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(54) Title: LINEAR SUCKER ROD TOP DRIVES

(57) Abstract: Several unique screw-based linear sucker rod top drives are disclosed, along with a unique failsafe system where the terminals of a permanent magnet motor are connected to a braking resistor in the event of variable frequency drive failure to provide a braking effect against free-fall of the sucker rod string.

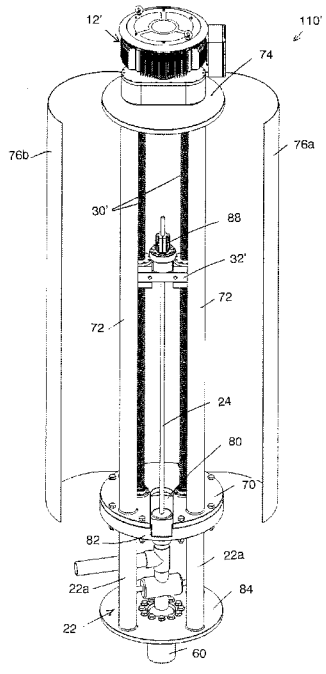


FIGURE 5B

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LINEAR SUCKER ROD TOP DRIVES

FIELD OF THE INVENTION

The invention relates generally to the oil and gas industry, and more particularly to devices for effecting reciprocal motion of sucker rods that drive downhole pumps to produce well fluids to the surface.

BACKGROUND OF THE INVENTION

The invention includes apparatuses that provide reciprocating motion to drive downhole sucker rod pumps for fluid producing wells typically found in the oil & gas industry. Sucker rod pumps consist of two valves that are operated by reciprocating motion and relative pressures in the pump body. The sucker rod pump is actuated by a long string of sucker rods that are screwed together to make a long, slender string of rods. At the surface, a machine is required to pull the rod upwardly to lift fluid to the surface in successive, repetitive motion. Once the fluid is lifted, the machine also needs to lower the rod string and the upper pump body back down in order to capture the next volume of fluid to be pumped to surface.

Traditional pump jack machines are arguably the work horse of the oil & gas industry. While reliable and robust, they are expensive and utilize a large surface space and significant material resources to drive the downhole reciprocating pump. The machines are required to operate very slowly such that the maximum cycle speed is typically less than 20 cycles per minute and usually less than 5 cycles per minute. This very slow speed means that in normal circumstances at least two speed reduction transmissions take place. A prime mover, typically an AC induction motor, has its speed reduced via belts & pulleys to drive a gearbox. The gearbox further reduces the speed to drive the pump jack at the low cycle speed noted earlier. The reciprocating motion is produced by means of a simple mechanism. However, in order to increase the reciprocation motion from a typical minimum of 24-inches up to a typical maximum of 144-inches, the size of the mechanism needs to be scaled accordingly. A large pump jack mechanism becomes elaborate and expensive. Some of these machines can be noisy, particularly if maintenance is required. Some production locations are located close to residential areas. In these types of areas, where noise pollution may be an issue, quieter solutions may be preferred and/or required.

Others have introduced linear motion devices, such as Linear Rod Pumps (LRPs), examples of which can be found in U.S. Patent No. 8,668,475 by Unico, Inc. These devices have a much smaller footprint than traditional pump jacks, and feature an electric motor driving a 90°

gearbox that in turn drives a pinion gear engaged to a vertical rack to which the sucker rod is coupled. The motor direction reverses whenever the pump needs to change direction from up to down or down to upward motion. That is, the motor is driven in opposite directions for the two halves of each full oscillation of the sucker rod. One potential drawback is the need for a gearbox between the motor and the rack, which contributes to an overall power transmission solution of notable complexity, part count, and energy inefficiency.

Other linear technology for reciprocating operation of sucker rods includes hydraulically driven rod pumps, where the linear motion of the sucker rod is achieved by one or more linear hydraulic actuators. The prime mover can be a petrochemical fueled engine driving a hydraulic pump that is subsequently used to move the linear actuator(s) up and down. One example of a hydraulic rod pump is found in U.S. Patent Application Publication 2010/0300679 of National Oilwell Varco (NOV). One potential drawback of hydraulically driven systems is that hydraulic leaks can occur, and when they do occur, usually all of the hydraulic fluid in the entire system is dispensed onto the operator's lease, as the system is under very high pressure. Additionally, hydraulic power delivery is inherently inefficient. Long term operating costs of a hydraulic system will typically be higher than a similarly equipped electric system. Like the linear rod pumps, where the gearbox is required as an intermediate power transmission stage between the rotational output of the electric motor and the vertical displacement of the rack, the hydraulic system likewise employs multiple stages between the prime mover and the vertical rod displacement, requiring conversion of the rotational output of the prime mover to hydraulic pressure by the pump, which in turns drives the linear displacement of the actuator(s).

Other linear technology for reciprocating operation of sucker rods includes screw-based linear sucker rod top drives. Examples such screw-based designs include those found in U.S. Patents 2,891,408 of Burt; 2,913,910 of Gillum; 3,065,704 of Hill; and 5,404,767 of Sutherland; U.S. Patent Application Publication US20060275161 of St. Denis; Russian Patents RU2133875 of Tsjuan et al. and RU2482332 of Valentinovich; and Chinese Utility Model 203891844 of Wensheng et al. Wensheng et al. uses a permanent magnet motor directly driving the lead screw for an efficient direct-drive relation therebetween, thereby avoiding the gearbox transmission of the LRP system and the hydraulic power conversion of hydraulic systems.

However, there remains room for improvement in the general field of linear sucker rod top drives, and Applicant has developed several unique designs offering alternatives and improvements to the prior screw-based designs, and well as improved serviceability of well components without removal of the sucker rod top drive.

SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided a linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a rotary screw device comprising:

a first rotary screw component; and

a second rotary screw component cooperatively mated with the first rotary screw component for linear displacement of said second rotary screw component along a longitudinal axis of said rotary screw device under relative rotation between said first and second rotary screw components about said longitudinal axis;

a drive source operatively coupled to said rotary screw device to drive said relative rotation between said first and second rotary screw components; and

a sucker rod connection carried by said second rotary screw component and arranged for coupling of the sucker rod thereto, whereby said linear displacement of said second rotary screw component drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis of the rotary screw device;

an anti-rotation arrangement for constraining rotation of the second rotary screw component around the longitudinal axis, said anti-rotation arrangement comprising:

a first anti-rotation element carried on the second rotary screw component; and

a second anti-rotation element attached to a stationary frame located at a longitudinal distance from said second rotary screw component, the first and second anti-rotation elements being keyed together to prevent relative rotation therebetween and one of said first and second anti-rotation elements being longitudinally extendable and collapsible to accommodate movement of the second rotary screw component toward and away from the stationary frame along the longitudinal axis.

According to a second aspect of the invention, there is provided a linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a rotary screw device comprising:

a first rotary screw component; and

a second rotary screw component cooperatively mated with the first rotary screw component for linear displacement of said second rotary screw component along a

longitudinal axis of said rotary screw device under relative rotation between said first and second rotary screw components about said longitudinal axis;

a drive source operatively coupled to said rotary screw device to drive said relative rotation between said first and second rotary screw components; and

a sucker rod connection carried by said second rotary screw component and arranged for coupling of the sucker rod thereto, whereby said linear displacement of said second rotary screw component drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis of the rotary screw device;

wherein the drive source comprises a motor, a stator of which is mounted a fixed stationary position surrounding the first rotary screw component in concentric relation therewith around the longitudinal axis, the first rotary screw component defining a rotatably driven output of said motor, whereby operation of said motor linearly displaces the second rotary screw component along the longitudinal axis.

According to a third aspect of the invention, there is provided a linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a rotary screw device comprising:

a first rotary screw component; and

a second rotary screw component cooperatively mated with the first rotary screw component for linear displacement of said second rotary screw component along a longitudinal axis of said rotary screw device under relative rotation between said first and second rotary screw components about said longitudinal axis;

a drive source operatively coupled to said rotary screw device to drive said relative rotation between said first and second rotary screw components; and

a sucker rod connection carried by said second rotary screw component and arranged for coupling of the sucker rod thereto, whereby said linear displacement of said second rotary screw component drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis of the rotary screw device;

wherein the first rotary screw component is a hollow outer rotary screw component of greater axial length than the second rotary screw component, and the second rotary screw component is an inner rotary screw component engaged to the hollow outer rotary screw component within a hollow interior thereof for longitudinal displacement back and forth therein.

According to a fourth aspect of the invention, there is provided a linear sucker rod

top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a rotary screw device comprising:

a first rotary screw component; and

a second rotary screw component cooperatively mated with the first rotary screw component for linear displacement of said second rotary screw component along a longitudinal axis of said rotary screw device under relative rotation between said first and second rotary screw components about said longitudinal axis;

a drive source operatively coupled to said rotary screw device to drive said relative rotation between said first and second rotary screw components; and

a sucker rod connection carried by said second rotary screw component and arranged for coupling of the sucker rod thereto, whereby said linear displacement of said second rotary screw drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis of the rotary screw device;

wherein the first rotary screw component is one of a pair of parallel externally-threaded rotary screw components that are each engaged through a respective axial bore in the second rotary screw component, and the drive source is arranged to drive simultaneous rotation of said pair of parallel externally-threaded rotary screw components, whereby the first rotary screw component is linearly displaced along the pair of parallel externally-threaded rotary screw components during said simultaneous rotation thereof; and

wherein the drive source comprises a motor operatively coupled to the pair of parallel externally-threaded rotary screw components and residing in alignment with the sucker rod connection on the second rotary screw component so as to center the motor in alignment with the sucker rod.

According to a fifth aspect of the invention, there is provided a linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a linear motion generator having an output component arranged for linear displacement under driven operation of said linear motion generator; and

a sucker rod connection carried by said output component of the linear motion generator and connected or connectable to the sucker rod to drive linear movement thereof under said driven operation of the linear motion generator;

a movable base component on which the linear motion generator is carried;

a stationary base component mounted or mountable in an elevated position over a wellhead; and

a movable connection between the movable base component and the stationary base component booth to enable movement of the movable base component between a working position in which the linear motion generator stands atop the movable base component in an operating position aligned over the wellhead, and a maintenance position in which the linear motion generator is at least partially withdrawn from its operating position over the wellhead.

According to a sixth aspect of the invention, there is provided a linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a drive source comprising a motor;

a rotary screw mechanism comprising:

an externally threaded shaft rotatably driven by the motor about a central longitudinal axis of said externally threaded shaft, on which the motor is also centered;

a carriage having:

an internally threaded bore at which the carriage is operably engaged with the externally threaded shaft for linear displacement of the carriage along said longitudinal axis under driven rotation of the externally threaded shaft by the motor;

a sucker rod connection carried on said carriage at a location radially outward from the externally threaded shaft to one side thereof for coupling of the sucker rod to said carriage, whereby said linear displacement of said carriage drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis at a position offset outwardly therefrom; and

a linear guide standing upright in a stationary position at a radial distance outward from the externally threaded shaft, the carriage being slidably engaged with said linear guide to constrain the carriage against rotation about the longitudinal axis.

According to a seventh aspect of the invention, there is provided a linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a linear motion generator having an output component arranged for linear displacement under driven operation of said linear motion generator; and

a permanent magnet motor operably coupled to the linear motion to drive operation of the linear motion generator during at least an upstroke thereof, with rotational movement of the permanent magnet motor being linked to the linear motion generator in both the upstroke thereof

and a downstroke thereof;

a variable frequency drive connected to the permanent magnet motor to normally control operation thereof;

a secondary electrical load that is independent of an operative state of the variable frequency drive and is arranged for selective connection to terminals of the permanent magnet motor thereof to apply a voltage across said terminals of the permanent magnet motor to the secondary load; and

a failsafe mechanism operable to connect the secondary load to the terminals of the permanent magnet motor in response to detected failure of the variable frequency drive;

wherein connection of the secondary load across the terminals of the permanent magnet creates a braking effect on rotation of the motor during the downstroke of the linear motion generator, thereby slowing a gravitationally induced lowering of the sucker rod during a failed state of the variable frequency drive.

