the second portion of the fluid passageway discussed above.

[0071] As best seen in Figure 9D, the end plug of the illustrated embodiment also contains one or more solenoid valve assemblies 920 mounted in apertures formed in the end plug. The illustrated solenoid valve assemblies 920 are also in fluid communication with the valve housing (Figure 9C) and configured to control the direction, flow rate, and/or pressure of the fluid moving through the valve housing to or from the fluid chamber. The solenoid valve assemblies are connected to an electrical controller via wires 922 that extend through wire grommets 924, although other electrical configurations can be used in other embodiments. The valve housing contains the valves needed to control the fluid (e.g., flow rates, flow direction, pressure, etc.) for operation of the linear actuator assembly such that all the valves are fully contained in the end plug. As a result, the actuator rod will move or otherwise react substantially instantaneously upon activating or adjusting the valves, with no time delay or lag, because the effects of fluid compressibility and componentry elasticity (particularly in hoses and lines connected to remotely located valves) are virtually eliminated. This arrangement provides intrinsic, partial, or complete control of cylinder functionality.

[0072] The end plug 900 with the valves 902 contained therein is removable as a unit from the rear end portion of the cylinder. This arrangement of the valves in the end plug greatly aids in system troubleshooting, because each cylinder contains its own controls. If any of the valves need maintenance or replacement, the fluid supply and return lines 904 and 906 can be disconnected and the end plug assembly with the end plug and integral control valves can be removed as a unit and replaced with a new or different end plug assembly. This replacement of the end plug results in very little downtime for the vehicle, and the replacement process is not labor-intensive. The removed end plug assembly can then be serviced in due course without having to keep the vehicle out of service.

[0073] Another benefit of having the control valves in the end plug is that an operator can quickly and easily troubleshoot and diagnose a situation if a problem occurs with a linear actuator assembly on a vehicle having multiple linear actuator assemblies. Prior art systems often use a complex valve manifold located remote from the conventional linear actuators, and the manifold contains all the valves that control the linear actuators. If any of the multiple linear actuators malfunction, the diagnosis process can be very time-consuming, complex, and labor-intensive. The arrangement in the current embodiments with the end plug and integral control valves avoids the diagnosis complexities because the manifold is eliminated and all of the valves for each linear actuator are contained in that assembly's end plug. Any problem with a linear actuator's valves can be diagnosed by going directly to the linear actuator assembly at issue and troubleshooting the problem for that particular linear actuator.

[0074] Figure 13 is an isometric view of a two-way linear actuator assembly 160 in accordance with another embodiment. Figure 14 is a cross-sectional view of the linear actuator assembly of Figure 13 taken substantially along the lines 14-14. The illustrated linear actuator assembly 160 utilizes fluid pressure to drive an actuator rod 162 in two directions, toward the retracted position (shown in Figure 13) and toward the extended position. The linear actuator assembly includes a cylinder 164 that defines an interior area 165 and is similar to the cylinder 14 discussed above. The cylinder 164 of the illustrated embodiment is also a cylinder as discussed above made of metal or other suitable materials to withstand the operating pressures of the two-way linear actuator assembly. None of the linear actuator assembly's components are welded together during the assembly process.

[0075] The cylinder and the actuator rod have substantially the same construction as described above except that the cylinder's inner diameter is larger than the outer diameter of the actuator rod. As best seen in Figure 14, a piston 166 is securely attached to a rear end portion 168 of the actuator rod such that the piston divides the interior area into front and rear fluid chambers 171 and 173. The outer surface of the piston sealably and slideably engages an inner surface 167 of the cylinder such that the driving fluid is substantially restricted from flowing past the piston between the front and rear fluid chambers. Accordingly, the actuator rod is moved toward the extended position by directing the hydraulic or pneumatic fluid into the rear fluid chamber, while exhausting fluid from the front fluid chamber. The actuator rod is moved toward the retracted position by directing the fluid into the forward fluid chamber, while exhausting fluid from the rear chamber.

[0076] The linear actuator assembly has an end plug 170 that extends into the rear end portion of the cylinder similar to the end plug discussed above. The end plug 170 includes an annular groove 172 that contains a seal 174 that prevents the pressurized fluid within the rear fluid chamber from passing between the cylinder and the end plug. The seal 174 can be a unit pressed into the annular groove before the end plug is inserted into the cylinder, or the seal can be a "formed-in-place" seal injected or otherwise disposed into the annular groove after the end plug is positioned in the cylinder, as discussed above.

[0077] The end plug 170 of the illustrated embodiment includes a protruding connection portion 176 that extends beyond the rear end portion of the cylinder.

The protruding portion has an aperture 178 that pivotably receives the mounting pin 26 (shown in phantom lines in Figure 14). In another embodiment, the end plug can have the same configuration as the end plug 90 discussed above wherein the entire end plug is contained within the rear end portion of the cylinder and coaxially aligned apertures in the end plug and the cylinder receive the mounting pin. As indicated above, the surface defining the aperture in the end plug can be coated with the lubricious material. The mounting pin can also be provided with a coating or layer of the lubricious material, thereby providing a low friction interface between the components while eliminating the need for rear cylinder pivot bushings. The end plug can include a fluid passageway therethrough coupled to fluid conduit lines and a power source and configured to direct hydraulic or other driving fluid into and out of the fluid chambers. In another embodiment, the end plug includes the interior valve assemblies as discussed above that control the flow rate, pressure, and/or direction of the hydraulic fluid into and out of the fluid chambers. Other embodiments can use other fluid lines and valve configurations for the passage of the fluid into and out of the cylinder.

[0078] The linear actuator assembly of the illustrated embodiment includes a front end cap 181 attached to the exterior of the cylinder's forward portion 182, and a front gland 180 positioned in the interior area at the cylinder's forward portion 182. The end cap acts as a retaining device to contain the front gland in the cylinder. The end cap 181 of the illustrated embodiment has internal threads 183 (Figure 14) that mate with external threads 185 on the cylinder's forward portion. Accordingly, the threaded end cap can be easily removed from the cylinder to access the front gland, such as for maintenance or inspection. Other embodiments can use other securing means for retaining the end cap on the cylinder.

[0079] The front gland 180 has an outer diameter that corresponds with the inner diameter of the cylinder, such that the front gland can fit into and frictionally engage the inside surface of the cylinder. The front end of the gland includes a lip 187 that contacts the forward edge of the cylinder and prevents the gland from sliding too far into the cylinder. The end cap securely holds the lip against the forward edge of the cylinder. A rear portion 184 of the front gland has an annular groove 186 that contains a seal 187 therein that sealably engages the inside surface of the cylinder. The seal of the illustrated embodiment is a Parker Hannifin

PolyPak™ seal configured to maintain a seal under the fluid pressures within the cylinder, although other embodiments can use different seals. For example, the seal 187 in other embodiments can be a formed-in-place seal, as discussed above.

[0080] The front gland 180 has a fluid passageway 188 in fluid communication with an aperture 190 formed in the forward portion of the cylinder. The fluid passageway and the aperture are in fluid communication with the front fluid annulus chamber 191 and positioned to allow the driving fluid to move into or out of the forward fluid chamber 171.

[0081] In one embodiment, not shown, a front portion of the front gland includes an annular groove containing a seal that sealably engages the inner surface of the cylinder. Forward of the seal is a retention ring that securely engages the front gland and a retaining groove formed in the inner surface of the cylinder. The retention ring locks the front gland in position within the cylinder and prevents axial movement of the gland during operation of the linear actuator assembly.

[0082] The actuator rod extends through and is slideably disposed through an elongated hole 196 in the front gland. The elongated hole has an inner diameter that corresponds with the outside diameter of the actuator rod such that the outer surface of the actuator rod slideably engages the surface of the front gland defining the elongated hole. The actuator rod of the illustrated embodiment is provided with a lubricious surface (such as a lubricious material discussed above) that provides a low-friction engagement between the actuator rod and the front gland. The lubricious surface of the actuator rod acts as a low-friction bearing surface that supports the actuator rod during movement between the extended and retracted positions. In another embodiment, the front gland can be provided with a lubricious coating or the like that engages the actuator rod sliding through the front gland. This arrangement with the coating of lubricious material on the surface of the actuator rod and/or the inner surface of the gland eliminates the need for a front gland bushing for dual direction cylinders. Accordingly, the linear actuator assembly of the illustrated embodiment has fewer parts, is less complex, is easier to assemble, has a lower profile, is lighter weight, is corrosion-resistant, and is less expensive to manufacture than the prior art.

[0083] The front portion of the gland has an annular groove 200 extending around the elongated hole 196. A seal 202 is contained in the annular groove and sealably and slideably engages the actuator rod 162 and prevents fluid from exiting the forward fluid chamber through the elongated hole 196. The end cap contains a scraper assembly 206 that engages the surface of the actuator rod during movement between the extended and retracted positions.

[0084] The actuator rod has a forward portion 208 that extends forwardly out of the front gland and is exterior of the cylinder. In one embodiment (not shown in Figure 14), the forward portion of the actuator rod includes an aperture that receives a mounting pin, substantially as discussed above. In the illustrated embodiment of Figure 14, the forward portion of the actuator rod has a domed end surface 210 and a hole 212 extending through the actuator rod adjacent to the domed end surface. In the illustrated embodiment, the domed end surface is a convex shape, such as a substantially semi-spherical shape, although other curved or contoured surfaces can be used.

[0085] As best seen in Figures 14 and 15, the actuator rod's forward portion 208 and the domed end surface 210 extend into a receiving pocket 214 formed in a self-aligning coupler 216. The receiving pocket has a concave portion, such as a substantially semi-spherical shape, that generally corresponds to the shape of the actuator rod's convex portion so as to allow some pivotal motion between the self-aligning coupler and the actuator rod's domed end surface. The self-aligning coupler is pivotally connected to the actuator rod's forward portion by a pin 220 that extends through axially aligned holes in the coupler and the actuator rod, although other attachment mechanisms could be used in other embodiments.

[0086] The pin of the illustrated embodiment is press fit into the actuator rod so the pin does not move relative to the actuator rod. The holes in the self-aligning coupler, however, have a slightly larger diameter than the pin, so the self-aligning coupler can pivot about the pin in at least one plane relative to the end of the actuator rod. As seen in Figure 15, in one embodiment, the holes in the self-aligning coupler are sized to be larger than the pin's outer diameter so that the coupler can move in multiple planes relative to the end of the actuator rod. In another embodiment, the pin can be press fit into the holes in the self-aligning coupler. The hole through the actuator rod has a larger diameter than the pin so the pin and self-aligning coupler can pivot and move relative to the end of the actuator rod in one plane or in multiple planes.

