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Abstract of the Disclosure

HYDRAULIC CYLINDER WITH SPECIFIC PERFORMANCE DIMENSIONS

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

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Description

HYDRAULIC CYLINDER WITH SPECIFIC PERFORMANCE DIMENSIONS

## Technical Field

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

## Background

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

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

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

**[0004]** Motor graders are used primarily as finishing tools to sculpt a surface of a construction site or a road bed to a final shape and contour. Typically, motor graders include many hand-operated controls to steer the wheels of the grader, position a blade, and articulate the front frame of the grader. The blade is adjustably mounted to the front frame to move relatively small quantities of earth from side to side. In addition, the articulation of the front frame is adjusted by rotating the front frame of the grader relative to the rear frame of the grader. To produce a final surface contour, the blade and the frame may be adjusted to many different positions. Positioning the blade of a motor grader can be a complex and time-consuming task. In particular, operations such as, for example, controlling surface elevations, angles, and cut depths may require a significant portion of the operator's attention. Such demands placed on the operator may cause other tasks necessary for the operation of the motor grader to be neglected.

**[0005]** One way to simplify operator control is to allow the operator to recall an input stored in a memory associated with a control device. One example of such a memory control is disclosed in U.S. Patent No. 7,729,835 issued to Morris et al. on June 1, 2010 (the '835 patent). In particular, the '835 patent discloses an excavator having a working implement and hydraulic actuators that allow the working implement to be raised, lowered, and moved closer to or further from a body of the excavator. The excavator is equipped with a first joystick having a thumbwheel control and a second joystick having a function selection switch and a memory control. The function selection switch allows an operator to select from multiple operating functions. The thumbwheel allows the operator to control the selected operating function. The memory control allows an input by the operator to be memorized and recalled at a later time. The input is memorized until the memory control is deactivated or a new input is memorized by the memory control.

**[0006]** In contrast to the hydraulic actuators disclosed in the '835 patent, hydraulic cylinders of the present disclosure are designed with ranges of specific performance dimensions determined through extensive analysis including application of physics-based equations, finite element analysis, and other computational analyses taking into consideration the kinematics and structural stresses that will be placed on the cylinders during use, in combination with empirical data and other customer-centric data directed toward meeting specific job requirements and solving one or more of the problems set forth above and/or other problems of the prior art.

Summary

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

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

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receiving a trunnion pin adapted for pivotally connecting the distal end of the tube to the first structural element of the motor grader. A rod eye bore may be defined through a proximal end of the rod and configured for receiving a rod eye pin adapted for pivotally connecting the proximal end of the rod to the second structural element of the motor grader.

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

## Brief Description of the Drawings

**[0010]** Figs. 1 and 2 illustrate an exemplary hydraulic cylinder that may be used to actuate one structural element on a machine such as a motor grader relative to another structural element of the machine;

**[0011]** Fig. 3 illustrates an exemplary hydraulic cylinder that may be used to articulate a front frame of a motor grader;

**[0012]** Fig. 4 illustrates an exemplary hydraulic cylinder that may be used in steering a motor grader;

**[0013]** Fig. 5 illustrates another exemplary hydraulic cylinder that may be used in steering a motor grader;

**[0014]** Fig. 6 illustrates an exemplary center shift hydraulic cylinder that may be used in controlling the position of a moldboard on a motor grader;

**[0015]** Fig. 7 illustrates an exemplary hydraulic cylinder that may be used in controlling the amount of lean of the wheels on a motor grader;

**[0016]** Fig. 8 illustrates an exemplary hydraulic cylinder that may be used to control a position of a blade tip on a motor grader;

**[0017]** Fig. 9 illustrates an exemplary hydraulic cylinder that may be used in controlling the amount of lift of a blade on a motor grader;

**[0018]** Fig. 10 illustrates an exemplary hydraulic cylinder that may be used to control the position of a ripper on a motor grader; and

**[0019]** Fig. 11 illustrates an exemplary side shift hydraulic cylinder that may be used in controlling the position of a blade on a motor grader.

## Detailed Description

**[0020]** The hydraulic cylinders shown in Figs. 1 – 11 are exemplary hydraulic cylinders that may be used as actuators on a motor grader or other heavy machinery having multiple systems and components that cooperate to accomplish a task. An exemplary motor grader may include a steerable front frame, and a driven rear frame that is pivotally connected to the front frame. The front frame may include a pair of front wheels (or other traction devices), and support a cabin. A rear frame may include compartments for housing a power source (e.g., an engine) and associated cooling components, the power source being operatively coupled to rear wheels (or other traction devices) for primary propulsion of the motor grader. The rear wheels may be arranged in tandems at opposing sides of the driven rear frame. Steering of the motor grader may be a function of both front wheel steering and articulation of the front frame relative to the rear frame.

**[0021]** The motor grader may also include ground-engaging work tools such as, for example, a moldboard blade and a dozing blade. The moldboard blade and the dozing blade may both be operatively connected to and supported by the front frame. In an exemplary embodiment, the moldboard blade may hang from a general midpoint of the front frame, at a location between the front and rear wheels. The dozing blade may be supported at a leading end of the front frame (e.g., at a location forward of the front wheels, relative to a normal travel direction). In some embodiments, the rear frame may also support one or more ground-engaging work tools (e.g., a ripper), if desired. It is contemplated that the moldboard blade, the dozing blade, and/or the ripper could alternatively be connected to and supported by another portion of the motor grader, such as by another portion of the front frame and/or the rear frame.

**[0022]** Both of the moldboard blade and the dozing blade may be supported via separate hydraulic arrangements. In particular, a first hydraulic arrangement having any number of different hydraulic actuators (e.g., hydraulic cylinders and/or hydraulic motors) may be configured to shift the moldboard blade or a tip of the blade vertically toward and away from the front frame, to shift the moldboard blade side-to-side, and/or to rotate the moldboard blade about horizontal and/or vertical axes. A second hydraulic arrangement having any number of different actuators may be configured to shift the dozing blade vertically toward and away from the front frame. It is contemplated that the moldboard blade and the dozing blade may move in additional and/or different ways than described above, if desired.

**[0023]** A cabin on the motor grader may house components configured to receive input from a machine operator indicative of a desired machine and/or work tool movement. Specifically, the cabin may house one or more input devices embodied, for example, as single- or multi-axis joysticks located in proximity to an operator seat. Input devices may be proportional-type controllers configured to position or orient the motor grader, articulate the front frame of the motor grader relative to the rear frame, or position or orient the work tools such as a moldboard, a dozer blade, and a ripper, by producing position signals indicative of desired speeds and/or forces in a particular direction. It is contemplated that different input devices may alternatively or additionally be included within the cabin such as, for example, wheels, knobs, push-pull devices, switches, pedals, and other operator input devices known in the art.

**[0024]** During operation of the motor grader, the operator may manipulate the input devices from inside the cabin to perform tasks that require high precision. For example, the operator may need to position the moldboard blade and/or the dozing blade at precise locations and/or in precise orientations in order to create a planned contour at a worksite without causing collision with another portion of the motor grader and/or with obstacles at the worksite. Similarly, the operator may need to move the motor grader, itself, along a precise trajectory. And in order for the operator to make these movements accurately and efficiently, and without damaging the motor grader or its surroundings, the operator may sometimes rely on position-feedback from a locating device.

**[0025]** As each motor grader travels about the worksite, a Global Navigation Satellite System (GNSS), a local laser tracking system, or another type of positioning device or system may

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communicate with the locating device to monitor the movements of the motor grader and/or the ground-engaging work tools (e.g., the moldboard blade, the dozing blade, and/or the ripper) and to generate corresponding position signals. The position signals may be directed to an onboard controller, for comparison with an electronic contour plan of the worksite and for further processing. The further processing may include, among other things, determining a current ground location under the motor grader; a planned final contour of the worksite; a current elevation of the moldboard blade and/or the dozing blade relative to the ground location; a current elevation of the moldboard blade and/or the dozing blade relative to the planned final contour; and/or a current elevation of the dozing blade relative to the moldboard blade.

**[0026]** The controller may embody a single microprocessor or multiple microprocessors that include a means for controlling an operation of the motor grader. Numerous commercially available microprocessors can be configured to perform the functions of the controller. The controller may include a memory, a secondary storage device, a processor, and any other components for running an application. Various other circuits may be associated with the controller such as power supply circuitry, signal conditioning circuitry, solenoid driver circuitry, and other types of circuitry.

**[0027]** The position-feedback described above may be provided visually to the operator of the motor grader. For example, a display may be provided within the cabin in proximity to the operator seat. The display may include one or more monitors (e.g., a liquid crystal display (LCD), a cathode ray tube (CRT), a personal digital assistant (PDA), a plasma display, a touch-screen, a portable hand-held device, or any such display device known in the art) configured to actively and responsively show the different elevations described above to the operator of the motor grader. The display may be connected to the controller, and the controller may execute instructions to render graphics and images on the display that are associated with operation of the motor grader.