BRIEF DESCRIPTION OF THE DRAWINGS

One embodiment of the invention will now be described in conjunction with the accompanying drawings in which:

Figure 1 is a vertical cross-section of a first embodiment rotary screw linear sucker rod top drive apparatus, in which the vertical output shaft of an electric motor is an internally threaded hollow shaft defining an outer component of a rotary screw mechanism whose cooperating inner component carries a sucker rod of a downhole pump while being rotationally constrained by a set of telescopic sleeves.

Figure 2 is a vertical cross-section of a second embodiment rotary screw linear sucker rod top drive apparatus, which differs from the first embodiment in that rotation of the inner rotary screw component is instead constrained by a set of guide rods passing therethrough within the hollow interior of the outer rotary screw component.

Figure 3 is a vertical cross-section of a third embodiment rotary screw linear sucker rod top drive apparatus, which differs from the first two embodiments in that the rotary screw mechanism is a sealed oil-containing unit, and rotation of the inner rotary screw component and attached sucker rod is constrained by external guide rods situated outside the sealed screw mechanism in a separate guide section of the apparatus.

Figure 4 is a vertical cross-section of a fourth embodiment rotary screw linear sucker rod top drive apparatus, in which the rotary screw mechanism employs two externally threaded shafts driven by a common motor to linearly displace a multi-bored nut that carries the

sucker rod, where the use of multiple screw shafts omits the need for separate rotational-constraint of the nut.

Figure 5A is an elevational rear perspective view of a fifth embodiment rotary screw linear sucker rod top drive apparatus, with a pivotal base component thereof in a working position and an openable/closeable housing thereof in a closed condition, whereby a dual-shaft screw mechanism similar to that of the fourth embodiment stands upright within the protective confines of the housing in an operational state aligned over a wellhead.

Figure 5B is an elevational front perspective view of the fifth embodiment rotary screw linear sucker rod top drive apparatus of Figure 5A with the housing thereof in an open condition revealing access to the dual-shaft screw mechanism.

Figure 5C is a partial elevational front perspective view of the fifth embodiment rotary screw linear sucker rod top drive as cross-sectioned in a non-central vertical plane thereof to reveal internal components of a simple gear box that connects the common motor to the two externally threaded shafts of the rotary screw mechanism.

Figure 5D is a side elevational perspective view of the fifth embodiment rotary screw linear sucker rod top drive apparatus of Figure 5A with the pivotal base component thereof in a maintenance position tilting the housing outwardly away from the wellhead for improved access thereto.

Figure 6 is a vertical cross-section of a sixth embodiment rotary screw linear sucker rod top drive apparatus in which the rotor of the electric motor features an internally threaded nut defining an outer component of the screw mechanism, the inner component of which is a singular externally threaded shaft to which the sucker rod is connected via a carriage that also engages a set of guide rods to rotationally constrain the inner screw component and attached sucker rod.

Figure 7 is a vertical cross-section of a seventh embodiment rotary screw linear sucker rod top drive apparatus in which the motor drives a singular externally threaded shaft of the screw mechanism that is situated in concentric alignment with the motor, while the cooperating second component of the screw mechanism which is an internally threaded carriage that carries the sucker rod in an offset position alongside the threaded shaft while being rotationally constrained by a linear guide slidably mated with the carriage in a position also offset to the side of the threaded shaft.

Figures 8A and 8B schematically illustrate a rotary screw linear sucker rod top drive employing a permanent magnet motor with a failsafe braking system, where Figure 8A illustrates the system during an upstroke of a normal operating cycle, and Figure 8B illustrates a failsafe

braking operation during the downstroke after failure of the motor's variable frequency drive.

DETAILED DESCRIPTION

Figure 1 shows a rotary screw linear sucker rod top drive apparatus 10 according to a first embodiment of the present invention. Briefly, the apparatus features a permanent magnet motor 12, a rotary screw device 14, a cover 16, and an anti-rotation arrangement 20. The apparatus is mounted atop a booth or pedestal stand 22, which in a conventional manner has an open vertical pathway running centrally therethrough to accommodate passage of a sucker rod 24 through the central pathway of the booth between the top drive apparatus 10 and the wellhead over which the booth 22 is mounted. In typical fashion, the booth 20 features spaced apart vertical legs 22a that elevate the top drive apparatus 10 at a spaced distance above the wellhead while leaving open side areas between these legs around the perimeter of the booth. This open side areas of the booth enable access to the sucker rod 24, a stuffing box mounted on the wellhead, and/or any other equipment located within the interior area of the booth. Accordingly, such access is readily available without having to remove the top drive apparatus.

The motor 12 features a stator 26 mounted atop the booth 22 in a stationary, rotationally-fixed position. The rotor 28 of the motor is defined partly by a hollow outer component 30 of the rotary screw device, which is an internally threaded shaft that replaces the rotationally driven output shaft of a conventional motor. The hollow outer rotary screw component 30 has an axial length that notably exceeds that of the motor stator 26 and is helically threaded over its full length in order to define the maximum available stroke length of the sucker rod 24. The axial bore of the hollow outer rotary screw component 30 is open at both the upper and lower ends thereof, thus defining a hollow interior space of the hollow outer rotary screw component that fully spans the axial direction thereof on a central vertically-oriented longitudinal axis L of the apparatus 10. In the illustrated embodiment, the bottom end of the hollow outer rotary screw component 30 lies near or flush with the booth-mounted bottom end of the motor stator 26, while the upper portion of the hollow outer rotary screw component 30 reaches a notable distance upward from the top end of the motor stator 26. This way, the motor stator defines a lower end of the apparatus, thereby concentrating the weight of the motor nearer to this bottom end of the apparatus for notable stability without an extensive support framework that my otherwise be needed for higher motor placement options. The stator's position closing around the hollow outer rotary screw component 30 in concentric relation thereto about the longitudinal axis L provides the apparatus with a small footprint and balanced structure compared to prior LRP and screw based top drives where the motor is offset to one side of the rack or screw based linear motion generator.