[0087] The self-aligning coupler includes an aperture 222 forward of the receiving pocket that pivotally receives the mounting pin 26 (shown in phantom lines) that connects to the device carrying the linear actuator assembly. The self-aligning coupler interconnects the actuator rod and the mounting pin such that the coupler will allow for some pivotal motion of the coupler relative to the mounting pin during operation of the linear actuator assembly. The self-aligning coupler requires less space than conventional alignment devices at least in part because the relative motion is between the coupler and the actuator rod in multiple planes. Accordingly, the end of the actuator rod effectively becomes part of the self-aligning coupling arrangement. This orientation and movement of the self-aligning coupler helps maintain axial alignment of the cylinder and the actuator rod, thereby alleviating binding issues associated with pivot mounts rigidly affixed to the actuator rod. Accordingly, the configuration of the self-aligning coupler prevents and/or reduces stress, excessive wear, and poor performance experienced by conventional linear actuators because of misalignment of the components during assembly or installation. Also, the configuration of the self-aligning coupler of the illustrated embodiment is uncomplicated, requires fewer parts, and is less expensive than prior art alignment systems. The resulting linear actuator assembly is a simple construction that does not sacrifice performance to achieve the simpler and less expensive linear actuator.

[0088] Figure 16 is a cross-sectional view of a linear actuator assembly 160 with formed-in-place seals in accordance with another embodiment. In this embodiment, the inner surface of the cylinder adjacent to the end plug includes a rear annular groove 226 radially aligned with the annular groove 172 in the end plug 170. The cylinder also has one or more injection apertures 228 in communication with the cylinder's rear annular groove and the end plug's annular groove when the end plug is in position in the cylinder. Uncured thermal plastic or other suitable flowable sealing material is injected or otherwise directed through the injection apertures so as to fill the annular space defined by the mating annular grooves. The seal material is allowed to cure or set up, thereby providing a formed-in molded seal that sealably fills and engages the mating annular grooves around the entire end plug. In other embodiments, multiple injection apertures can be used to facilitate the injection and formation of the seals.

[0089] The cylinder of the illustrated embodiment also includes an annular groove 232 formed adjacent to a mating groove 234 in the front gland when the front gland is positioned in the front end portion of the cylinder. A plurality of injection apertures 228 are in communication with the mating annular grooves. Sealing material, such as an uncured thermal plastic material is pressure injected through the injection apertures to fill the space defined by the mating grooves 232 and 234, thereby forming a seal 236 between the front gland and the cylinder. A similar configuration for forming other seals can be provided in other embodiments by incorporating grooves in the inner surface of the cylinder with grooves in the front gland or the end plug and dispensing uncured material, such as thermal plastic or other material, therein and allowing the material to cure so as to form the seal that adheres to all contacted surfaces.

[0090] When cured, the seal forms a permanent seal that crosses over the annular interface between the inner surface of the cylinder and outer surface of the end plug or front gland or other member. The cured material can act to resist movement of the end plug and/or the front gland within the cylinder. The resulting formed-in-place seals provide several benefits over conventional seals. For example, the formed-in-place seals can be formed at a lower cost than conventional seals. In static applications of the formed-in-place seals, surface finish is not a factor for mating seal surfaces. Also, the formed-in-place seals have a higher degree of reliability compared to conventional seals, particularly in static applications.

[0091] The formed-in-place seals of the illustrated embodiment are configured so that they do not irreleaseably lock the end plug or front gland in the cylinder. The end plug or front gland can still be removed from the cylinder, although the seal will be destroyed. The destroyed seal material can be cleaned out of the annular grooves and a replacement seal can be formed in place after the end plug or front gland is inserted back into the cylinder. In another embodiment, the seal is configured to act as a locking device that fixedly retains the end plug or front gland in place in the cylinder. It is noted that in other embodiments, the use of the injected seal material is not limited to static sealing. By matching a singular groove to a release coated straight bore, a dynamic seal can be created between two components with improved performance reliability and lower cost for wide-ranging applications.

[0092] Figure 17 is an isometric view of a vehicle 300 having a plurality of linear actuator assemblies 302 in accordance with an embodiment of the present invention. The vehicle 300 of the illustrated embodiment is a personnel lift having a body 304 mounted to a chassis 306, a proximal boom arm 308, an intermediate boom arm 310, and a distal boom arm 312. A personnel basket 314 is attached to the end of the distal boom arm. Each of the actuator assemblies 302 can have a construction similar to at least one of the linear actuator assemblies described above.

[0093] In the illustrated embodiment, the linear actuator assemblies 302 have a construction similar to the assemblies discussed above and illustrated in Figures 9B, 9C, and 9D, wherein the valves used to control movement of the assembly are contained in the end plug in the cylinder. Accordingly, the vehicle does not need (or include) a conventional complex valve manifold coupled to the body and remote from the linear actuator assemblies. Instead, the fluid supply and return lines 125 and 127 are connected to the linear actuator assemblies. The fluid supply and return lines can have segments daisy-chained together in series or in parallel depending on the configuration needed for movement of the boom arms and/or the personnel basket.

[0094] One of the benefits of this vehicle configuration is that the arrangement of fluid lines in greatly simplified and there is substantially no time delay in moving the actuator rod in response to an operator moving a joystick or other controller. This configuration eliminates the significant time delays that can occur because of the time needed for line pressurization and line swelling that can occur in flexible fluid lines when the valve manifold is remote from the linear actuators. Unlike the prior art, the linear actuator assemblies of the illustrated embodiment with the control valves in the end plug move as soon as the valves are activated in response to the operator's movement of the joystick or other controller. The result is very responsive linear actuator assemblies, thereby providing a very responsive personnel lift or other vehicle or machine.

[0095] From the foregoing, it will be appreciated that specific embodiments of the invention have been described herein for purposes of illustration, but that various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

CLAIMS

I claim:

1. A linear actuator assembly connectable to first and second mounting portions, the first mounting portion being moveable relative to the second mounting portion, comprising:

a cylinder body having an interior area and a rear end portion positionable adjacent to the second mounting portion;

an actuator rod slideably disposed in the cylinder body, the actuator rod having a forward end portion exterior of the cylinder body and positionable adjacent to the first mounting portion;

an end plug positioned at least partially within the rear end portion of the cylinder body, the end plug closing the rear end portion of the cylinder body;

a first retaining member coupled to the forward end portion of the actuator rod and being connectable to the first mounting portion to allow the actuator rod to pivot about the first retaining member relative to the first mounting portion; and

a second retaining member removably engaging the end plug and the rear end portion of the cylinder body, the second retaining member being connectable to the second mounting portion to allow the cylinder body to pivot about the second retaining member relative to the second mounting portion, and the second retaining member retaining the end plug within the rear end portion of the cylinder, wherein the end plug can be slideably removed from the cylinder body upon disengagement of the second retaining member from the end plug.

2. The assembly of claim 1 wherein the second retaining member extends through the end plug and the rear end portion of the cylinder body.

3. The assembly of claim 1 wherein the second retaining member is a mounting pin extending through the end plug and the rear end portion of the cylinder body.

4. The assembly of claim 1 wherein connection of the first retaining member to the first mounting portion and connection of the second retaining member to the second mounting portion hold the actuator rod and cylinder body together and prevent the actuator rod from sliding axially out of the cylinder.

5. The assembly of claim 1 wherein the actuator rod is restricted from separating from the cylinder body when the first retaining member is connected to the first mounting portion and when the second retaining member is connected to the second mounting portion, and the actuator rod being free to slide out of the cylinder body when the first retaining member is disconnected from the first mounting portion and when the second retaining member is disconnected from the second mounting portion.

6. The assembly of claim 1, further comprises a self-aligning coupler pivotally connected to the forward end portion of the actuator rod and being pivotably moveable relative to the actuator rod in a plurality of planes, the first retaining member engaging the self-aligning coupler.

7. The assembly of claim 1, further comprises a self-aligning coupler pivotably connected to the forward end portion of the actuator rod and being moveable relative to the forward end portion of the actuator rod in a plurality of planes, and the first retaining member is connected to the self-aligning coupler.

8. The assembly of claim 1 wherein the end plug has an aperture therein defined by an interior surface of the end plug, the second retaining member being removably positioned in the aperture, at least one of the second retaining member and the interior surface having a lubricious coating that provides a lubricious interface between the retaining member and the interior surface of the end plug.

9. The assembly of claim 1 wherein the end plug has an aperture therein defined by an interior surface of the of the end plug, the second retaining member being removably positioned in the aperture, at least one of the second retaining member and the interior surface being impregnated with a lubricious coating that provides a lubricious interface between the second retaining member and the interior surface of the end plug.

10. The assembly of claim 1 wherein the first retaining member is a mounting pin extending through the forward end portion of the actuator rod.

11. The assembly of claim 1 wherein the forward end of the actuator rod has an aperture therein defined by an interior surface, the first retaining member being removably positioned in the aperture, at least one of the first retaining member and the interior surface having a lubricious coating that provides a lubricious interface between the first retaining member and the interior surface of the actuator rod.

12. The assembly of claim 1 wherein the forward end of the actuator rod has an aperture therein defined by an interior surface, the first retaining member being removably positioned in the aperture, at least one of the first retaining member and the interior surface being impregnated with a lubricious coating that provides a lubricious interface between the first retaining member and the interior surface of the end plug.

13. The assembly of claim 1 wherein at least one of the first retaining member and the first mounting portion has a lubricious coating that provides a lubricious interface therebetween.

14. The assembly of claim 1 wherein the end plug contains a plurality of control valves operable to control movement of the actuator rod relative to the cylinder body.

15. The assembly of claim 1 wherein the cylinder body has an exterior surface, and further comprising an external shaft seal assembly connect to an exterior surface of the cylinder body and sealably engaging the actuator rod.

16. The assembly of claim 1, further comprising a formed-in-place seal engaging the end plug and the cylinder body.

17. A linear actuator assembly connectable to first and second mounting portions, the first mounting portion being moveable relative to the second mounting portion, comprising:

a cylinder body having an interior area and a rear end portion positionable adjacent to the second mounting portion;

an actuator rod moveably disposed in the cylinder body, the actuator rod having a forward end portion exterior of the cylinder body and positionable adjacent to the first mounting portion;

an end plug connected to the rear end portion of the cylinder body, the end plug having a weldless interface with the cylinder body and closing the rear end portion of the cylinder body;

a first retaining member coupled to the forward end portion of the actuator rod and being connectable to the first mounting portion to allow the actuator rod to pivot about the first retaining member relative to the first mounting portion; and

a second retaining member removably engaging the end plug and being connectable to the second mounting portion to allow the cylinder body to pivot about the second retaining member relative to the second mounting portion, wherein the end plug can be removed from the cylinder body.

18. The assembly of claim 17 wherein the second retaining member extends through the end plug and the rear end portion of the cylinder body.