**[0028]** In some embodiments, the display may also be configured to receive input indicative of different modes of machine operation. For example, the display may include one or more buttons (real or virtual), switches, knobs, dials, etc. that, when manipulated by the operator, generate corresponding signals directed to the controller. These signals may be used by the controller to implement, for example, a manual mode of operation, a semi-autonomous mode of operation, and/or a completely autonomous mode of operation. During the manual mode of operation, the operator of the motor grader may manipulate the input devices to directly control movement of the moldboard blade and the dozing blade. During the semi-autonomous mode of operation, the operator may move

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the input devices to directly control movement of only one work tool (e.g., only the moldboard blade). And in response to the movement of the manually-controlled work tool and/or based on one or more of the relative locations described above, the controller may responsively and autonomously regulate movement of the remaining work tool (e.g., the dozing blade or the ripper). During the autonomous mode of operation, the controller may be programmed to regulate movement of all work tools via actuation of different hydraulic cylinders completely automatically using input from different sensors.

**[0029]** The various hydraulic arrangements, input device(s), controller(s), and display(s) may together form a motor grader control system. In some embodiments, the control system may additionally include one or more sensors and/or one or more valves associated with the hydraulic arrangements. The controller may be configured to use input received via the input device(s), an electronic plan tailored for a particular work site, and location information to generate signals for selectively energizing valves to cause corresponding movements of particular hydraulic actuators. The sensors may be position sensors that are configured to generate signals indicative of the positions of the related work tools (e.g., of the cutting edges of the moldboard blade and the dozing blade). In one embodiment, the sensors may be associated with one or more hydraulic actuators, and configured to detect extensions of the actuators. Based on the detected extensions and known kinematics of the motor grader, the controller may be configured to determine the positions of the moldboard blade and/or the dozing blade. In another embodiment, the sensors may be joint-angle sensors, configured to detect pivoting of one or more links within the hydraulic arrangements of the motor grader. Based on the detected pivoting and known kinematics of the motor grader, the controller may be configured to determine the positions of the moldboard blade and/or the dozing blade. In yet another embodiment, the sensors may be configured to directly measure a position of the moldboard blade and/or the dozing blade (e.g., relative to the front frame). In any of the disclosed embodiments, the signals generated by the sensors may represent offset positions, relative to a position of the motor grader or of a portion of the motor grader. Other types of sensors may also or alternatively be utilized to determine the cutting edge location of each blade, if desired.

**[0030]** Valves may be configured to selectively direct pressurized fluid into and/or out of different chambers within the hydraulic actuators of various hydraulic arrangements on the motor grader in response to manual input received via an input device and/or in response to commands generated by the controller. For example, the valves may be movable between positions at which a pump supply

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passage is connected with a particular chamber, or a tank drain passage is connected with the particular passage. As is known in the art, these connections may result in an imbalance of pressure inside the associated actuator(s) that functions to either extend or retract the actuator(s). Moreover, hydraulic cylinders are preferably designed with specific ranges of dimensions for a stroke, a pin-to-pin length when fully retracted, a bore diameter of a tube that forms the body of the hydraulic cylinder, an outer diameter of the tube, a diameter of a rod that extends from a piston assembly slidably supported within the tube to define a head-end chamber on one side of the piston assembly and a rod-end chamber on the opposite side of the piston assembly, a diameter of a rod-end pin, and a diameter of a trunnion pin at the head end of the cylinder, depending on the specific machines and load applications where the hydraulic cylinders will be used. Additionally, hydraulic cylinders used on heavy machinery may benefit from a combination of the specific performance dimensions disclosed herein along with features such as damping devices and head seal arrangements that improve the operational characteristics, fatigue life, and performance under extreme conditions.

**[0031]** A power source for the motor grader may embody an engine such as, for example, a diesel engine, a gasoline engine, a gaseous fuel-powered engine, or any other type of combustion engine known in the art. It is contemplated that the power source may alternatively embody a non-combustion source of power such as a fuel cell, a power storage device, a tethered motor, or another source known in the art. The power source may produce a mechanical or electrical power output that may then be converted to hydraulic power for moving the various hydraulic cylinders that are used as actuators to move structural elements or portions of the machine relative to each other or to a ground surface on which the machine is operating. An operator station on the motor grader may include devices that receive input from a machine operator indicative of desired machine maneuvering. Specifically, the operator station may include one or more operator interface devices, for example a joystick, a steering wheel, or a pedal, that are located proximate an operator seat. Operator interface devices may initiate movement of the motor grader, for example travel and/or tool movement, by producing displacement signals that are indicative of desired machine maneuvering. As an operator moves the interface device, the operator may affect a corresponding machine movement in a desired direction, with a desired speed, and/or with a desired force.

**[0032]** As shown in Figs. 1 and 2, an exemplary hydraulic cylinder, which may be used as an actuator for moving one structural element or combination of elements on a motor grader relative to another structural element or combination of elements of the motor grader, may include a tube (or

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cylinder barrel) 322 and a piston assembly 420 arranged at the distal end of a rod 332 within tube 322 to form a first chamber 352 and an opposing second chamber 354 on opposite sides of piston assembly 420. Tube 322 is closed on one end by a cylinder bottom or trunnion cap at a distal end 342. At the opposite end, tube 322 is closed by a cylinder head and head seal assembly 520 where piston rod 332 comes out of the cylinder. First chamber 352 on the cap end side of piston assembly 420 may be considered the "rod-end" chamber, and second chamber 354 may be considered the "head-end" chamber of the hydraulic cylinders. An exemplary embodiment of piston assembly 420, shown in Fig. 2, may be provided at a distal end of rod 332. Piston assembly 420 may be held on the distal end of rod 332 by various means, such as between a piston retention assembly and a bushing, or by a nut at the distal end of piston rod 332, as shown in Fig. 2. Rod 332 may have a diameter 334, and piston assembly 420 may also include a plurality of annular seals spaced along the outer periphery of piston assembly 420 and forming a slidable seal between piston assembly 420 and an inner circumferential surface of tube 322 as rod 332 and piston assembly 420 reciprocate back and forth within tube 322 with changes in the pressure and/or flow rate of hydraulic fluid supplied to and released from head-end chamber 354 and rod-end chamber 352.

**[0033]** Head-end chamber 354 and rod-end chamber 352 may each be selectively supplied with pressurized fluid and drained of the pressurized fluid to cause piston assembly 420 to displace within tube 322, thereby extending and retracting rod 332 from tube 322, and changing an effective length of the hydraulic cylinder. Extension and retraction of rod 332 from tube 322 results in moving one part of the motor grader or linkage structure connected to rod 332 relative to another part of the machine or linkage structure connected to the trunnion cap fixed at the distal end 342 of tube 322. A flow rate of fluid into and out of head-end chamber 354 and rod-end chamber 352 may relate to a translational velocity of the hydraulic cylinder, while a pressure differential between chambers 354, 352 may relate to a force imparted by the hydraulic cylinder on the associated linkage structure of the motor grader.

**[0034]** As shown in Fig. 2, a proximal end 344 of rod 332 may pass through head seal assembly 520 attached at the end of tube 322 through which rod 332 passes. Head seal assembly 520 may include a plurality of axially spaced seals along the inner, circumferential periphery of head seal assembly 520, configured to form a slidable seal with the outer periphery of the proximal end 344 of rod 332. A plurality of bolts may fix head seal assembly 520 to a rod end boss, with a portion of head seal assembly 520 extending at least partially radially inward from a rod end boss of tube 322,

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and configured for radially supporting the proximal end 344 of rod 332 as rod 332 and piston 420 reciprocate relative to tube 322. The proximal end 344 of rod 332 may include a rod eye bore of diameter 252 extending through rod 332 orthogonal to the central axis of rod 332, and configured to receive a rod eye pin for pivotally attaching the proximal end 344 of rod 332 to a first structural element of machine 10, such as a rod eye pin pivotally connecting the rod-end of the hydraulic cylinder to a first structural element of the motor grader. The distal end 342 of tube 322 may similarly include a trunnion cap bore of diameter 242 extending through the distal end 342 of tube 322 orthogonal to the central axis of rod 332 and tube 322, and configured to receive a trunnion pin pivotally attaching distal end 342 of tube 322 to a second structural element of the motor grader, such as a trunnion pin configured to pivotally connect the head-end of the hydraulic cylinder to the second structural element.