The rotary screw mechanism features an inner screw component 32 in the form of an externally threaded nut matingly engaged with the threaded interior of the hollow outer rotary screw component 30, whereby driven rotation of the hollow outer rotary screw component 30 by the motor 12 linearly displaces the inner rotary screw component 30 along the longitudinal axis L on which the two screw components are concentrically disposed. It will be appreciated that the term "nut" in being used herein to denote the axially-shorter one of two cooperating components of a rotary screw device, regardless of whether this component is internally or externally threaded. The screw device may be a lead screw, with direct thread-to-thread mating between the inner and outer rotary screw components; a roller screw with intermediate rollers engaged between the threads of inner and outer rotary screw components; or a ball screw, with spherical balls rollingly disposed in the raceways formed by the cooperatively aligned threading of the inner and outer rotary screw components. For example, rotary screw products having this externally threaded inner nut and internally threaded outer shaft configuration are commercially available from SKF in their line of inverted roller screw products.

The linear rotary screw sucker rod top drives in the aforementioned prior art employ externally threaded shafts on which an internally threaded nut is mated, whereby the presently disclosed embodiment and its use of a hollow internally threaded shaft as the motor output with a cooperating inner screw member disposed therein allows for a radially compact footprint of concentrically disposed components all residing on the same longitudinal axis on which the sucker rod is carried. The sucker rod 24 is attached to the inner rotary screw component 32 by a suitable sucker rod connection, for example by receipt of an upper end of the sucker rod 22 within a central axial bore of the inner rotary screw component, as shown, and use of a suitable clamp (not shown) to secure the sucker rod to the inner rotary screw component.

To lock the inner rotary screw component 32 against rotation about the longitudinal axis L, a first anti-rotation element is defined on the inner rotary screw component in the form of a reduced-diameter solid-shank extension 34 fixed to the topside of the inner rotary screw component 32 for cooperation with a second anti-rotation element in the form of a set of telescopically expandable/collapsible sleeves 36 mounted to the underside of a top wall 38 of the cover 16 that closes over the top end of the hollow outer rotary screw component 30 at an axial distance thereabove. The shank 34 is stepped down in cross-sectional size from the externally threaded main body of the inner rotary screw component 32, thus having an outer diameter that is also smaller than the inner diameter of the hollow outer rotary screw component 30. The shank 34, or at least the top end thereof, has a square, or other flat-sided, non-circular, irregular or splined outer periphery that

is matingly shaped to match the interior cross-section of the smallest, innermost sleeve 36a of the telescopic sleeve set 36 so accomplished a keyed rotation-preventing engagement between the extension 34 and the innermost sleeve 34. The sleeves are likewise mated in a keying fashion to prevent any relative rotation therebetween, and the largest outermost sleeve 36b is affixed to the top wall 38 in the cover, which in turn is fastened to the top of the motor stator in a non-rotatable manner so as to define a stationary reference frame to which the inner rotary screw component 32 is rotationally locked by cooperation of the extension 34 and the telescopic sleeves. In a simple embodiment, the sleeves and extension may be of square or rectangular cross-section to prevent rotation therebetween while allowing axial sliding therebetween along the longitudinal axis. The term "key" is being used herein to denote the prevention of relative rotation between the "keyed together" components for rotation together in a locked manner, and not to a specific means of accomplishing that rotationally-locked condition, which in addition to the aforementioned use of non-circular, splined or irregular cross-sectional shapes of the mated components may be achieved by used of an actual keyed joint relying on a separate key to mate with a keyway and keyseat in the two mating components to block relative rotation therebetween.

Figure 1 shows the sleeve set in a fully collapsed condition corresponding to the uppermost attainable position of the inner rotary screw component 32 at the top end of the hollow outer rotary screw component 30. Here, the inner sleeves are nested within the largest outermost sleeve, and the extension 34 reaches upwardly into the smallest sleeve 36a in a fully raised position surrounded by all sleeves of the set. Each sleeve, perhaps with the exception of the largest outermost sleeve, has an outer diameter smaller than the inner diameter of the hollow outer rotary screw component 30, whereby these sleeves can reach downwardly into the hollow interior of the hollow outer rotary screw component 30 as the sleeves telescopically extend downwardly during lowering of the inner rotary screw component 32.

Suitable slide limits, for example in the form of cooperating pins and longitudinal slots at the side walls of the sleeves, prevent any of the inner sleeves from fully separating from the immediately surrounding sleeve. In one embodiment, the innermost sleeve, near its bottom end, is pinned to the extension 34 to ensure that downward motion of the inner rotary screw component 32 will pull the innermost sleeve downwardly therewith regardless of whether the downward gravitational bias of the innermost sleeve 36a is enough to overcome the friction between the sleeves. If the downward gravitational bias of the sliding sleeves is sufficient to overcome any frictional resistance between the sleeves, then initial downward movement of the inner rotary screw component 32 and its extension 34 will cause all but the fixed outermost sleeve 36b to initially slide

downward, and each sliding sleeve will stop only once its lowermost limit is reached. If the frictional resistance exceeds the gravitational bias, then the innermost sleeve will move downwardly initially, followed by accompanying movement of the next surrounding sleeve once the innermost sleeve has reached its sliding limit relative thereto, until all of the sliding sleeves have been extended out from the fixed outermost sleeve. The length and number of sleeves is selected as required to accommodate the required stroke length of the apparatus.