19. The assembly of claim 17 wherein the second retaining member is a mounting pin extending through the end plug and the rear end portion of the cylinder body.

20. The assembly of claim 17 wherein the end plug is at least partially within the rear end portion of the cylinder.

21. The assembly of claim 17 wherein the end plug directly engages the inside surface of the cylinder.

22. The assembly of claim 17 wherein connection of the first retaining member to the first mounting portion and connection of the second retaining member to the second mounting portion hold the actuator rod and cylinder body together and prevent the actuator rod from sliding axially out of the cylinder.

23. The assembly of claim 17 wherein the actuator rod is restricted from separating from the cylinder body when the first retaining member is connected to the first mounting portion and when the second retaining member is connected to the second mounting portion, and the actuator rod being free to slide out of the cylinder body when the first retaining member is disconnected from the first mounting portion and when the second retaining member is disconnected from the second mounting portion.

24. The assembly of claim 17 wherein the end plug has an aperture therein defined by an interior surface of the of the end plug, the second retaining member being removably positioned in the aperture, at least one of the second retaining member and the interior surface having a lubricious coating that provides a lubricious interface between the retaining member and the interior surface of the end plug.

25. The assembly of claim 17 wherein the end plug includes a plurality of control valves operable to control movement of the actuator rod relative to the cylinder body.

26. An articulatable assembly, comprising:

first and second members articulatable relative to each other, the first member having a first mounting portion and the second member having a second mounting portion; and

an actuator assembly connected to the first and second members, the actuator assembly comprising:

a cylinder body having an interior area;

a shaft disposed in the cylinder body, the shaft having a free end portion exterior of the cylinder body;

an end plug removably connected to the cylinder body and closing a portion of the interior area;

a first retaining member coupled to the free end portion of the shaft and connected to the first mounting portion and configured to allow the shaft to pivot relative to the first mounting portion about a longitudinal axis of the first retaining member; and

a second retaining member removably retaining the end plug in the portion of the cylinder body, the second retaining member being connected to the second mounting portion and configured to allow the cylinder body to pivot relative to the second mounting portion about a longitudinal axis of the second retaining member, wherein the end plug can be removed from the portion of the cylinder body upon disengaging the second retaining member from the end plug.

27. The assembly of claim 26 wherein the second retaining member extends through the end plug and the portion of the cylinder body.

28. The assembly of claim 26 wherein the end plug has a first aperture and the cylinder body has a second aperture coaxially aligned with the first aperture when the end plug is in the portion of the cylinder body, and the second

retaining member extends through the first and second apertures to releasably lock the end plug in the portion of the cylinder body.

29. The assembly of claim 26 wherein the second retaining member is a mounting pin extending through the end plug and through the portion of the cylinder body.

30. The assembly of claim 26 wherein a connection of the first retaining member to the first mounting portion and a connection of the second retaining member to the second mounting portion hold the shaft and cylinder body together and prevent the shaft from sliding axially out of the cylinder.

31. The assembly of claim 26 wherein the shaft is restricted from separating from the cylinder body when the first retaining member is connected to the first mounting portion and when the second retaining member is connected to the second mounting portion, and the shaft being separable from the cylinder body when the first retaining member is disconnected from the first mounting portion or when the second retaining member is disconnected from the second mounting portion.

32. The assembly of claim 26, further comprises a self-aligning coupler pivotally connected to the free end portion of the shaft and being pivotably moveable relative to the shaft in a plurality of planes.

33. The assembly of claim 26 wherein the end plug has an aperture therein defined by an interior surface of the of the end plug, the second retaining member being removably positioned in the aperture, at least one of the second retaining member and the interior surface having a lubricious coating that provides a lubricious interface between the retaining member and the interior surface.

34. The assembly of claim 26 wherein the first retaining member is a mounting pin extending through the free end portion of the shaft.

35. The assembly of claim 26 wherein the free end of the shaft has an aperture therein defined by an interior surface, the first retaining member being removably positioned in the aperture, at least one of the first retaining member and the interior surface having a lubricious coating that provides a lubricious interface between the first retaining member and the interior surface.

36. The assembly of claim 26 wherein the end plug contains a plurality of control valves operable to control movement of the shaft relative to the cylinder body.

37. The assembly of claim 26 wherein the end plug contains a plurality of control valves operable to control movement of the shaft relative to the cylinder body, the end plug and the control valves are removable from the cylinder body as a unit.

38. The assembly of claim 26 wherein the cylinder body has an exterior surface, and further comprising an external shaft seal assembly connect to an exterior surface of the cylinder body and sealably engaging the shaft.

39. The assembly of claim 26, further comprising a formed-in-place seal engaging the end plug and the cylinder body.

40. A vehicle, comprising:

a vehicle body;

first and second members coupled to the vehicle body and being articulatable relative to each other, the first member having a first mounting portion and the second member having a second mounting portion; and

an actuator assembly connected to the first and second members, the actuator assembly comprising:

a cylinder body having an interior area;

a shaft disposed in the cylinder body, the shaft having a free end portion exterior of the cylinder body;

an end plug removably connected to the cylinder body and closing a portion of the interior area;

a first retaining member coupled to the free end portion of the shaft and connected to the first mounting portion and configured to allow the shaft to pivot relative to the first mounting portion about a longitudinal axis of the first retaining member; and

a second retaining member removably retaining the end plug in the portion of the cylinder body, the second retaining member being connected to the second mounting portion and configured to allow the cylinder body to pivot relative to the second mounting portion about a longitudinal axis of the second retaining member, wherein the end plug can be removed from the portion of the cylinder body upon disengaging the second retaining member from the end plug.

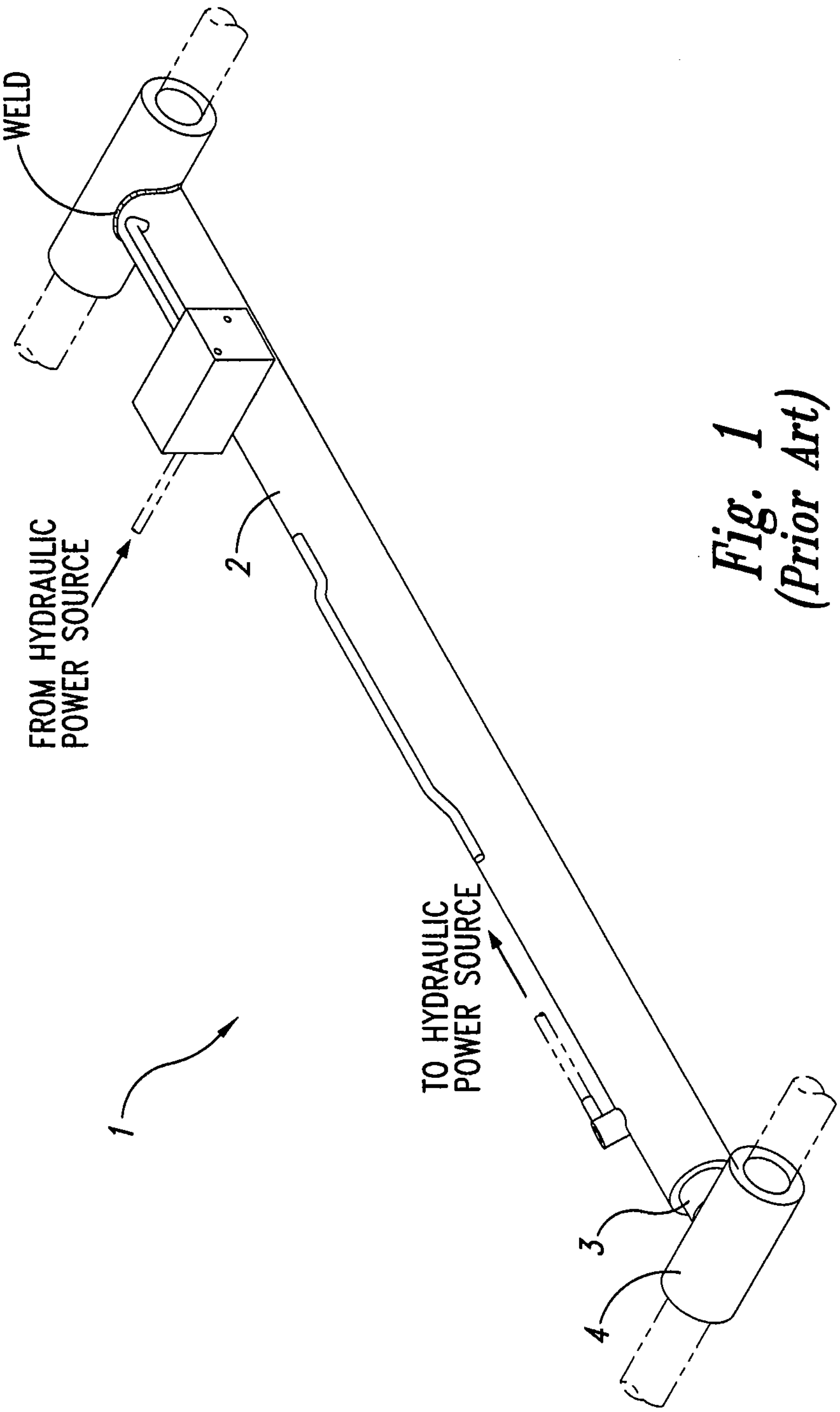

Fig. 1
(Prior Art)