**[0035]** In all of the exemplary embodiments of hydraulic cylinders 20, 22, 24, 26, 28, 30, 32, 34, and 36, shown in Figs. 3 – 11, values for different dimensions of the hydraulic cylinders are determined based on the specific performance requirements for each hydraulic cylinder in a particular application on a motor grader. The specific performance dimensions include, but are not limited to, the tube bore diameter 324 and outside diameter 326 for each tube 322, the thickness of each tube 322 defined by the radial distance between the tube bore diameter and the outside diameter of each tube 322, the rod diameter 334 for each rod 332, the diameter 252 of a rod eye bore extending through proximal end 344 of rod 332, the diameter 242 of a trunnion cap bore extending through the distal end 342 of tube 322, the outer diameter of a trunnion at the distal end 342, or the inner diameter of a bearing that receives the trunnion at the distal end 342, the pin-to-pin length 132 between the center of the rod eye bore and the center of the trunnion cap bore or the center of the bearing that receives a trunnion at the distal end 342 when rod 332 is fully retracted into tube 322, and the stroke 222 determined by the total distance rod 332 moves when traveling from a fully retracted position within tube 322 to a fully extended position. The diameter 252 of a rod eye bore, and hence the diameter of a rod eye pin configured for pivotally connecting rod 332 of each hydraulic cylinder to a structural element of machine 10, and the diameter 242 of a trunnion cap bore extending through the distal end 342 of tube 322, or the diameter of a trunnion received within a bearing at the distal end of the tube 322 in some embodiments, and hence the diameter of a trunnion pin or the diameter of the trunnion at the distal end of the tube configured for pivotally connecting tube 322 of each hydraulic cylinder to another structural element of machine 10, are determined based at least in part on the size of the structural elements of the motor grader to which the pins are pivotally attached, and the loads and structural stresses experienced by these elements during operation, such as shear stresses, torsional stresses, compression stresses, and tension stresses that will be experienced under load during actuation of each hydraulic cylinder. The pin-to-pin dimension 132, shown in Fig. 1, which may also be represented as a pin-to-trunnion dimension when a trunnion at the distal end of tube 322 is received within a bearing, for each hydraulic cylinder is determined based at least in part on the sizes, ranges of motion, working loads, and structural interrelationships of the structural elements of a particular machine, such as the front frame and the moldboard of each motor grader. The stroke 222 for each hydraulic cylinder, shown in Fig. 2, is similarly determined based at least in part on the sizes, ranges of motion, working loads, and structural interrelationships of the structural elements of each machine. Rod 332 and piston 420 are shown in Figs. 1 and 2 fully contracted into tube 322, with stroke 222 being determined by the distance that piston 420 can travel from this fully contracted position when bottomed out at the closed, distal end 342 of tube 322 to a fully extended position of rod 332 when piston 420 contacts head seal assembly 520 connected to the proximal end of tube 322.

**[0036]** A motor grader may include a hydraulic system having a plurality of circuits that drive the fluid actuators (hydraulic cylinders) described above to move one part of the motor grader, such as the moldboard, relative to another part of the motor grader, such as the front frame. Each of the circuits may be similar and include a plurality of interconnecting and cooperating fluid components that facilitate the use and control of the associated actuators. For example, each of the circuits may include a pump fluidly connected to its associated actuator(s) via a closed loop formed by left-side and right-side passages. Specifically, each of the circuits may include a common left pump passage, a common right pump passage, a left actuator passage for each actuator, and a right actuator passage for each actuator. In circuits having linear actuators, left and right actuator passages may be commonly known as head-end and rod-end passages, respectively. Within each circuit, the corresponding pump may be connected to its associated actuators via a combination of left and right, pump and actuator passages.

**[0037]** To retract a linear actuator, the right actuator passage of a particular circuit may be filled with fluid pressurized by the pump, while the corresponding left actuator passage may be filled with fluid returned from the linear actuator. In contrast, to extend the linear actuator, the left actuator passage may be filled with fluid pressurized by the pump, while the right actuator passage may be filled with fluid exiting the linear actuator. Each pump may have variable displacement and be controlled to draw fluid from its associated actuators and discharge the fluid at a specified elevated pressure back to the actuators in a single direction. That is, the pump may include a stroke-adjusting mechanism, for example a swashplate, a position of which is hydro-mechanically adjusted based on, among other things, a desired speed of the actuators to thereby vary an output (e.g., a discharge rate) of the pump. The displacement of the pump may be adjusted from a zero displacement position at which substantially no fluid is discharged from the pump, to a maximum displacement position at which fluid is discharged from the pump at a maximum rate into the right pump passage. The pump may be drivably connected to a power source of the motor grader by, for example, a countershaft, a belt, or in another suitable manner. Alternatively, the pump may be indirectly connected to the power source via a torque converter, a gear box, an electrical circuit, or in any other manner known in the art. It is contemplated that pumps of different circuits may be connected to the power source in tandem (e.g., via the same shaft) or in parallel (via a gear train), as desired.

**[0038]** Pumps configured to provide pressurized hydraulic fluid to hydraulic actuators may also be selectively operated as motors. More specifically, when an associated actuator is operating in an overrunning condition, the fluid discharged from the actuator may have a pressure elevated higher than an output pressure of the corresponding pump. In this situation, the elevated pressure of the actuator fluid directed back through the pump may function to drive the pump to rotate with or without assistance from the power source. Under some circumstances, the pump may even be capable of imparting energy to the power source, thereby improving an efficiency and/or capacity of the power source.

**[0039]** In one exemplary embodiment of a hydraulic cylinder according to this disclosure, such as an articulation hydraulic cylinder 20 used in controlling movement of a front frame of a motor grader relative to a rear frame of the motor grader, as shown in Fig. 3, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 1004.4 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 409.25 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 100 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 121 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 63 mm ± 0.5 mm. The trunnion cap bore diameter 242 may be equal to 69.71 mm ± 0.25 mm, and the rod eye bore diameter 252 (through each arm of the clevis in the exemplary embodiment of Fig. 3) may be equal to 57.21 mm ± 0.25

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mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

**[0040]** In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a steering hydraulic cylinder 22 used in controlling the direction of movement of a motor grader, as shown in Fig. 4, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 698.5 mm ± 2.0 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 316 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 80.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 100.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 50.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 may be equal to 58 mm ± 0.25 mm and the rod eye bore diameter 252 may be equal to 48.0 mm ± 0.25 mm. In some exemplary embodiments, a bearing with an inner diameter of 38.1 mm ± 0.25 mm may be press fit within the trunnion cap bore diameter 242. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

**[0041]** In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a steering hydraulic cylinder 24 used to control the direction of movement of a motor grader, as shown in Fig. 5, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 698.5 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 316 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 80.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 100.0 ± 0.5 mm. The diameter 334 of rod 332 may be equal to 50.0 mm ± 0.5

mm. The trunnion cap bore diameter 242 may be equal to 58 mm ± 0.25 mm and the rod eye bore diameter 252 may be equal to 48.0 mm ± 0.25 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

**[0042]** In yet another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a center shift hydraulic cylinder 26 used for controlling the position of a moldboard on a motor grader, as shown in Fig. 6, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 955.3 mm ± 2.5 mm. The stroke 222 for this exemplary center shift cylinder may be equal to 479.6 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 100.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 118 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 65.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be defined by ball stud mounts with spherical radii equal to 48.5 mm ± 0.025 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

**[0043]** In yet another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a wheel lean hydraulic cylinder 28 used to control the tilt of a wheel on a motor grader, as shown in Fig. 7, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 543.1 mm ± 2.5 mm. The stroke 222 for this exemplary tow point cylinder may be equal to 174.8 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 100.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 118 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 55.0

mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 63.47 mm ± 0.025 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

**[0044]** In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a blade tip hydraulic cylinder 30 used in controlling the position of the tip of a blade on a motor grader, as shown in Fig. 8, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 711.0 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 355.5 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 100.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 118.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 50.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 61.85 mm + 0.10 mm and – 0.07 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

**[0045]** In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a hydraulic cylinder 32 used in lifting the blade of a motor grader, as shown in Fig. 9, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 822.2 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 1113.6 mm ± 2.0 mm. The tube bore diameter 324 may be equal to 100.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 118.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 65.0 mm ± 0.5 mm. The trunnion cap may define a trunnion outer diameter 242 that may be equal to 57.21 mm ± 0.25

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mm and the rod eye bore diameter 252 may be defined by a ball stud with a spherical radius equal to 48.5 mm ± 0.25 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

**[0046]** In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a ripper hydraulic cylinder 34 used in controlling the position of a ripper on a motor grader, as shown in Fig. 10, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 347.5 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 495.0 mm ± 1.5 mm. The tube bore diameter 324 may be equal to 130.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 154 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to 65.0 mm ± 0.5 mm. The trunnion cap may define a trunnion outer diameter equal to 63.5 mm ± 0.025 mm, and the rod eye bore diameter 252 may be equal to 76.2 mm ± 0.025 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

**[0047]** In another exemplary embodiment of a hydraulic cylinder according to this disclosure, such as a side shift hydraulic cylinder 36 used to control the position of a moldboard on a motor grader, as shown in Fig. 11, the hydraulic cylinder may have a pin-to-pin dimension 132 when fully retracted, with rod 332 and piston 420 bottomed out at the closed, distal end 342 of tube 322, equal to 1925.7 mm ± 2.5 mm. The stroke 222 for this exemplary hydraulic cylinder may be equal to 1531.9 mm ± 2.0 mm. The tube bore diameter 324 may be equal to 105.0 mm ± 0.5 mm, and the tube outer diameter 326 may be equal to 123.0 mm ± 0.5 mm. The diameter 334 of rod 332 may be equal to

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65.0 mm ± 0.5 mm. The trunnion cap bore diameter 242 and the rod eye bore diameter 252 may be equal to 38.5 mm ± 0.25 mm. The disclosed ranges of dimensions are determined for a particular machine based on one or more of physics-based equations, finite element analysis, empirical evidence, historical evidence, and other computational analyses that take into consideration factors such as kinematic interrelationships between the components on the machine connected to the rod end and the trunnion cap end of the cylinder, ranges of motion of the respective structural components, loads that will be experienced by the hydraulic cylinder during operation of the machine, desired fatigue life, hydraulic fluid pressures, and mechanical safety factors.