To reciprocate the sucker rod 24 within the wellbore along the longitudinal axis L, the motor 12 is operated in a first directional mode causing the hollow outer rotary screw component 30 to rotate in the direction causing the inner rotary screw component 32 to travel downwardly within the hollow outer rotary screw component 30, thereby effecting the downstroke of the sucker rod. Upon completion of the downstroke, operation of the motor in the first directional mode is terminated, and operation of the motor in the opposing second direction mode is initiated to drive the hollow outer rotary screw component 30 in the reverse direction, thereby causing the inner rotary screw component 32 to rise upwardly through the interior of the hollow outer rotary screw component 30, thus carrying the sucker rod through its upstroke. The cooperating sleeves 36 and extension 34 hold the inner rotary screw component 32 against rotation throughout the upstroke and downstroke of the sucker's rod's reciprocal motion.

While the illustrated embodiment uses a telescopically extendable collapsible sleeve set affixed to a stationary reference frame at the top wall of the cover to cooperate with a longitudinal extension situated atop the inner rotary screw component, other embodiments may feature the reverse configuration, where a telescopic assembly carried on the inner rotary screw component cooperates with a non-telescopic element fixed to the stationary reference frame. In either event, the telescopic element of the anti-rotation arrangement accommodates the reciprocating movement of the inner rotary screw component relative to the stationary reference frame through collapse and extension of the telescopic element as the inner rotary screw component moves toward and away from the stationary frame.

In addition, while the illustrated embodiment has the frame-attached anti-rotation element 36 situated above the rotary screw device, and the screw-carried anti-rotation element 34 situated on the topside of the longitudinally reciprocated screw component 32, other embodiments may have these elements respectively situated below the rotatably driven screw component 30 and at the underside of the longitudinally reciprocated screw component 32, provided that the elements are configured not to interfere with the sucker rod 24 that depends downward from the underside of the longitudinally reciprocated screw component 32. In such instance, the longitudinal extension 34

on the longitudinally reciprocated screw component 32 could be a hollow shank closing around the sucker rod 24, and the stationary frame could be an internal flange reaching inwardly toward the longitudinal axis beneath the rotatably driven screw component 30, for example at the bottom of the motor stator 26 or at the top of the booth 22. Such flange would to carry the anti-rotation sleeves in a position closing around the sucker rod 24.

It will also be appreciated that the use of a telescopic anti-rotation element to cooperate with a suitably keyed extension of the longitudinally displaceable screw component, or vice versa, could also be used in embodiments where the rotatably driven screw component is an externally threaded shaft and the longitudinally displaceable rotary screw component is an internally threaded nut, provided that the anti-rotation components are hollow in order to accommodate the externally threaded shaft within their confines.

Figure 2 illustrates a second embodiment linear rotary screw sucker rod top drive apparatus 10' that differs from the first illustrated embodiment mainly in terms of the anti-rotation arrangement for constraining the inner rotary screw component 32 against rotation around the longitudinal axis L. Instead of a telescopic anti-rotation arrangement, the second embodiment features a pair of parallel guide rods 40 running parallel to the longitudinal axis L within the hollow interior space of the hollow outer rotary screw component 30, and passing through two axial bores in the inner rotary screw components 32. The guide rods span from near the open upper end of the hollow outer rotary screw component 30 down through the open lower end thereof. Here, the bottom end of the motor stator 26 features an in-turned support flange 42, which as mentioned above could alternatively be used to accommodate placement of the first embodiment's telescopic anti-rotation arrangement below the hollow outer rotary screw component 30. In the second embodiment, this in-turned support flange 42 instead is used to fix the lower ends of the two guide rods 40 in place, while the opposing upper ends of the two guide rods 40 are fixed in place by fastened connection to the top wall 38 of the cover, for example by engagement of externally threaded upper ends of the two guides rods 40 with internally threaded bores of the cover's top wall 38. As shown in the figure, these threaded bores may be blind holes provided in respective bosses 44 on the underside of the cover's top wall. In the illustrated embodiment, where the bosses 44 reach downwardly into the hollow interior of the hollow outer rotary screw component 30 by a short distance, the uppermost attainable position of the inner rotary screw component 32 is dictated by contact of the upper side of the inner rotary screw component with these bosses. The illustrated guide rods 40 span a substantial majority of the outer rotary screw component's axial length, but stop slightly short of the upper end thereof. It will be appreciated that the guide rods 40 could also

reach fully through the open top end of the hollow outer rotary screw component 30. A thrust bearing 43 rotatably supports the lower end of the hollow outer rotary screw component 30 a short height above the in-turned support flange 42 of the motor stator 26.

The illustrated embodiment features two guide rods 40 situated equidistant from the longitudinal axis L in opposing radial directions therefrom, but it will be appreciated that the quantity and relative positioning of the guide rods may be varied, while serving the same purpose of blocking rotation of the inner rotary screw component 32 about the longitudinal axis. Like in the first embodiment, the cover 16 is held in fixed position to the stationary motor stator, which in turn is mounted in a fixed stationary position atop the booth 22, whereby the guide rods 40 are fixed in a stationary reference frame at the top wall of the cover and at the in-turned flange 42 at the bottom of the motor stator.

Figure 3 shows a third embodiment of the linear rotary screw sucker rod top drive apparatus 10'', which like the first and second illustrated embodiments features an internally threaded hollow outer rotary screw component 30 with an inner rotary screw component 32 internally engaged therewith for longitudinal displacement under driven rotation of the hollow outer rotary screw component 30 by a permanent magnet motor 12 whose stator 26 closes concentrically around the hollow outer rotary screw component 30 at the bottom end thereof. However, the motor stator 26 is not mounted directly on the booth 22 like in the first embodiment. Instead, a separate guide section 46 is installed in-line between the motor stator 26 and the booth 22. The guide section 46 features an outer frame containing two guide rods 40' that span vertically between in-turned flanges 42' at the top and bottom ends of the guide section's frame.