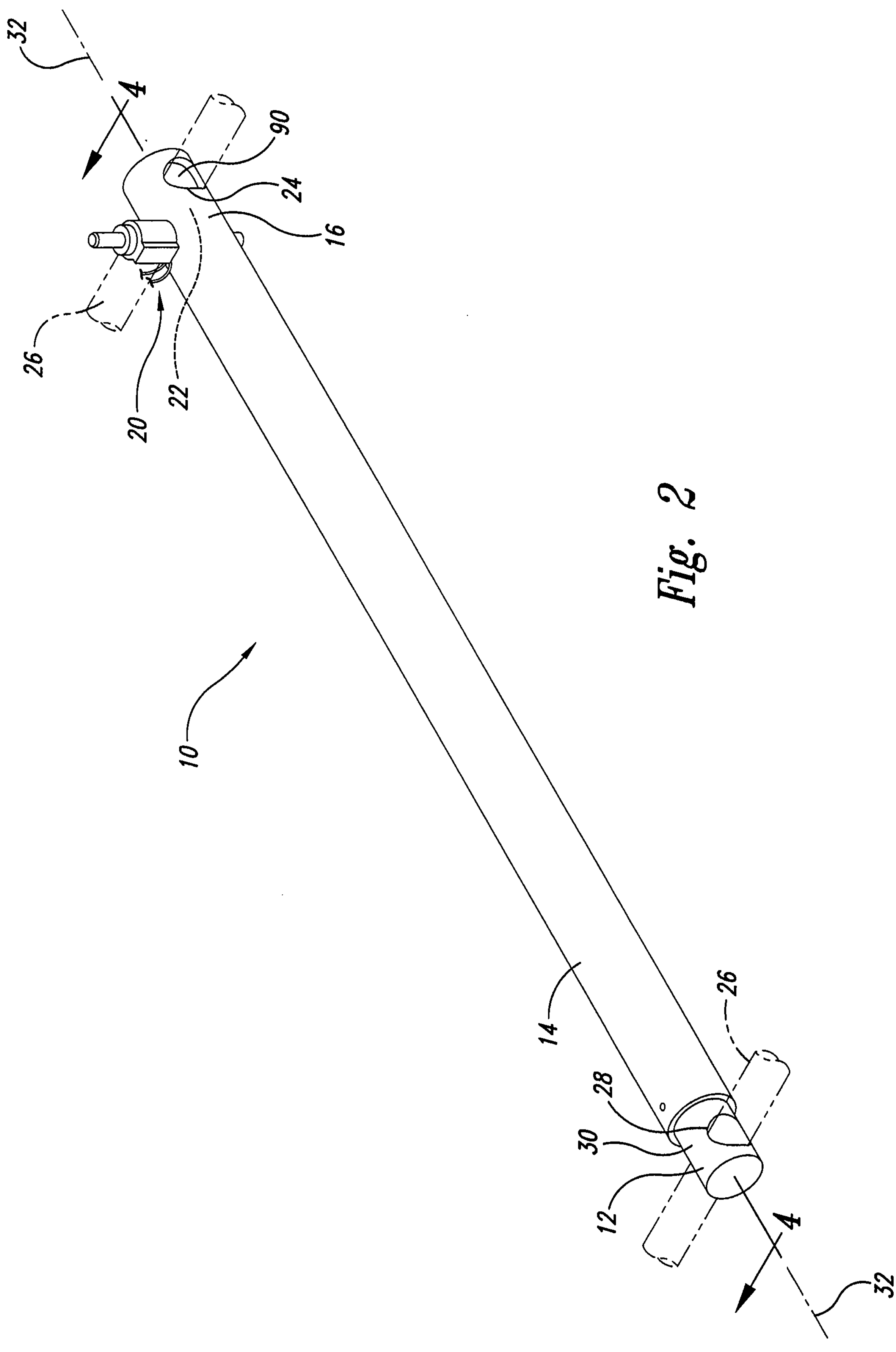

Fig. 2

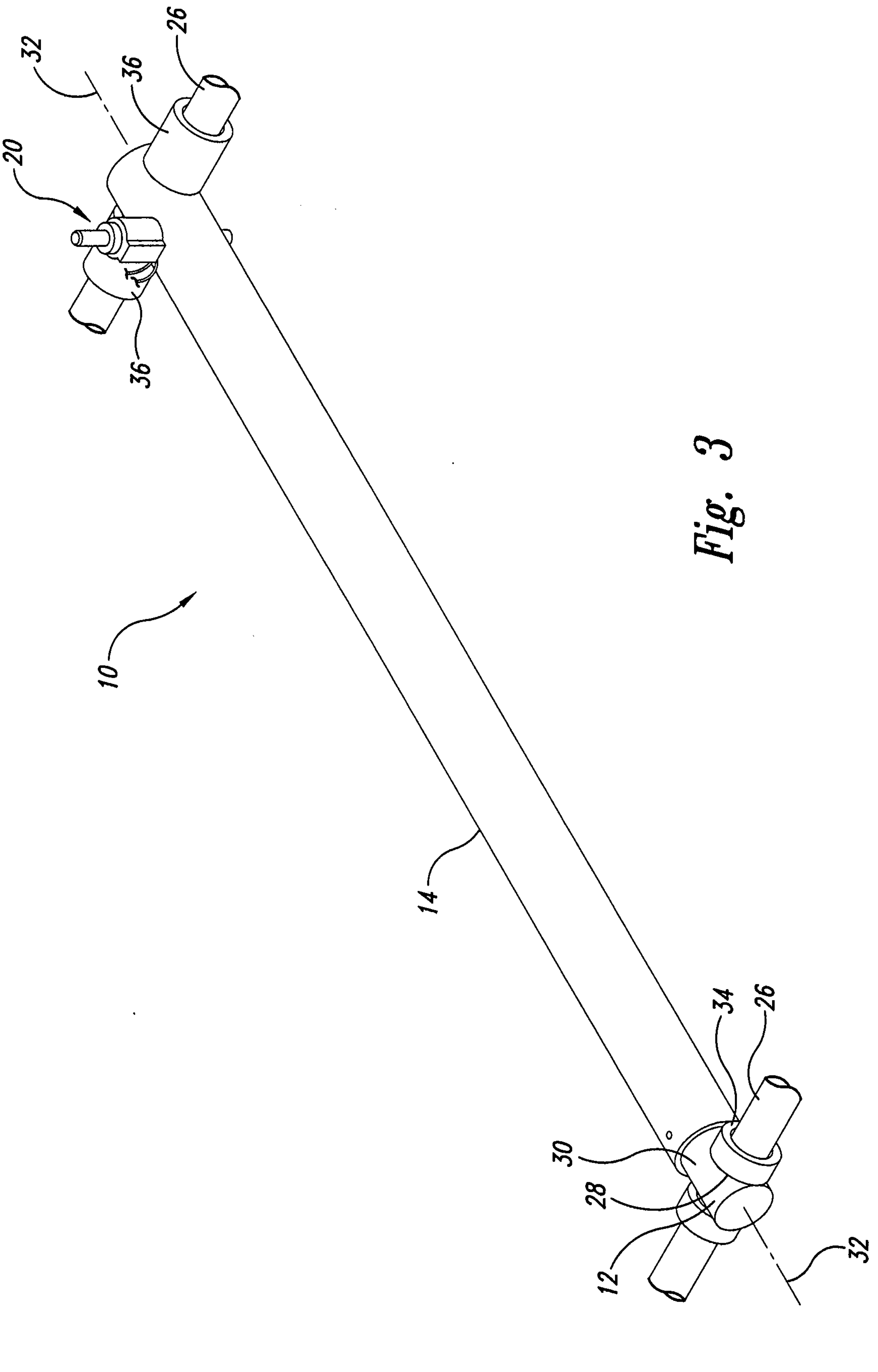

Fig. 3

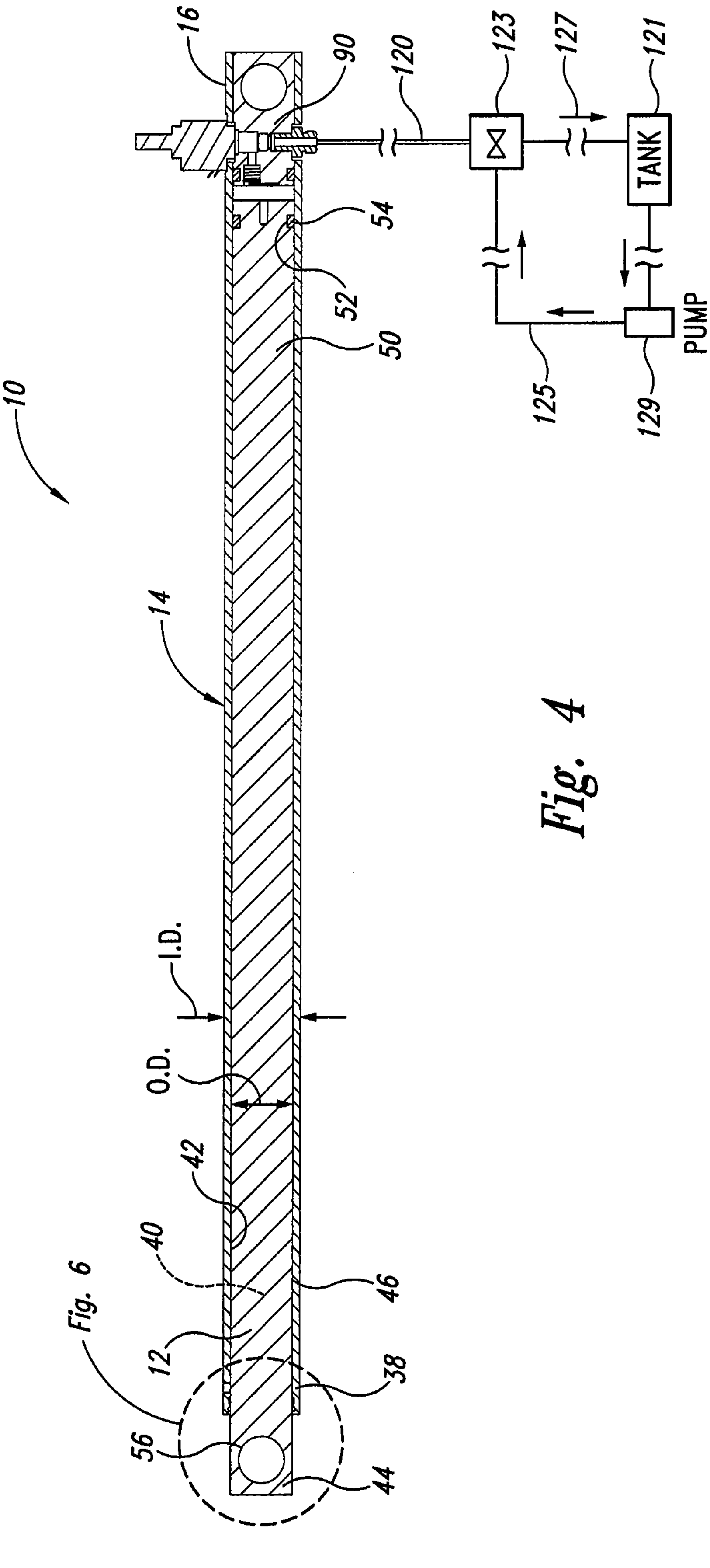
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Fig. 6
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Fig. 4