Industrial Applicability

**[0048]** The disclosed hydraulic cylinders may be applicable to any motor grader where application of specific performance dimensions for stroke, pin-to-pin length, rod diameter, tube bore diameter, tube outer diameter, rod eye pin diameter, and trunnion cap pin diameter for each hydraulic cylinder are based at least in part on the results of structural and kinematic analysis of the various structural elements of a particular machine needed to perform certain tasks, such as adjusting a position of a moldboard or a dozer blade to generate a desired profile along a surface being graded. The specific performance dimensions for each hydraulic cylinder used on the particular machine may be determined, at least in part, from physics-based equations, and empirical and historical data, including fatigue analysis for the structural elements under load, the size of the particular machine and the environment where it will operate, the materials being graded by the machine, relative locations of linkage points at which the head end and rod end of each hydraulic cylinder will be pivotally connected, hydraulic system pressures, hoop stresses, shear stresses, compressive stresses, and tension stresses on the various components of each hydraulic cylinder, and other mechanical design considerations.

**[0049]** During operation of a motor grader, an operator may command a particular movement of one or more components of the machine relative to another component of the machine, or relative to the ground. One or more corresponding signals indicative of the desired movement may be generated by an interface device manipulated by an operator or operated semi-autonomously or fully autonomously, and transmitted to an electronic controller, along with machine performance information, for example sensor data such a pressure data, position data, speed data, pump displacement data, and other data known in the art.

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**[0050]** In response to the signals from the interface device, and based on the machine performance information, the controller may generate control signals directed to pumps, motors, and/or to valves that control the flow of hydraulic fluid to the head-end chamber on one side of the piston for each hydraulic cylinder and the rod-end chamber on the opposing side of the piston. In one exemplary implementation, the controller may generate a control signal that causes a pump of a first circuit to increase its displacement and discharge fluid into a right pump passage at a greater rate than fluid is discharged by the pump to a left pump passage. In addition, the controller may generate a control signal that causes a switching valve to move toward and/or remain in one of the two flow-passing positions. After fluid from the right pump passage passes into and through a right-travel motor, for example, or into a head-end chamber or a rod-end chamber of a hydraulic cylinder, the fluid from the motor, or from the head-end or rod-end chamber on the opposite side of the piston assembly in the hydraulic cylinder may return to the pump via a left pump passage. At this time, the speed of the right-travel motor, or of movement of the rod and piston assembly in the hydraulic cylinder, may be dependent on a discharge rate of the pump and on a restriction amount, if any, provided by a switching valve on the flow of fluid passing through right-travel motor, or into or out of the hydraulic cylinder. Movement of the right travel motor may be reversed by moving the switching valve to the other of the two flow-passing positions.

**[0051]** A first hydraulic cylinder may be moved simultaneous with and/or independent of movement of a second hydraulic cylinder. In particular, while a first hydraulic cylinder is receiving fluid from a pump, one or more metering valves may be moved to divert some of the fluid into a second hydraulic cylinder. At this same time, each metering valve may be moved to direct waste fluid from a hydraulic cylinder back to a pump. When a switching valve and the appropriate metering valves are fully open, the movements of the first and second hydraulic cylinders may be linked and dependent on the flow rate of fluid from the pump.

**[0052]** During some operations, the flow rate of fluid provided to individual hydraulic cylinders from their associated pumps may be insufficient to meet operator demands. During this situation, the controller may cause the valve element(s) of one or more corresponding combining valves to pass fluid from one fluid flow circuit to another fluid flow circuit, thereby increasing the flow rate of fluid available to a particular hydraulic cylinder. At this time, fluid discharging from some of the hydraulic cylinders may be returned to the pump of a desired fluid flow circuit via a combining valve. Flow sharing between other circuits via other combining valves may be implemented in a similar manner.

**[0053]** Flow sharing may also be selectively implemented when an amount of fluid discharged from one actuator exceeds a rate at which the corresponding pump can efficiently consume return fluid. Some of this discharging fluid may be redirected via metering valves back into a rod-end or head-end chamber of another hydraulic cylinder. This operation may be known as regeneration, and results in an efficiency improvement.

**[0054]** Flows provided by pumps on the machine may be substantially unrestricted during many operations such that significant energy is not unnecessarily wasted in the actuation process. Thus, embodiments of the disclosure may provide improved energy usage and conservation. In addition, the ability to combine fluid flows from different circuits to satisfy demands of individual actuators may allow for a reduction in the number of pumps required within the hydraulic system and/or a size and capacity of these pumps. These reductions may reduce pump losses, improve overall efficiency, improve packaging of the hydraulic system, and/or reduce a cost of the hydraulic system. The application of specific performance dimensions for stroke, pin-to-pin length, rod diameter, tube bore diameter, tube outer diameter, rod eye pin diameter, and trunnion cap pin diameter for each hydraulic cylinder based at least in part on the results of structural and kinematic analysis of the various structural elements of a particular motor grader needed to perform certain tasks associated with a grading process also improves the efficiency and quality of the grading operation, increases longevity of the machine, and reduces the occurrences of failures of machine components or the need for repairs or maintenance.

**[0055]** It will be apparent to those skilled in the art that various modifications and variations can be made to the disclosed hydraulic actuators and systems. Other embodiments will be apparent to those skilled in the art from consideration of the specification and practice of the disclosed hydraulic systems. It is intended that the specification and examples be considered as exemplary only, with a true scope being indicated by the following claims and their equivalents.

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## LIST OF ELEMENTS

TITLE: HYDRAULIC CYLINDER WITH SPECIFIC PERFORMANCE DIMENSIONS

FILE: 08350.2735-00000 (CAT: 21-0218US01)

20: Hydraulic Cylinder
22. Hydraulic Cylinder
24. Hydraulic Cylinder
26. Hydraulic Cylinder
28. Hydraulic Cylinder
30. Hydraulic Cylinder
32. Hydraulic Cylinder
34. Hydraulic Cylinder
36. Hydraulic Cylinder
132. Pin-to-Pin Dimension
222. Stroke Dimension
242. Trunnion Cap Bore Diameter
252. Rod Eye Bore Diameter
322. Tube
324. Tube Bore Diameter
326. Tube Outer Diameter
332. Rod
334. Rod Diameter
342. Closed, Distal End of Tube
344. Proximal End of Rod
352. Rod-End Chamber
354. Head-End Chamber
420. Piston
520. Head Seal Assembly

## Claims

What is claimed is:

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

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

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

a piston mounted at a distal end of the rod;

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

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

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

a retracted pin-to-pin dimension from a center of the trunnion cap bore to a center of the rod eye bore when the rod and piston are fully retracted into the tube with the distal end of the rod positioned adjacent the closed, distal end of the tube is equal to 822.2 mm ± 2.5 mm;

a stroke dimension from a first, fully retracted position of the piston adjacent the closed, distal end of the tube to a second, fully extended position of the piston in contact with the head seal assembly at the proximal end of the tube is equal to 1113.6 mm ± 2.0 mm;

a diameter of the rod is equal to 65.0 mm ± 0.5 mm; and

a diameter of the tube bore is equal to 100.0 mm ± 0.5 mm.

2. The actuator of claim 1, wherein actuation of the first structural element relative to the second structural element results in at least one of a change in the position of a moldboard blade or a dozer blade of the motor grader relative to a ground surface on which the motor grader is operating, a change in position of the moldboard blade or the dozer blade relative to a front frame of the motor grader, a change in position of a ripper of the motor grader relative to the ground surface

on which the motor grader is operating, or a change in position of the ripper relative to a rear frame of the motor grader.

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

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

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

a piston mounted at a distal end of the rod;

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

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

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

a retracted pin-to-pin dimension from a center of the trunnion cap bore to a center of the rod eye bore when the rod and piston are fully retracted into the tube with the distal end of the rod positioned adjacent the closed, distal end of the tube is equal to 822.2 mm ± 2.5 mm;

a stroke dimension from a first, fully retracted position of the piston adjacent the closed, distal end of the tube to a second, fully extended position of the piston in contact with the head seal assembly at the proximal end of the tube is equal to 1113.6 mm ± 1.5 mm;

a diameter of the rod is equal to 65.0 mm ± 0.5 mm; and

a diameter of the tube bore is equal to 100.0 mm ± 0.5 mm.

4. The motor grader of claim 3, wherein actuation of the first structural element relative to the second structural element results in at least one of a change in position of a moldboard blade or a dozer blade of the motor grader relative to a ground surface on which the motor grader is

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operating, a change in position of the moldboard blade or the dozer blade relative to a front frame of the motor grader, a change in position of a ripper of the motor grader relative to the ground surface on which the motor grader is operating, or a change in position of the ripper relative to a rear frame of the motor grader.

5. A hydraulic cylinder configured for actuating a first structural element on a motor grader relative to a second structural element on the motor grader, the hydraulic cylinder comprising:

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

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

a piston mounted at a distal end of the rod;

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

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

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

a retracted pin-to-pin dimension from a center of the trunnion cap bore to a center of the rod eye bore when the rod and piston are fully retracted into the tube with the distal end of the rod positioned adjacent the closed, distal end of the tube is equal to 822.2 mm ± 2.5 mm;

a stroke dimension from a first, fully retracted position of the piston adjacent the closed, distal end of the tube to a second, fully extended position of the piston in contact with the head seal assembly at the proximal end of the tube is equal to 1113.6 mm ± 1.5 mm;

a diameter of the rod is equal to 65.0 mm ± 0.5 mm; and

a diameter of the tube bore is equal to 100.0 mm ± 0.5 mm.