A guide carriage 48 features a central collar-shaped coupling 50 secured circumferentially around the sucker rod 24 inside the guide section 46, and a pair of radial arms that span outwardly from the coupling 50 to each carry a respective linear bearing or bushing 52 that is slidably engaged on a respective one of the guide rods 40'. With the sucker rod 24 coupled to the inner rotary screw component 32 in a rotationally-locked manner, the guide rods 40' thus serve the same purpose as those of the second illustrated embodiment, specifically to constrain the inner rotary screw component 32 and attached sucker rod 24 against rotation around the longitudinal axis L.

In the third embodiment apparatus 10'', the hollow outer rotary screw component 30 is not fully open at the upper and lower ends thereof. Instead, each end of the hollow outer rotary screw component 30 is closed off by a respective bushing 54 that dictates the furthest attainable position of the inner rotary screw component 32 in the respective longitudinal direction, and a

respective seal 56 that is installed externally over the bushing to close off the hollow interior of the hollow outer rotary screw component 30 in a fluid-tight manner. The rotary screw device of the third embodiment is therefore a sealed unit, whereby the hollow interior space of the hollow outer rotary screw component 30, which is traversed by the inner rotary screw component during the reciprocal operation of the apparatus to drive the sucker rod, can be filled with an oil or grease for the purpose of lubricating and sealing the working components of the screw mechanism. This sealed oil/grease volume is generally indicated at 58 in Figure 3. Figure 3 also illustrates how the booth 22 can be mounted atop the wellhead 60 in a position surrounding a stuffing box or other seal 62 that is installed atop the wellhead to guide the sucker rod into the wellbore in a fluid-tight manner. The open sides areas of the booth between the vertical legs 22a thereof enable access to the exposed part of the sucker rod above the stuffing box 62, as well as access to the stuffing box 62 itself.

Turning now to Figure 4, a fourth embodiment linear rotary screw sucker rod top drive apparatus 110 differs from the preceding embodiments in the configuration of the screw device and the location and connection of the motor. In this embodiment, instead of the rotatably driven component of the screw device being a singular hollow screw component and the linearly displaceable component of the screw device being an inner component contained within the hollow screw component, the screw device features two rotatably driven externally threaded shafts 30' lying parallel to one another in symmetry across the longitudinal axis L on which sucker rod 24 lies. The linearly displaceable component is a singular nut 32' having two axial through-bores therein through which the externally threaded shafts 30' pass through the nut 32' to cooperate with internal threading of the nut at these bores to drive linear displacement of the nut 32 along the longitudinal axis L under synchronous driven rotation of the two shafts 30' by the motor 12'

The nut 32' is centered on the longitudinal axis L so that the sucker rod 24 is centrally connected to the nut, and the motor 12' is also centered on the longitudinal axis at an overhead position above the two threaded shafts 30'. In this embodiment, the stator of the motor thus does not concentrically surround the screw device, but rather is centered over the screw mechanism in a slighted elevated position thereabove. A simple gear-box 64 is disposed intermediately of the motor 12 and the screw mechanism, and features a central pinion gear 66 fixed on a downward-reaching output shaft of the motor, and a pair of identical drive gears 68 that are fixed on the top ends of the threaded shafts 30' of the rotary screw mechanism in meshed engagement with the toothed outer periphery of the central gear 66.

While the overhead placement of the motor in the fourth embodiment doesn't

achieve the same vertical space efficiency as the concentric stator placement of the motor in the preceding embodiments, the centrally aligned position of the motor directly overhead of the sucker rod 24 on the longitudinal axis with the drive shafts situated equidistant from the longitudinal axis in radially opposing directions nonetheless achieves a well-balanced structure for the linear rotary screw sucker rod top drive apparatus. The use of a permanent magnetic motor, or other type of low speed high torque motor, in this and any other embodiment minimizes or entirely eliminates the need for extraneous power transmission means between the motor and the screw mechanism, as demonstrated by the motor's direction action on the hollow outer screw component of the first three embodiments and by the mere three-gear power-splitting gearbox of the fourth embodiment used primarily, if not solely, for the purpose of driving both screw shafts 30' from a singular motor, and not for the purpose of dramatically altering the rotational output speed and torque of the motor. Also, the overhead placement of the motor with its driveshaft oriented vertically in parallel relation to the longitudinal axis in the fourth embodiment avoids the need for any directional-change in the rotary power transmission from the motor to the screw mechanism.

Turning to Figure 5, a fifth embodiment of the linear rotary screw sucker rod top drive apparatus 110' uses a similar overhead drive and dual-shaft rotary screw configuration as the fourth embodiment, but incorporates additional housing and support components, which are described in further detail as follows.

A housing of the screw device features a movable base component 70 in the form of a flat circular plate, four vertical pillars 72 standing upward from the topside of the movable base component 70 at equally spaced positions around the movable base component's outer periphery at a short radial distance inward therefrom, and a top wall 74 mounted to the top ends of the pillars 72 and having a matching circular shape to the movable base component 70. Three wall segments 76a, 76b, 76c span vertically upward from the movable base component 70 to the top wall 74, and each have an arcuate curvature in horizontal cross-section. The wall segments share the same radius of curvature and have a collective angular span of 360-degrees. The radius of curvature of each wall segment matches the radius of the circular outer periphery of the movable base component 70 and top wall 74, whereby the wall 360-degree span of the wall segments can span fully around the shared circumference of the movable base and top wall to enclose the screw device within an interior space of the housing that is delimited between the movable base component, top wall and three wall segments.