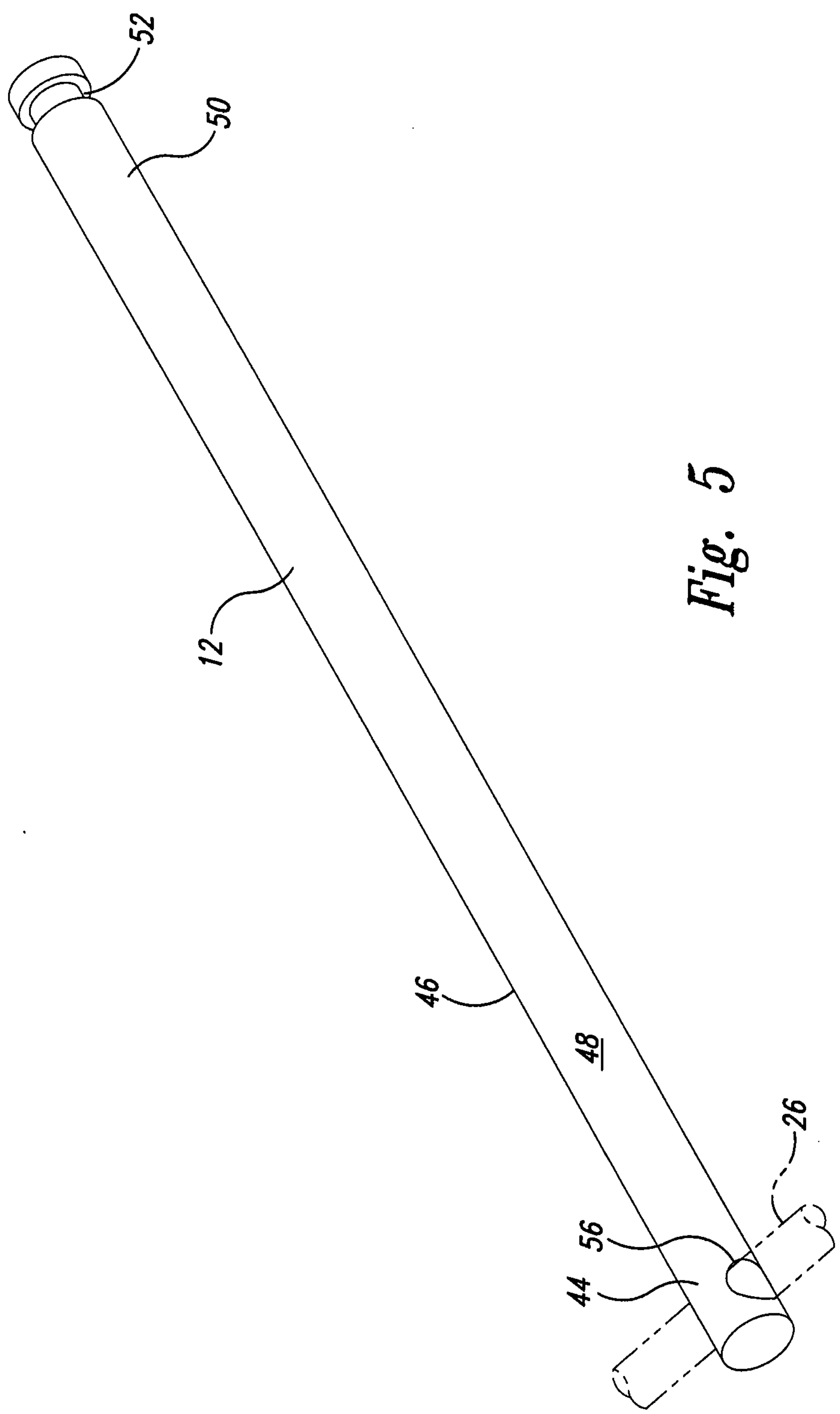

Fig. 5

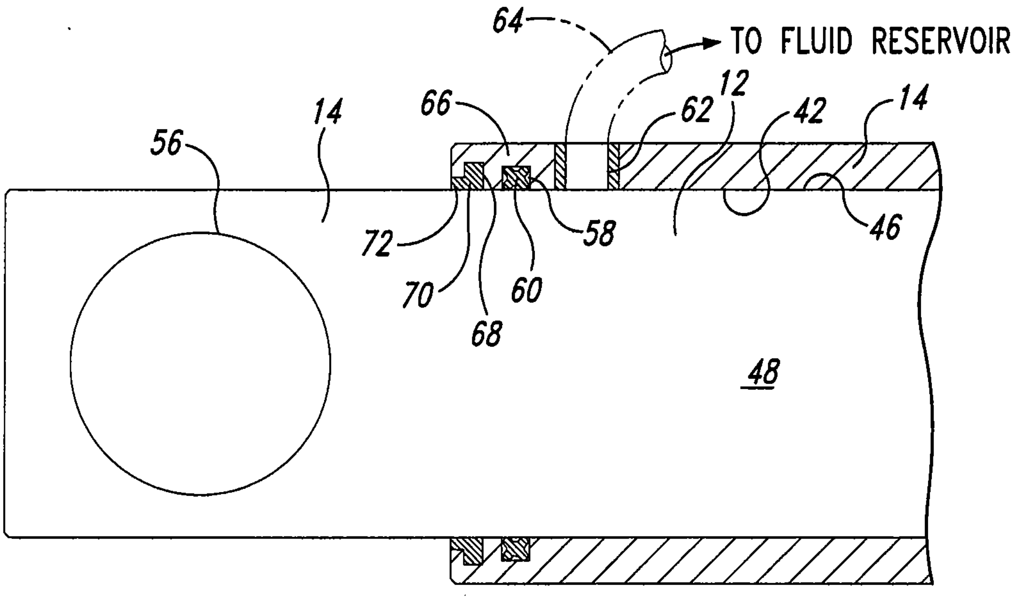
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Fig. 6

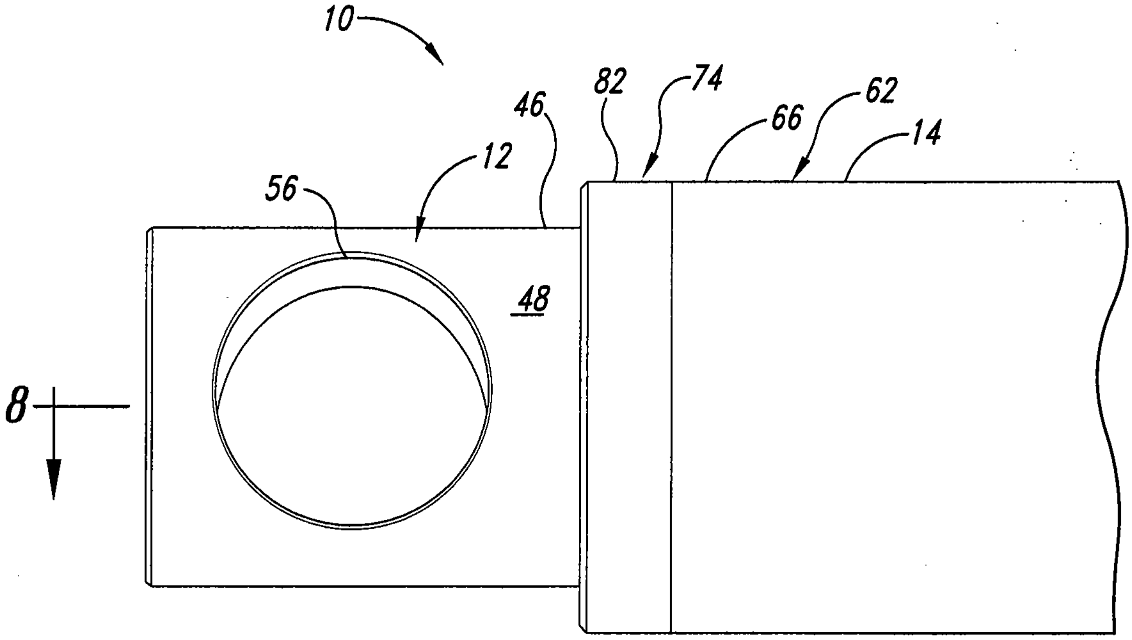
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Fig. 7

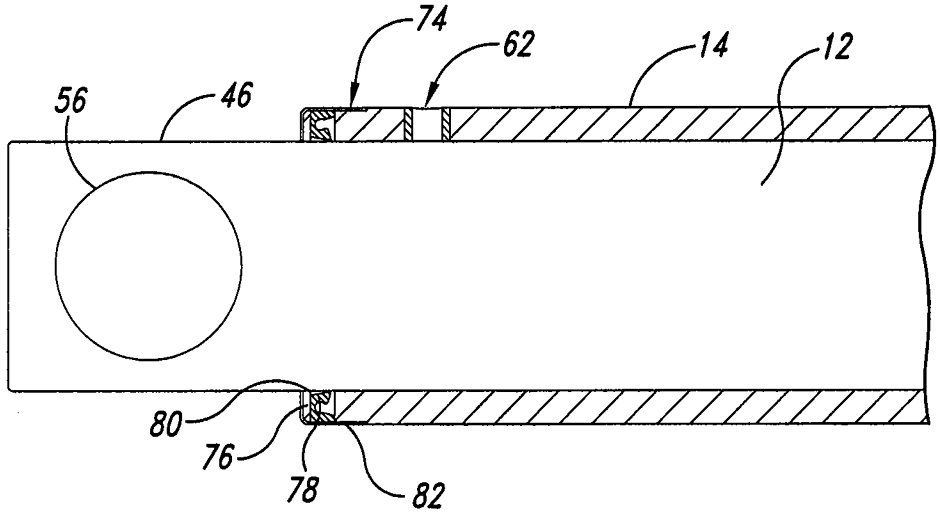
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Fig. 8