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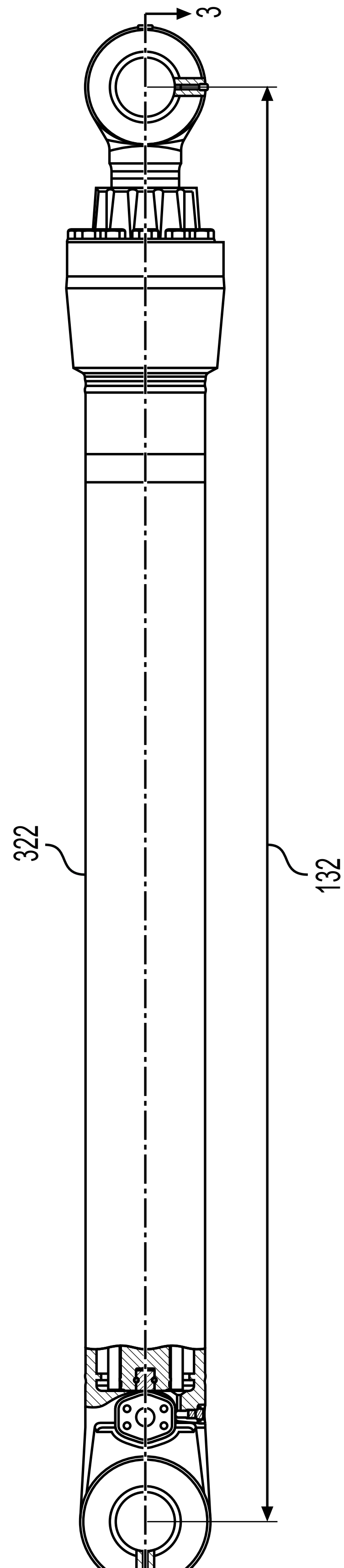


FIG. 1

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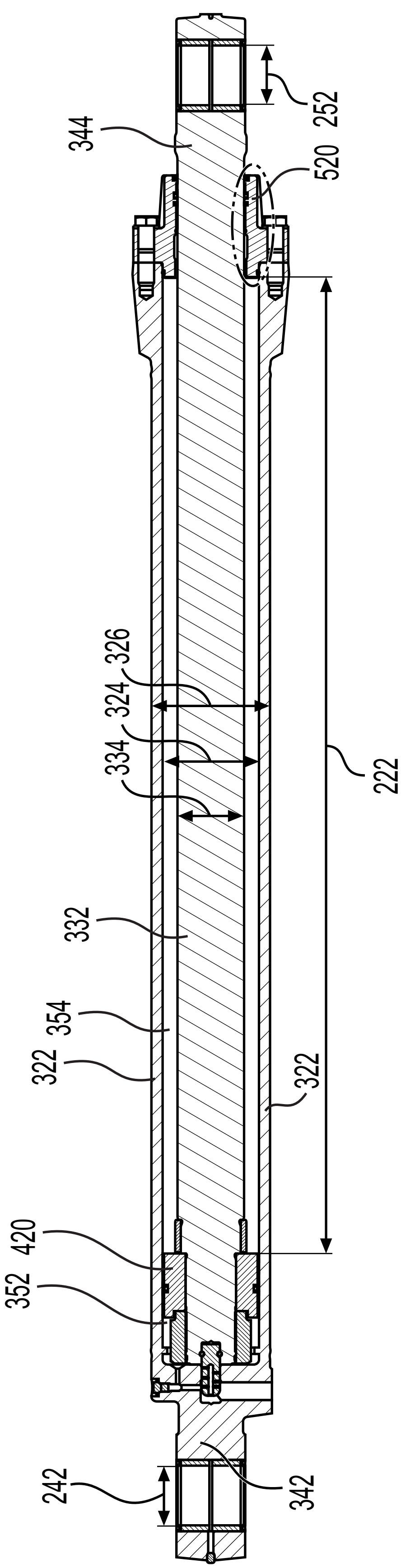


FIG. 2

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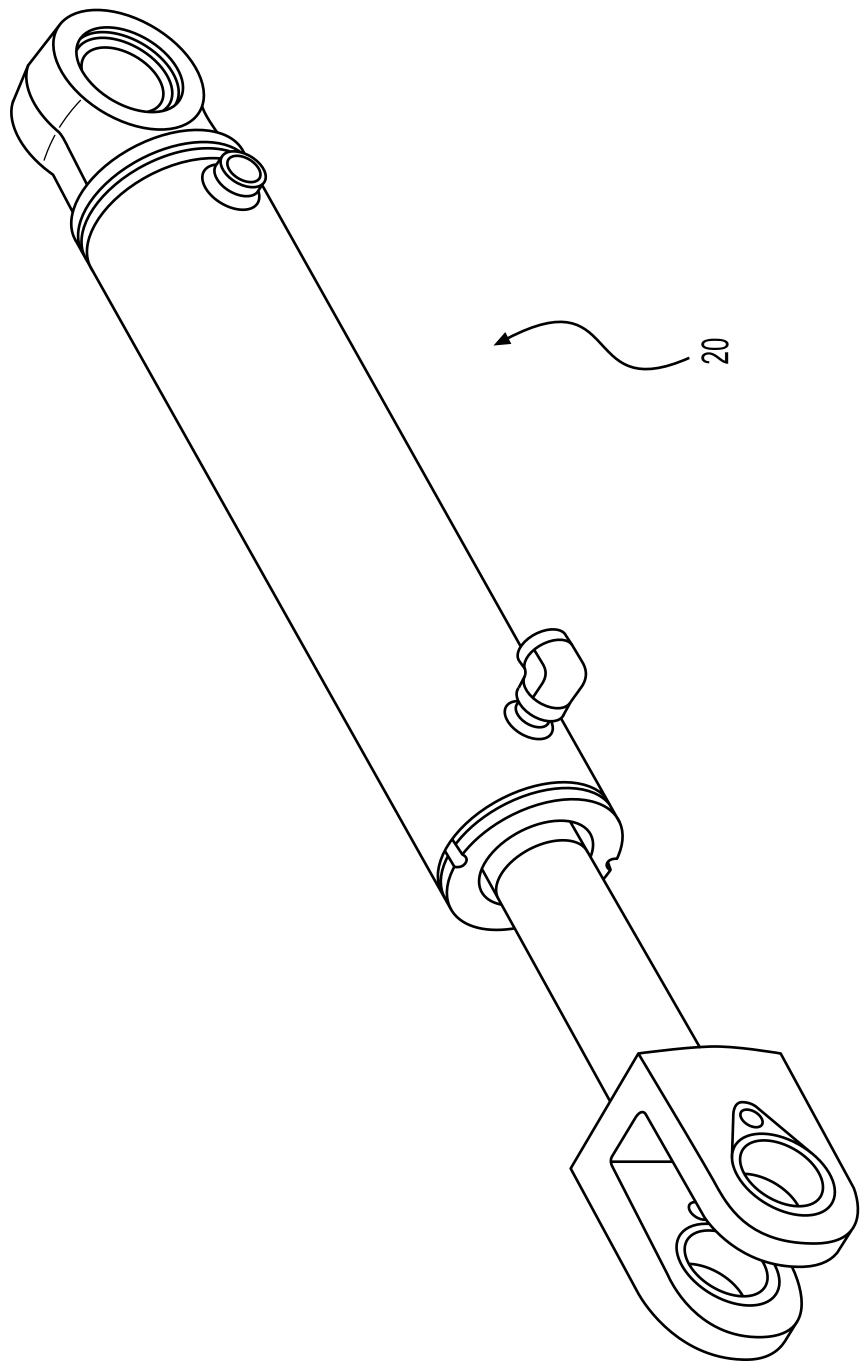