Figure 5A shows the housing in a closed condition concealing the screw device within the interior space of the housing. Two of the segments are movable segments 76a, 76b that

are individually and pivotally coupled to the third segment 76c by respective hinges 78a, 78b. The third wall segment 76c is a stationary segment fixed to the movable base component 70 and the top wall, and the hinges 78a, 78b define vertical pivot axes about which the first and second wall segments can respectively swing relative to the fixed third segment. Figure 5B shows the housing in a fully opened condition, in which the two movable wall segments 76a, 76b have been swung outwardly away from the outer periphery of the movable base component and top wall about their respective hinge axes in order to open up access to the interior space of the housing where the free edges of the movable wall segments would otherwise meet in their closed positions.

Still referring to Figure 5B, the movable base component 70 has a slot 80 therein which emanates radially outward from the center of the movable base component 70, where the sucker rod 24 normally passes through the slot 80 near the closed inner end thereof. The slot extends fully to the outer periphery of the movable base component 70, and therefore has an open outer end at the outer periphery of the movable base component 70. The top end of the booth 20 features a ring-shaped top plate 82 seated atop the vertical legs 22a of the booth, which in turn are seated atop a ring-shaped base plate 84 at which the booth is bolted to the wellhead 60. As best shown in Figures 5A and 5D, the top plate 82 of the booth 22 defines a stationary base component to which the movable base component 70 is hinged by a pivot pin 86 that passes horizontally through cooperating lugs 70a, 82a on the movable and stationary base components 70, 82. Accordingly, a pivotal connection between the movable and stationary base components enables pivoting of the movable base component 70 about a horizontal pivot axis relative to the stationary base component at the top end of the booth 20.

With reference to Figure 5B, the screw shafts 30' of the screw device extend vertically between the movable base component 70 and the top wall 74 of the housing, and the nut 32 cooperatively engaged on the screw shafts is linearly displaceable upwardly and downwardly along the longitudinal axis L on which the sucker rod is carried by the nut 32, for example by sucker rod clamp 88. The gearbox 64 is mounted atop the top wall 74 of the housing, and the motor 12 is mounted atop the gearbox 64. Accordingly, the pivotal connection of the movable base component 70 relative to the stationary base component 82 at the top of the booth pivotally carries the housing, screw drive, gearbox and motor on the booth 22. Figures 5A and 5B shows the movable base component in a working position seated flat atop the stationary base component 82 so that the housing and the screw mechanism stand vertically upright from the booth 22 with the shared central axis of the motor, gearbox, housing and screw mechanism residing coincident with the longitudinal axis of the sucker rod 20 that reaches downwardly through the stuffing box and

wellhead into the production tubing in the wellbore. The screw mechanism is thus cooperatively aligned with the wellhead in a suitable operating position for use of the apparatus to reciprocally drive the sucker rod within the wellbore.

Figure 5D on the other hand shows the movable base component pivoted into a maintenance position standing upwardly away from the stationary base component at the periphery thereof so that the housing and screw mechanism reach laterally outward from the booth 20 in a generally horizontal direction away from the wellhead in a position withdrawn from thereover, thereby revealing access to the top end of the booth 20 to improve access to the stuffing box, wellhead and other equipment located at or proximate the booth without requiring full detachment of the apparatus therefrom. With the sucker rod disconnected from the nut 32 of the screw mechanism, the slot 80 enables the tilting of the housing and screw mechanism away from the stationary base component 82 even with the upper end of the sucker rod reaching a short distance upwardly through the top end of the booth. The open end of the slot 80 in the movable base component is located opposite the fixed wall segment 76c of the housing so that opening of the movable wall segments 76a, 76b opens up the interior space of the housing at the open outer end of the slot 80, whereby freeing of an upwardly projecting top end of the sucker rod from the housing during tilting of the housing into the withdrawn position can be ensured even if the slot alone is not enough to accommodate the tilting motion of the housing relative to the sucker rod, which can be held in place via the open side areas of the booth 22

It will be appreciated that while the movable base component of the fifth embodiment is described and illustrated as being used to move a screw-based linear motion generator into and out of an operational position aligned over the wellhead to enable easier access to wellhead equipment during service or maintenance without having to fully remove the sucker rod top drive, it will be appreciated that the same movable base could be used to move other types of linear motion generators into and out of their operational positions, including rack-based linear motion generators and hydraulic actuator based linear motion generators. In the case of a rack or screw based linear motion generator, where the drive source is a motor mounted to the same framework, housing or structure as the linear motion generator, the motor is thus moved in synchronous fashion together with the linear motion generator during pivoting of the movable base component between the working and maintenance positions. On the other hand, in the event of use with a hydraulic based sucker rod top drive, where the drive source comprises a hydraulic pump connected to the one or more hydraulic actuators by flexible hoses, the drive source may be mounted independently of the movable base and linear motion generator.

In a variant of the fourth or fifth embodiment, rather than placing the motor and gearbox in an overhead position situated above the screw device, a motor with a hollow drive shaft is placed in an undermounted position beneath the rotary screw, and the sucker rod passes reaches downwardly through the axial through bore of the motor's hollow drive shaft into the wellbore. The power splitting gearbox for simultaneously and synchronously driving the two threaded shafts may be mounted above the motor so as to reside intermediately between the motor and the screw device. Alternatively, if the diameter of the motor is smaller than the horizontal distance between the two threaded shafts of the screw device, the gearbox may be mounted beneath the motor if the threaded shafts of the screw device, or extensions attached to the bottom ends thereof, reach downwardly past the motor at locations radially outward therefrom to connect to the undermounted gearbox beneath the motor.