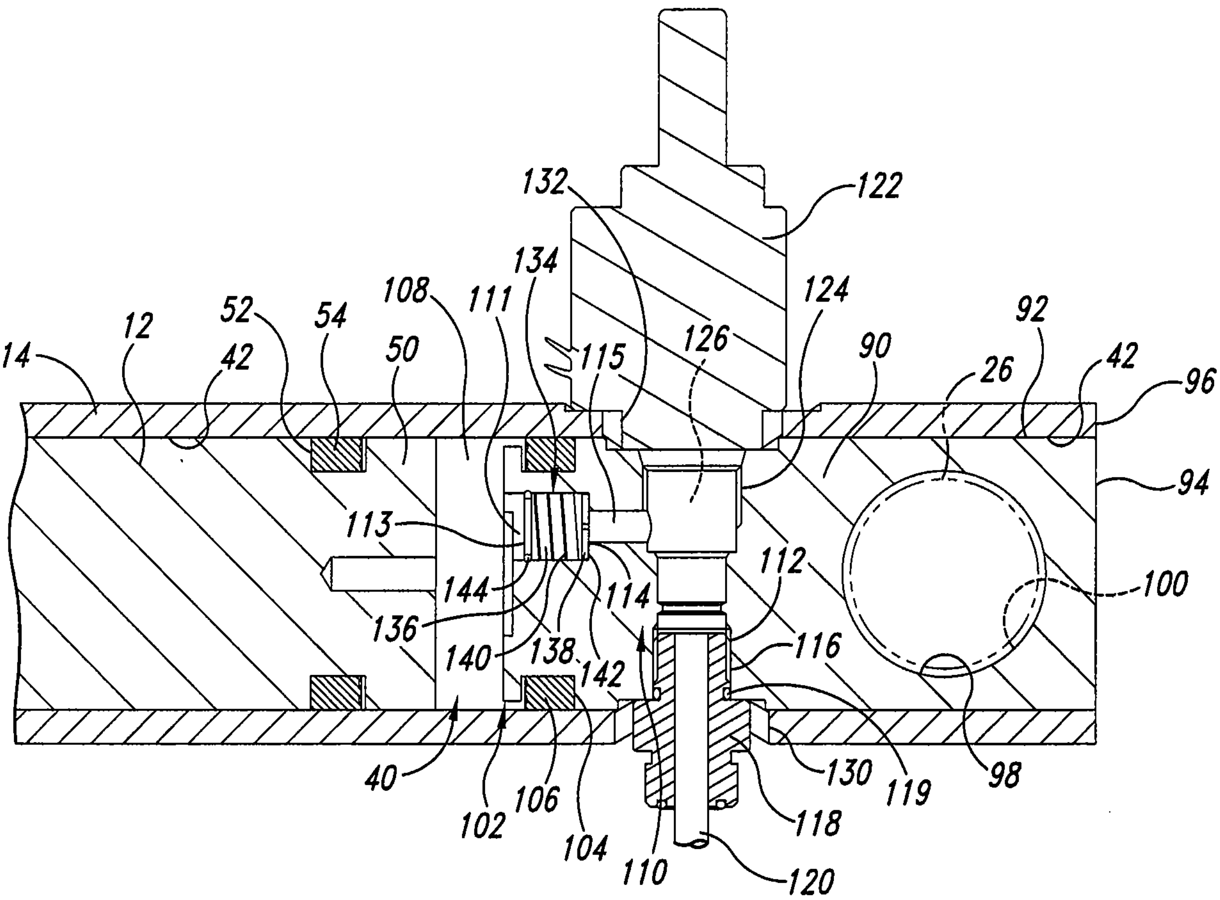
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Fig. 9A

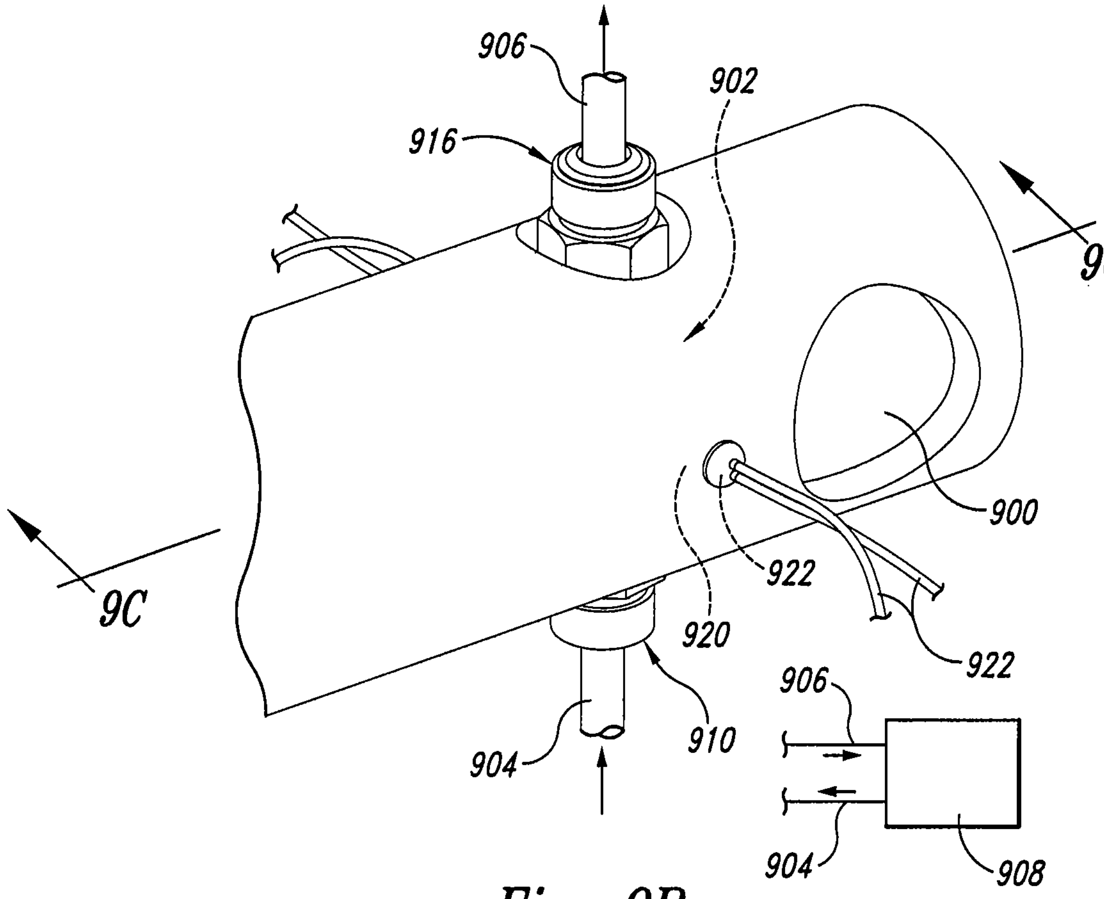
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Fig. 9B

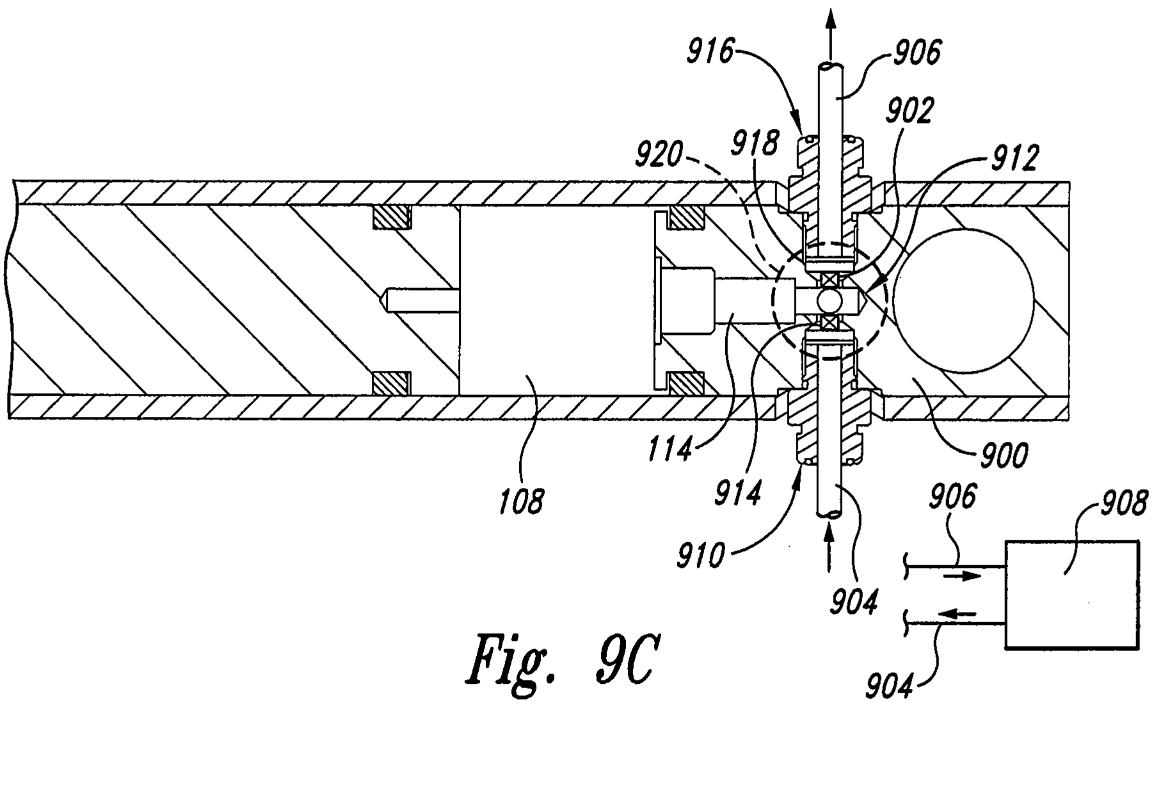
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Fig. 9C

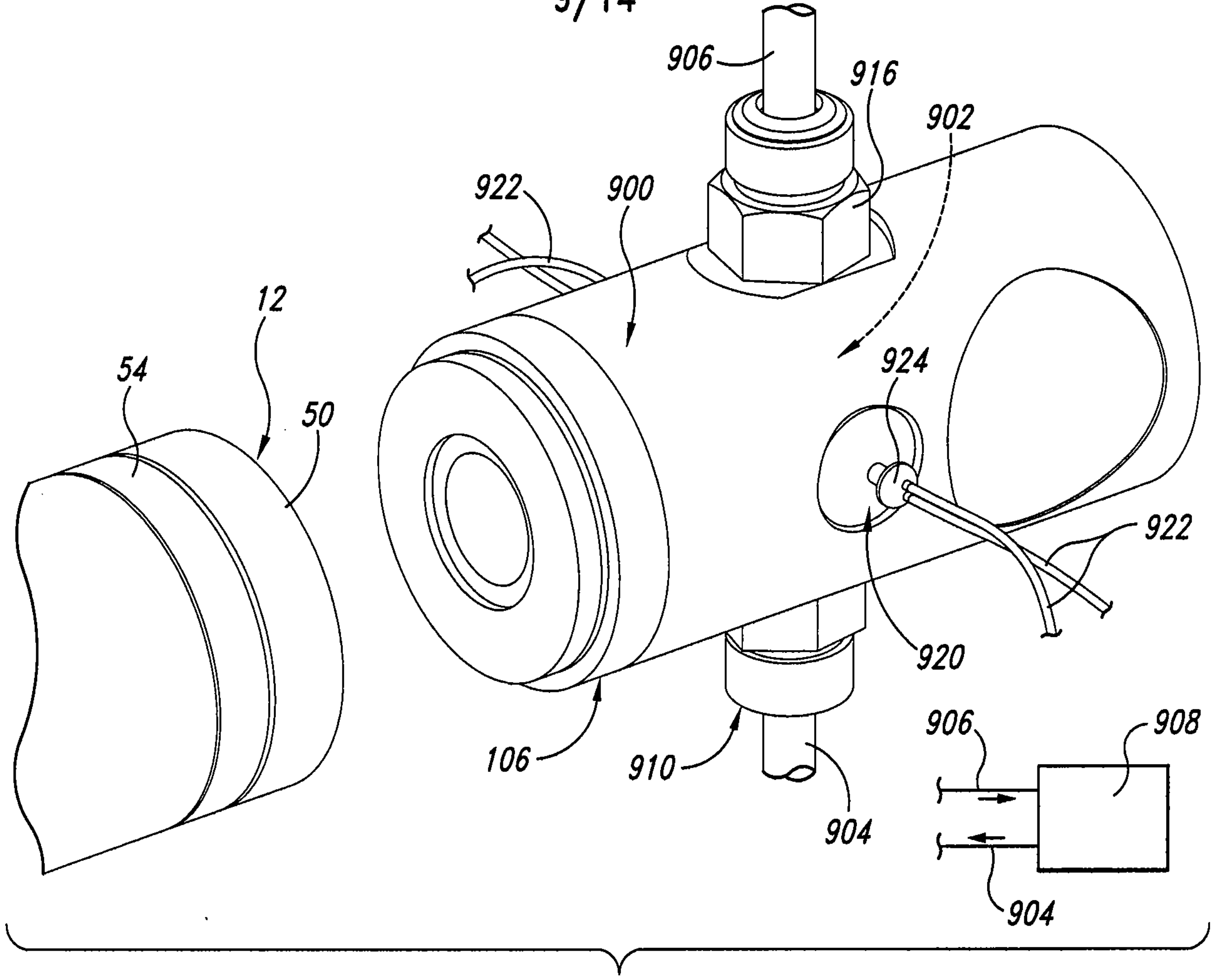
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Fig. 9D