FIG. 3

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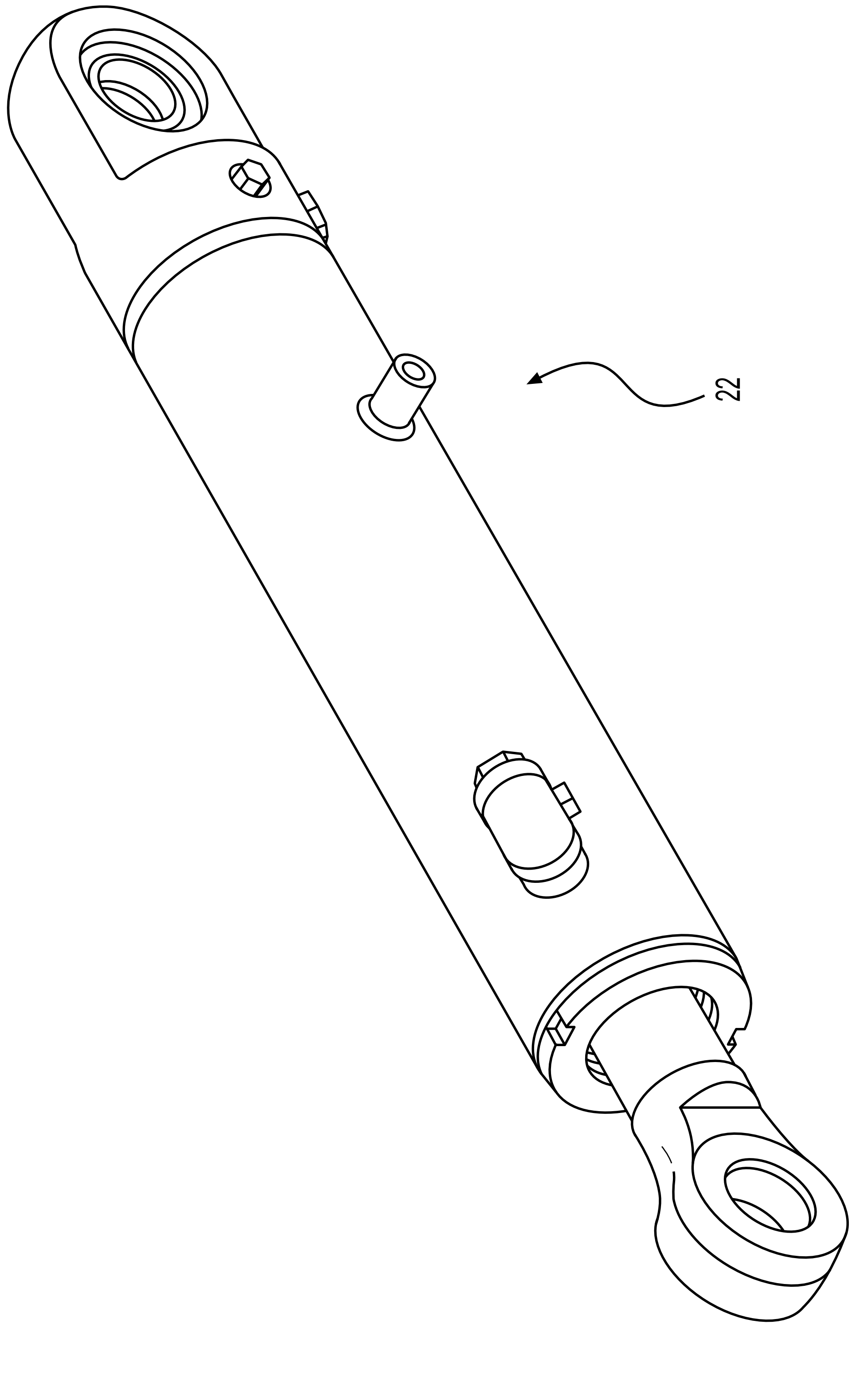


FIG. 4

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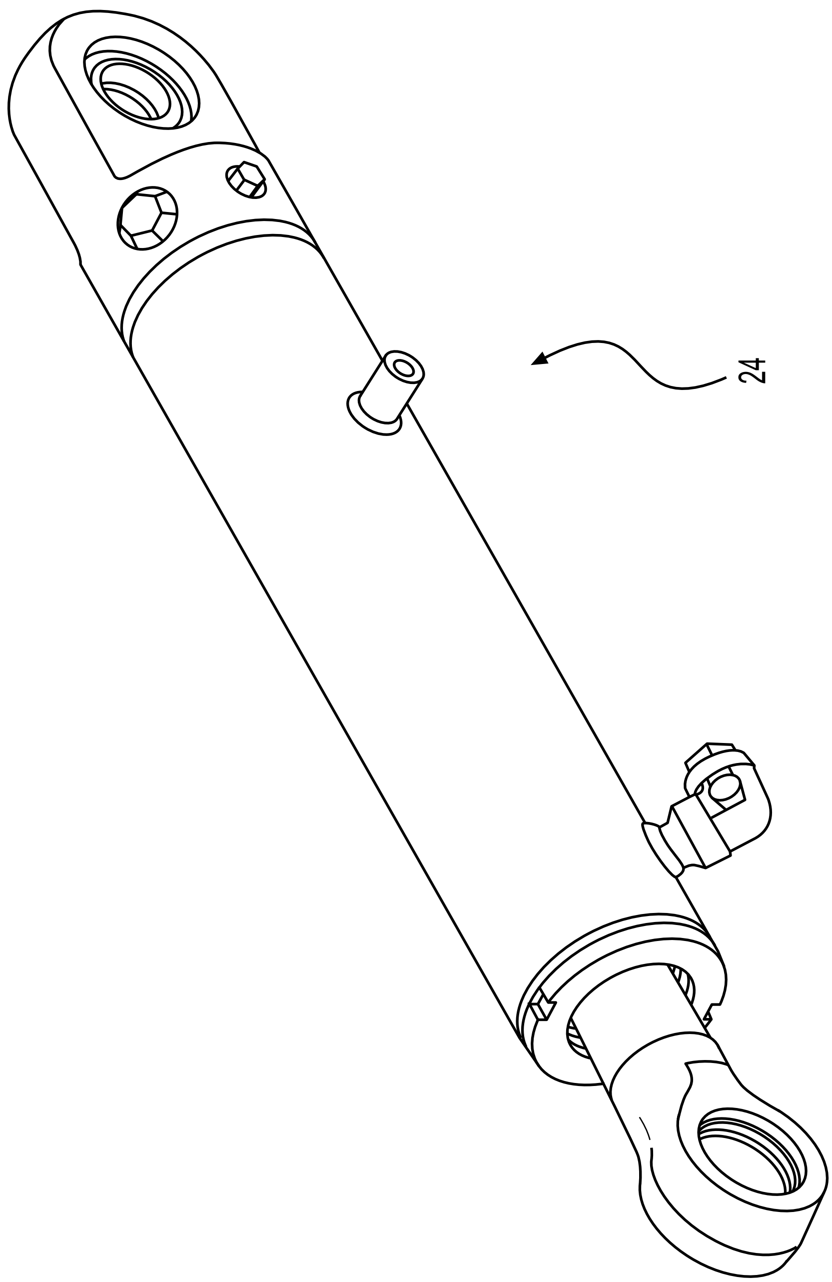


FIG. 5

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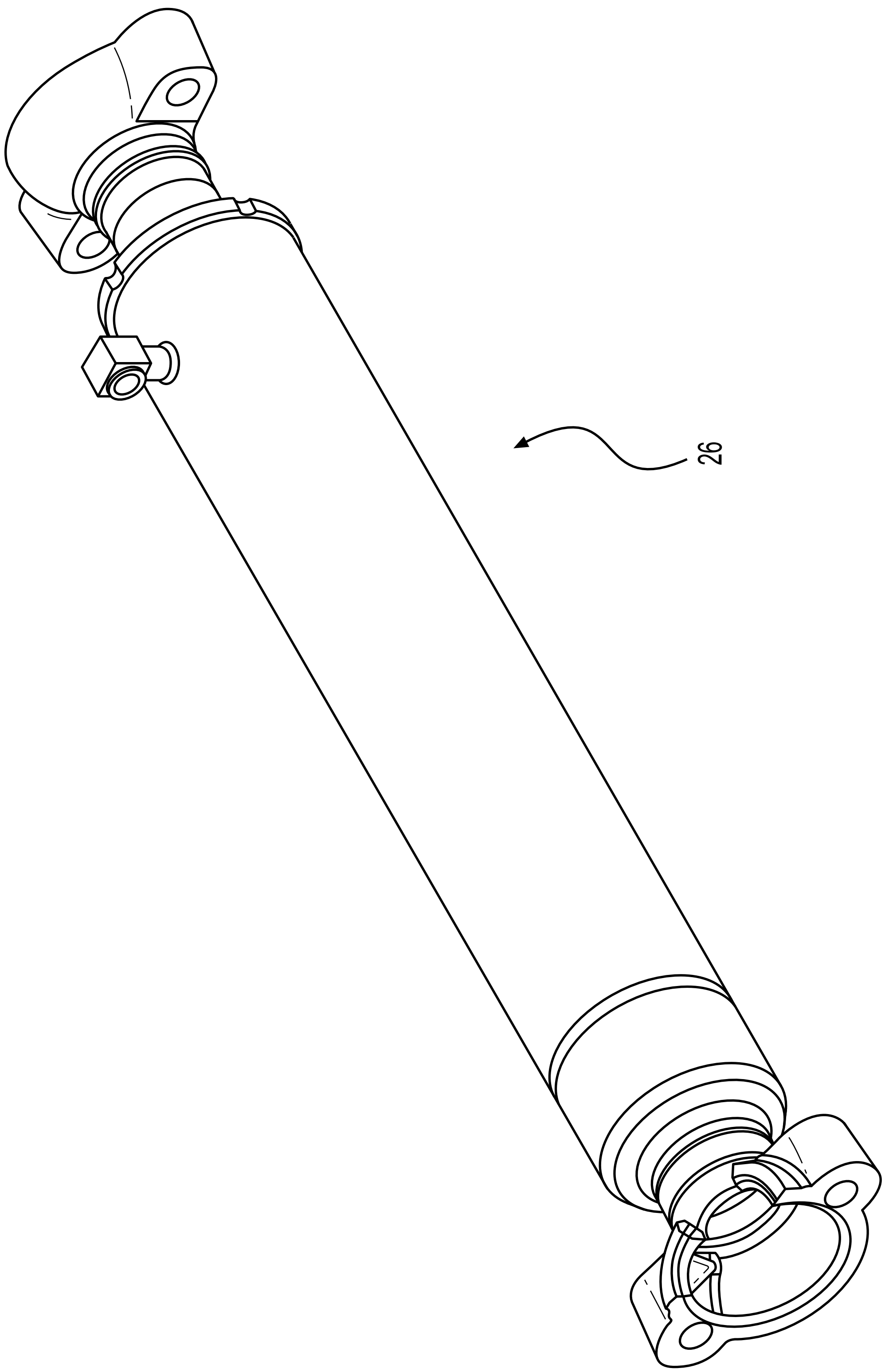