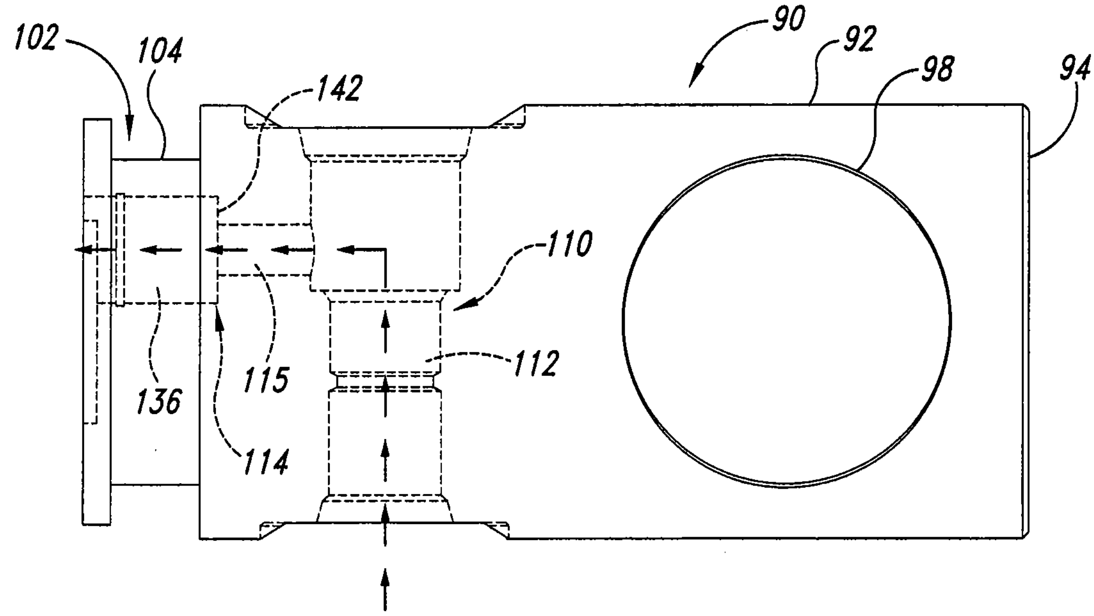
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Fig. 10

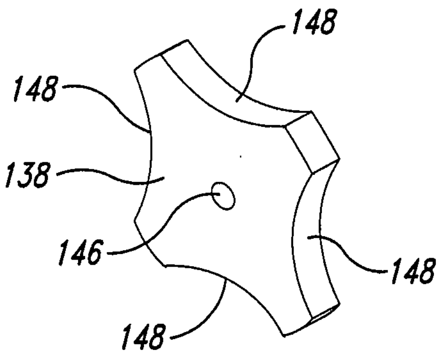

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Fig. 11

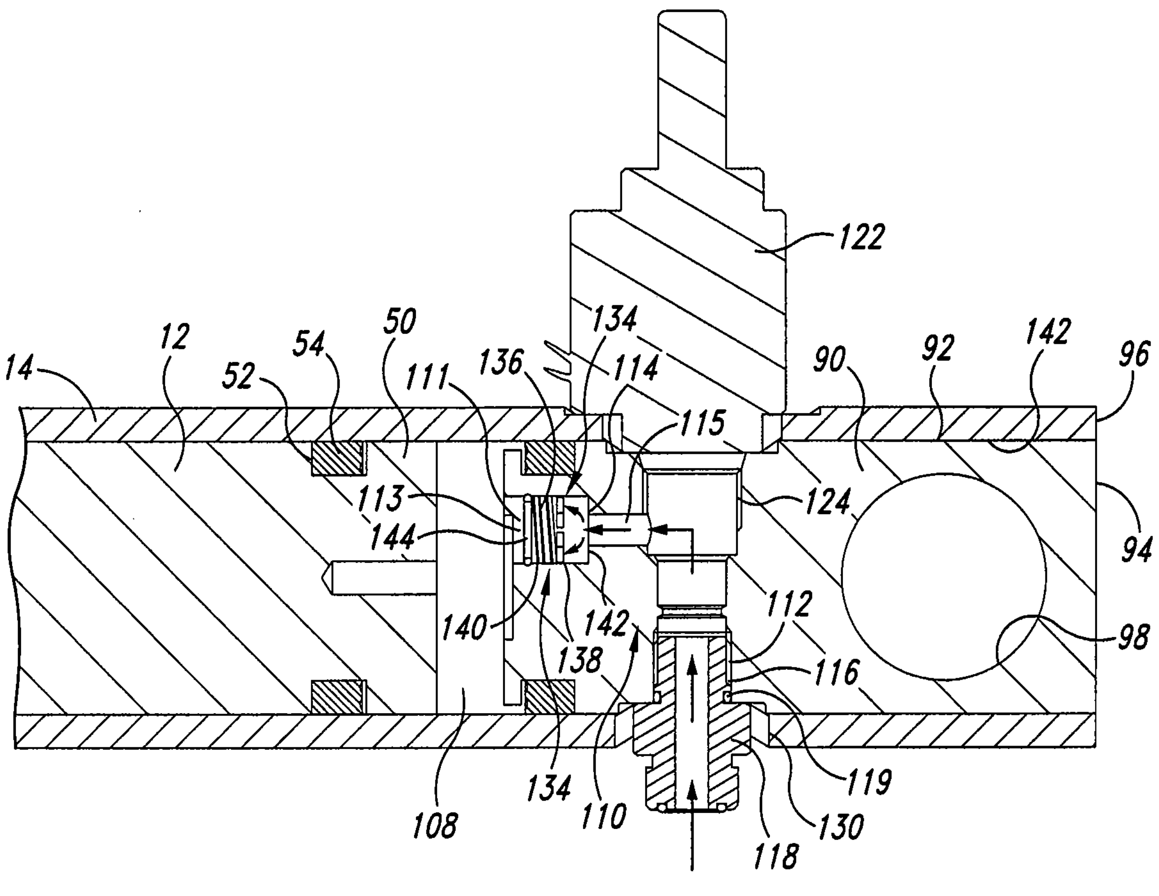

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Fig. 12

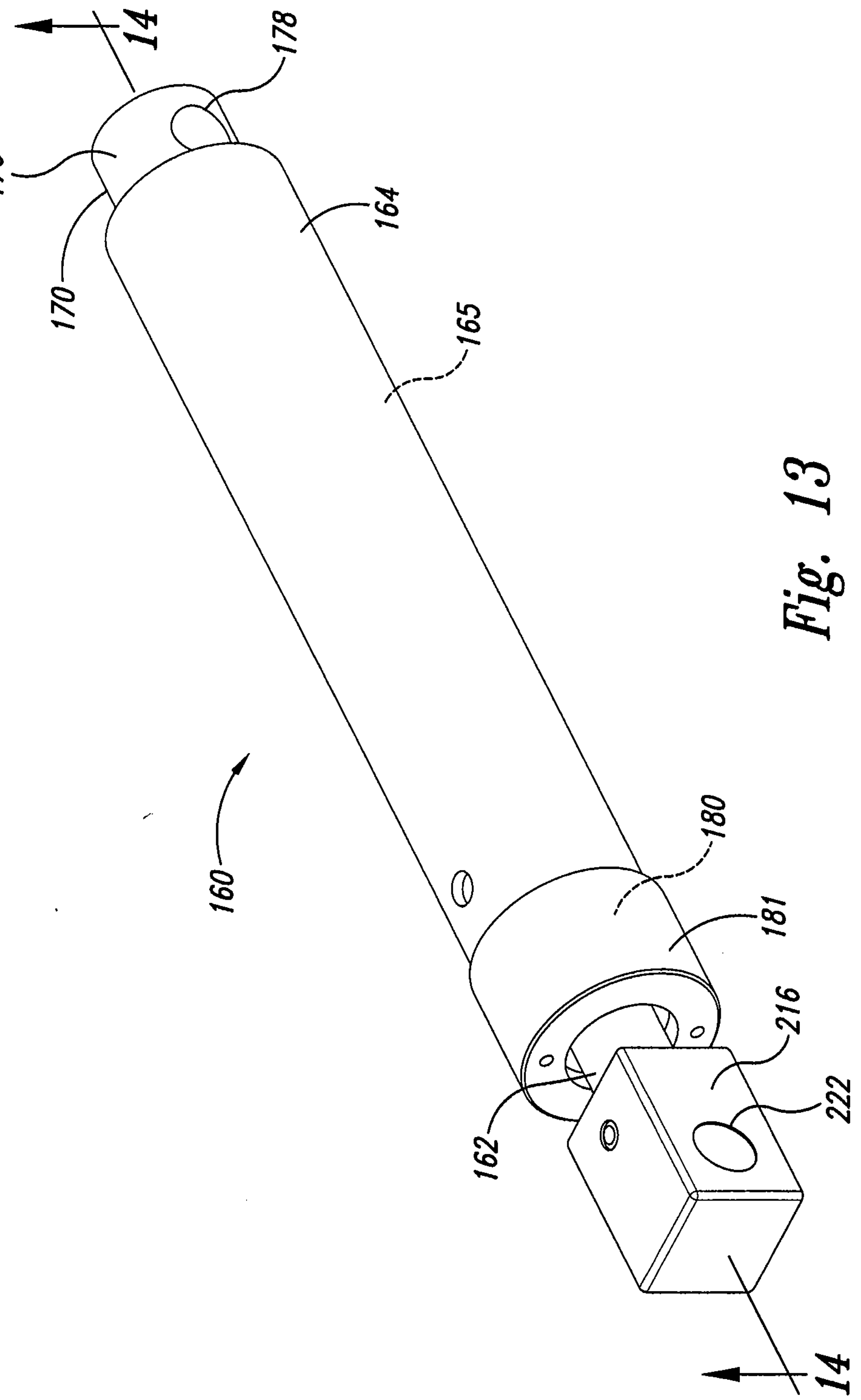

Fig. 13

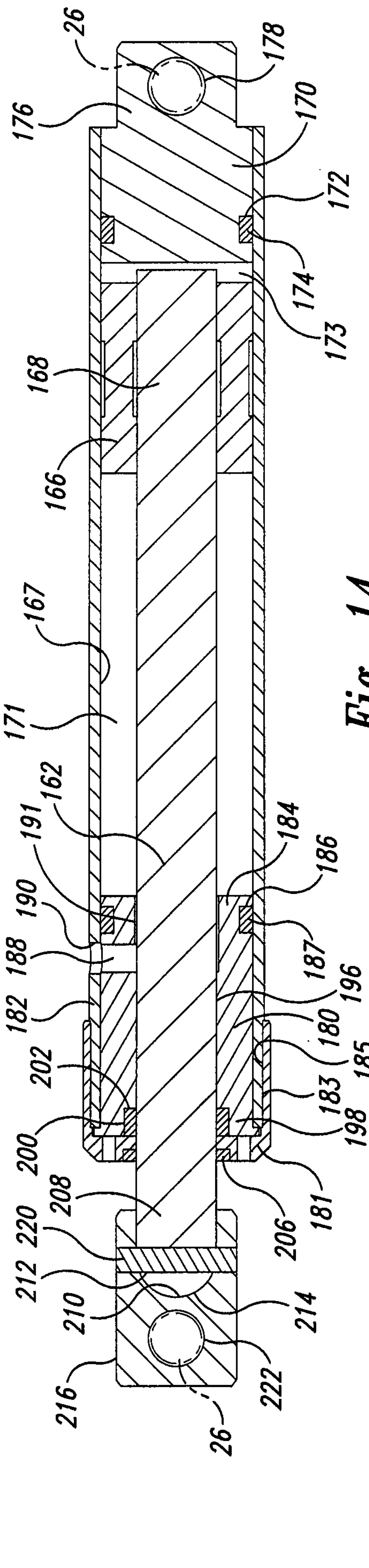
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Fig. 14

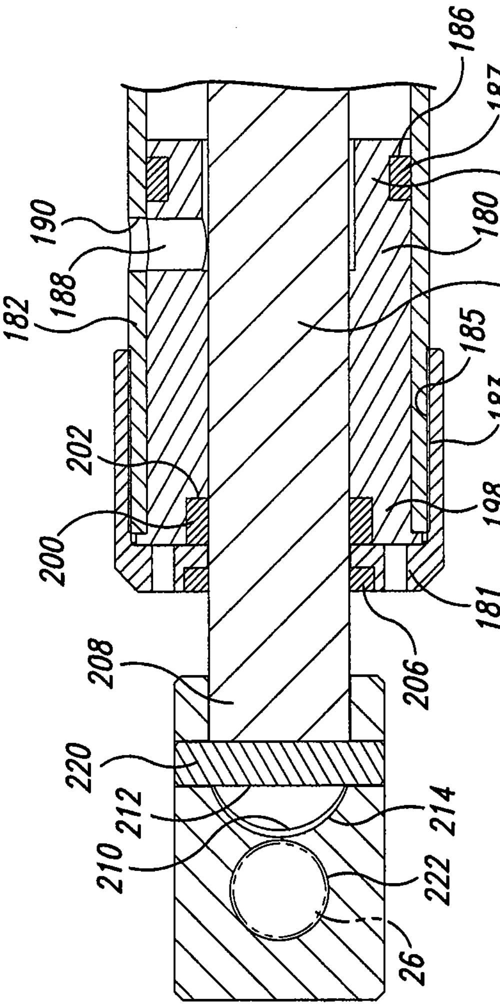
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Fig. 15

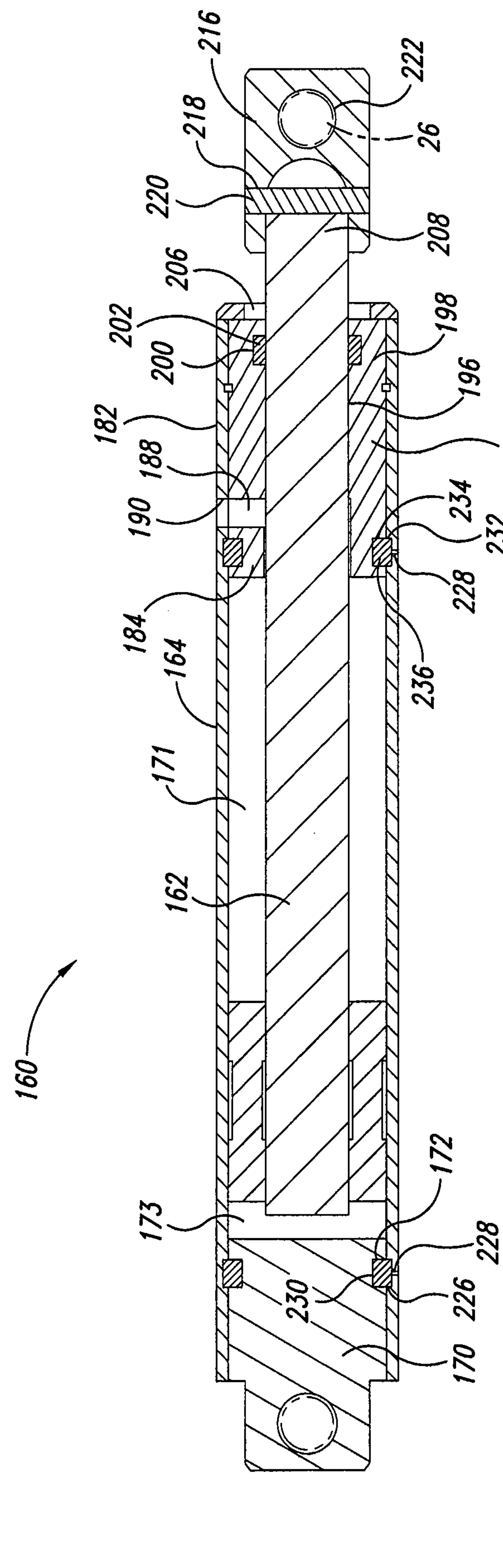
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Fig. 16

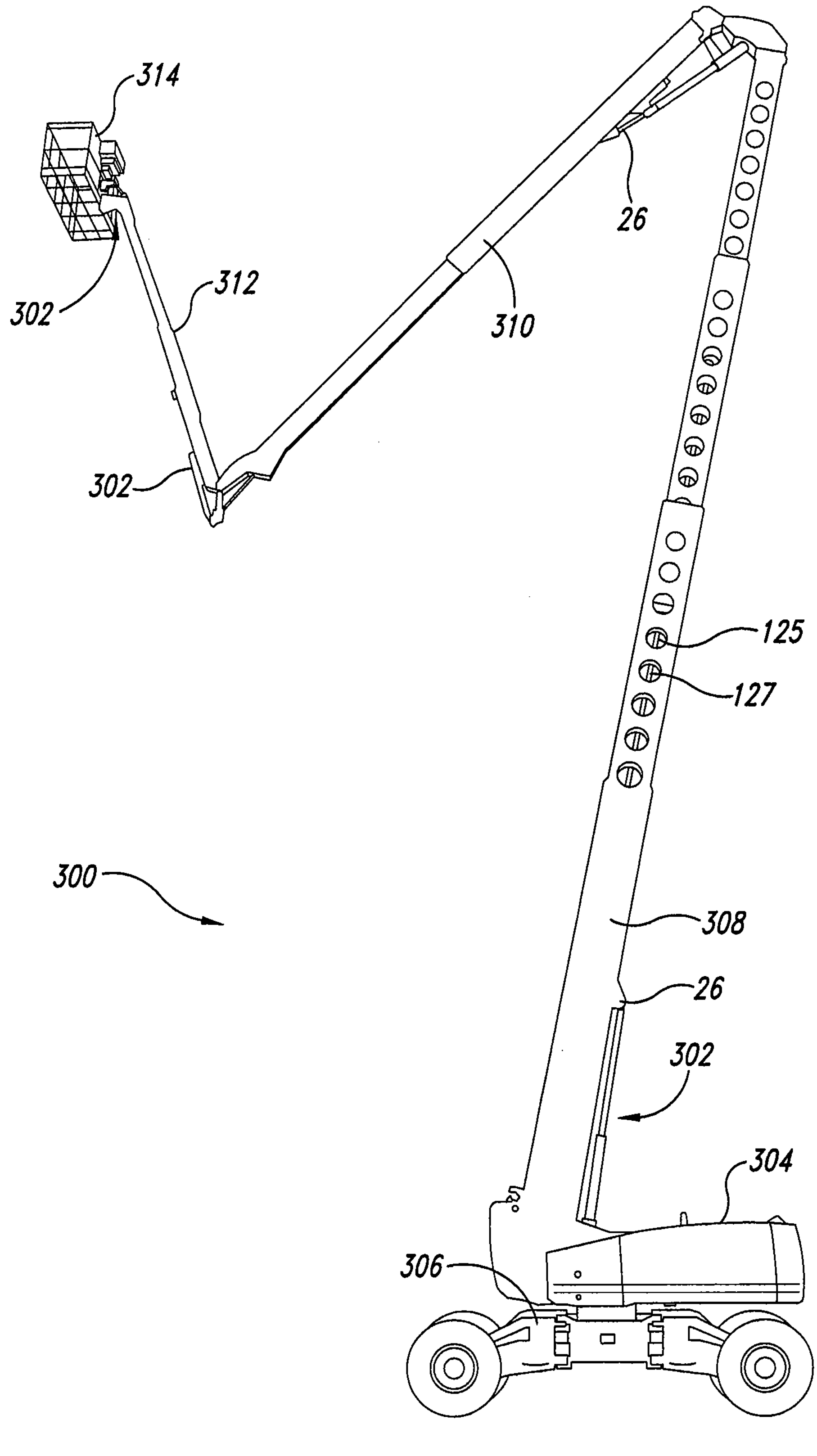

Fig. 17