FIG. 6

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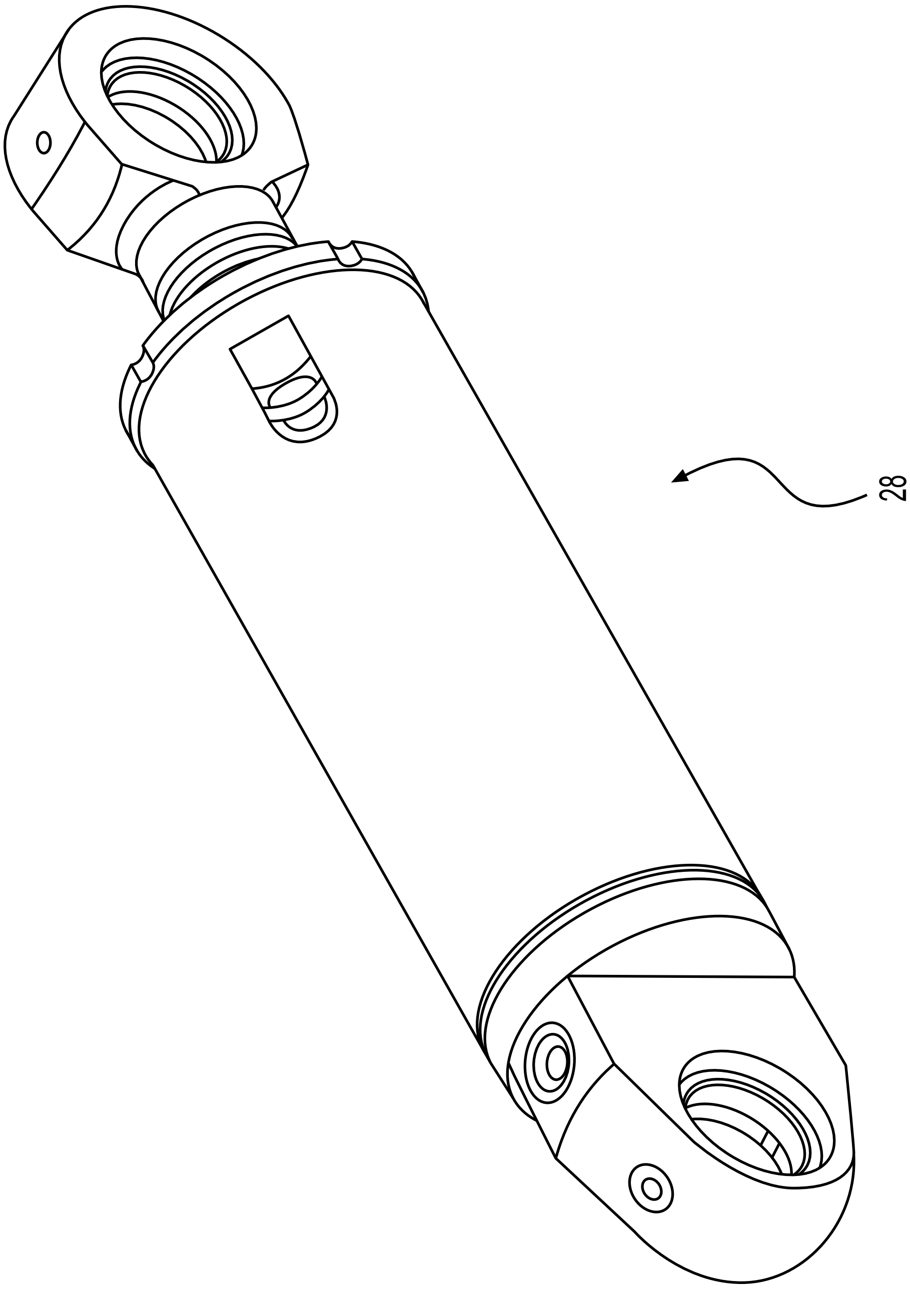


FIG. 7

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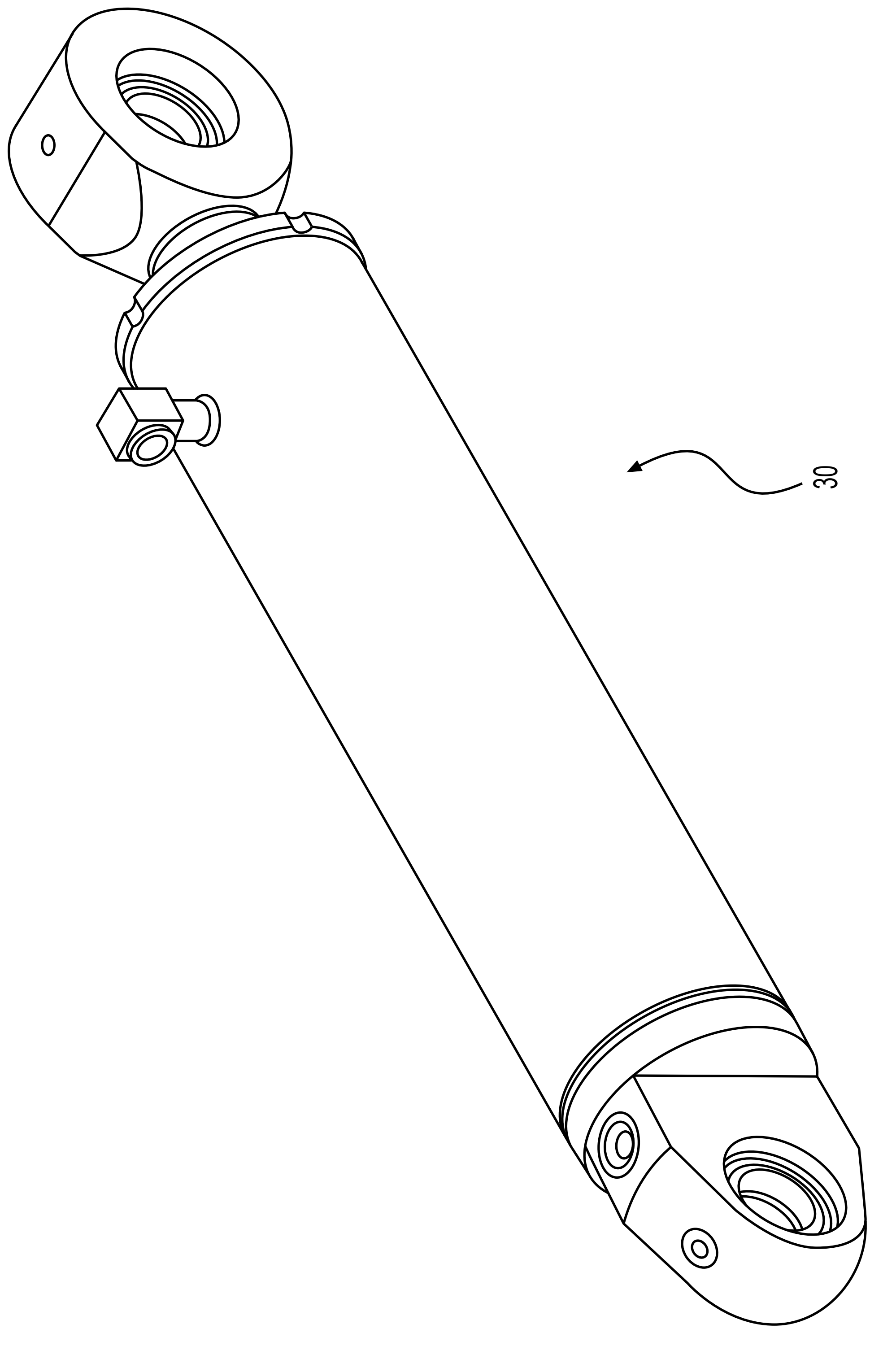


FIG. 8

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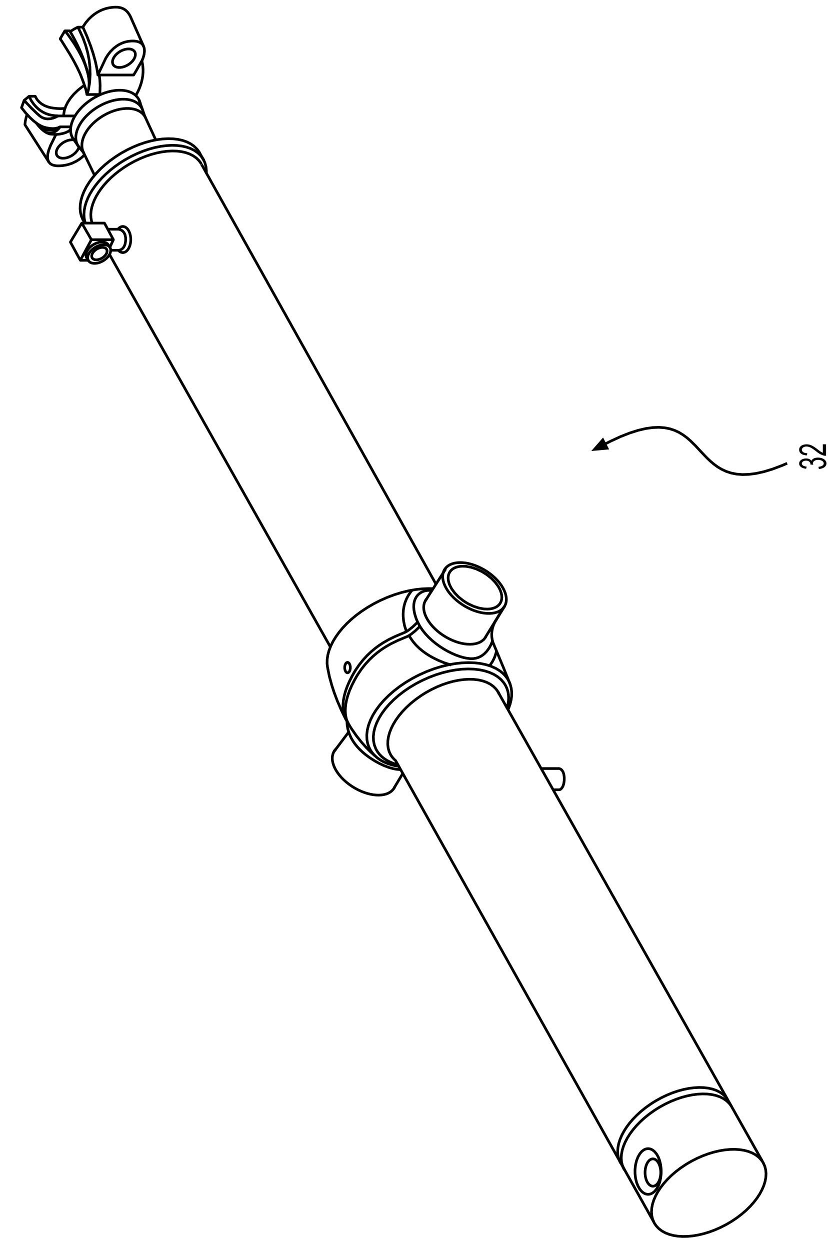


FIG. 9

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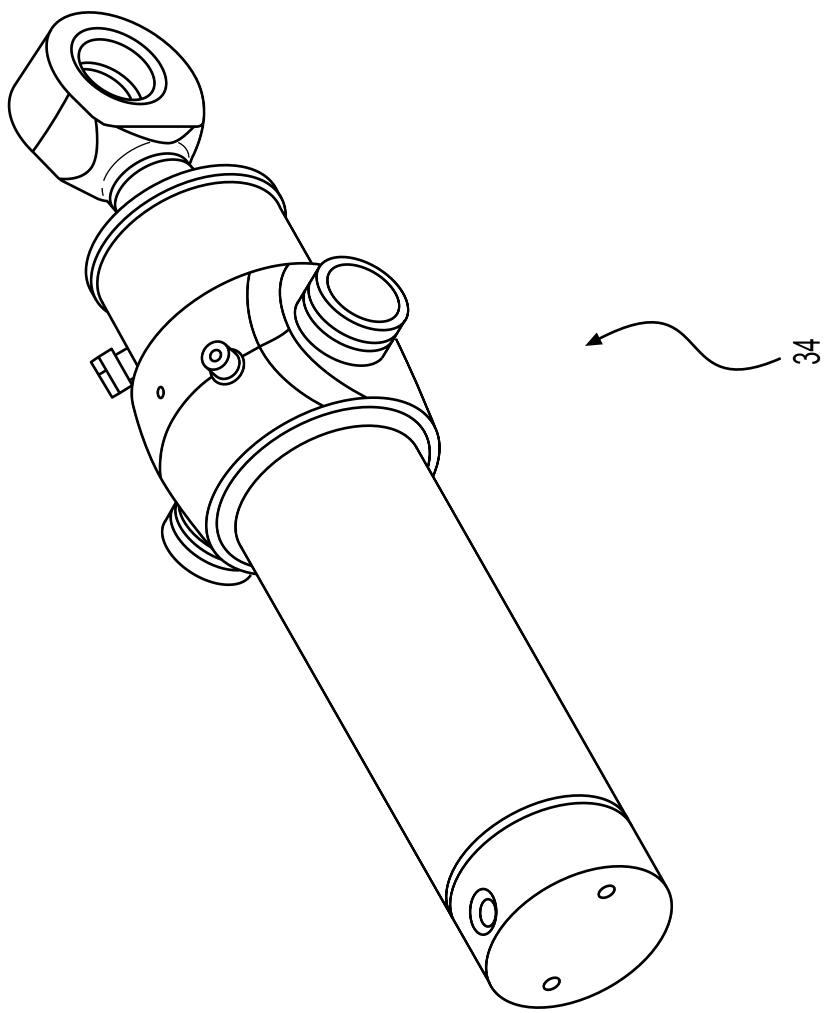


FIG. 10

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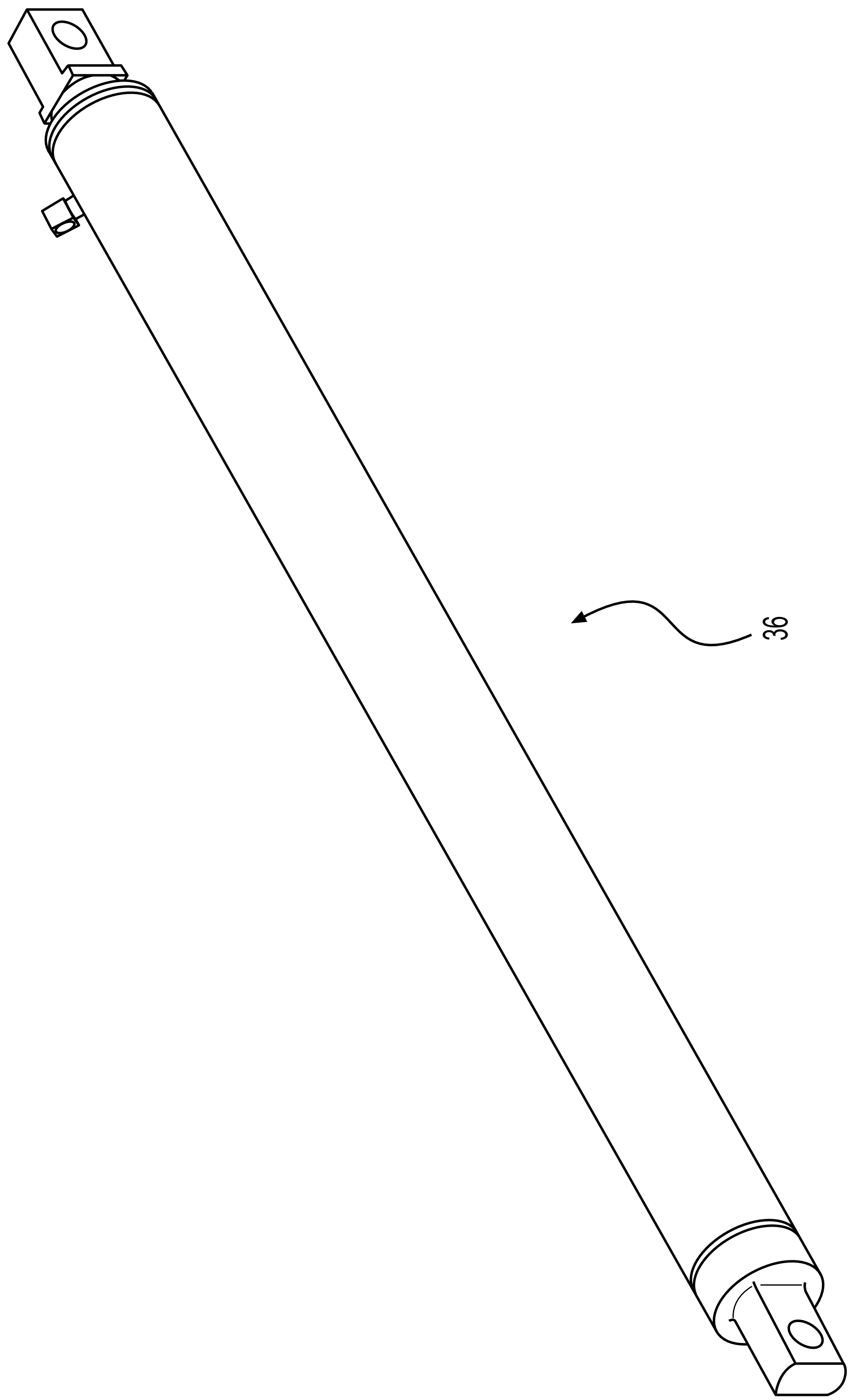


FIG. 11