Figure 6 shows a sixth embodiment linear rotary screw sucker rod top drive apparatus 110'', which is similar to the third embodiment in that it features a guide section with a lower in-turned flange bolted to the top ring of a booth and a motor stator mounted in a stationary position atop the upper in-turned flange of the guide section 46, but differs in that the rotatably driven screw component is not an elongated internally threaded shaft of greater axial length than the motor stator. Instead, the rotatably driven screw component is an internally threaded nut 30'' of lesser axial length than the motor stator 26, and the other component of the screw device is an elongated externally threaded shaft 32'' that defines the longitudinally displaceable screw component of this embodiment. The figure shows the motor as having a hollow rotor with an in-turned flange 28a to which a corresponding out-turned flange 30a on the internally threaded nut 30 is axially bolted in place of a conventional motor output shaft'. The sucker rod 24 is connected to the lower end of the elongated externally threaded shaft 32'' via a suitable coupler 90 and a carriage 48' that is similar to that of Figure 3, but is attached to the lower end of the elongated shaft 32''. The carriage 48', by way of its radial arms 50 and linear bearings/bushings 52, holds the threaded shaft 32'' against rotation using the guide rods 40' found within the guide section 46. The coupler 90 connects the sucker rod to the carriage, thereby connecting the sucker rod 24 to the externally threaded shaft 32''. Limit switches 92 at the underside and topside of the upper and lower in-turned flanges 42' of the guide section 96 may be used to dictate the range limits of the sucker rod's movement by changing the directional operation of the motor under contact of either limit switch by the carriage 48' that rides up and down the guide rods 40'. The sixth embodiment benefits from the same concentric stator placement from the first three embodiments, thereby demonstrating that this arrangement may be employed regardless of whether the motor drives an elongated shaft or an

axially-shorter screw component, such as an internally threaded nut. In Figure 6, a taller cover 16' is employed to accommodate movement of the elongated shaft 32'' upward from the motor during upstroke.

Finally, Figure 7 shows a seventh embodiment linear rotary screw sucker rod top drive apparatus 210 in which the motor 12' resides in an overhead position above the screw device like the fifth and sixth embodiments, but displaces the sucker rod 24 on a vertical axis that is horizontally offset from the longitudinal axis L shared by the motor and the screw device. Here, the motor drives an externally threaded shaft 30'' of the screw mechanism via a suitable coupler 91, and a carriage 32'' is operatively engaged around the threaded shaft 30 '' for vertical displacement therealong under driven rotation thereof by the motor. The carriage 32'' may have a dual-nut configuration with an axial bore having two different sets of threads cooperatively acting in a master/slave relationship with the externally threaded shaft 30'' at axially spaced positions therelong. At a radial distance outward from the threaded shaft 30'' at one side thereof, a sucker rod connection of the carriage features an axial bore of the carriage in which the upper end of the sucker rod is received. Further radially outward from the shaft on the same side thereof, the carriage also mated in a longitudinally slidable fashion with a vertically oriented guide rod or rail 92 of fixed stationary position, which thereby constrains the carriage 32'' against rotation about the longitudinal axis L of the threaded shaft during linear movement of the carriage therealong. While the illustrated embodiment shows a base 94 mounted in a fixed location off to one side of the wellhead to rotatably support the threaded shaft 30'' on a thrust bearing 43 with the motor situated overhead of the threaded shaft, other embodiments may alternatively place the motor at or near ground level beneath the threaded shaft.

Some embodiments of the present invention employ a permanent magnetic motor (PM motor), which may present notable advantages over an AC Induction motor, including higher efficiency, wider operating speed ranges, removing power transmission steps leading to higher efficiency, and removing hydraulic power transmission which removes the possibility for fluid spills. While the general advantages of PM motors are a broader operating envelope with best available efficiency resulting in lowest overall energy consumption and operating cost, PM motors generally cost more to produce. In LRP applications they may present a 'system' cost that is meaningfully lower than for a traditional 'pump jack' system. This cost reduction is possible due to smaller footprint (less mechanical equipment) and system implication (deletion of high cost speed reduction gearboxes). This may be of significant commercial advantage, as the oil and gas customer for this type of equipment is often capital cost sensitive, so having the ability and/or

capability to utilize the lowest capital cost drive technology may provide a significant cost advantage.

PM technology enables additional options during the down stroke. When receiving rotational energy, the PM motor acts like a generator, producing voltage at its terminals. For the typical downward stroke, where downward motion of the sucker rod and attached screw component is gravitationally induced, thereby tending to rotate the driven screw component in the downstroke direction, the VFD may recover energy from the process to minimize utility sourced energy requirements. This voltage can also be utilized effectively to resist rotation. This resistance is translated as braking effects and could be utilized to enhanced safety when used in conjunction with a linear actuation device. Accordingly, this energy may normally be stored in the capacitors of the DC bus of the variable frequency drive (VFD) that controls the motor operation, and in the case of a VFD problem condition (failure, shut-down, or other operational irregularity), this energy may be directed to a brake resistor to safely and controllably lower the rod pump system. In the prior art, if the variable frequency drive controlling the linear rod pump (LRP) fails for an AC induction driven LRP, then the braking capability fails, whereas the PM motor used in some embodiments of the present invention provides a failsafe braking action even in the event of VFD failure.

This functionality is schematically illustrated in Figures 8A and 8B, the former of which represents an upstroke of the sucker rod 24 during normal operation, and the latter of which represents the downstroke of the sucker rod during a failsafe mode of operation after a VFD problem condition arises. An electronic brake controller 300 has an input 300a that normally receives a standby signal from a properly setup VFD 302 during regular healthy operation thereof. The brake controller includes an brake switch 304 operable to switch between open/non-conductive and closed/conductive states. The closed/conductive state of switch 304 electrically connects brake resistor 306 across the terminals of the PM motor 12/12', while the open/non-conductive state of switch 304 breaks the electrical connection between the brake resistor 306 and the motor terminals.

Figure 8A shows normal operation, in which the properly setup and powered-on VFD is fully operational, and thus by default provides a standby signal to the brake controller 300. The brake controller accordingly remains in its standby state with the brake switch 304 in its open/non-conductive state, whereby the brake resistor 306 remains electrically disconnected from the terminals of the motor 12/12'. The downward block-arrows illustrate transfer of power in a downward direction through the system during the upstroke of the sucker rod. In such instances, the properly operating VFD 302 draws electrical power from an electrical utility or other source and delivers electrical power to the PM motor 12/12', which in turns provides forward mechanical

torque that is converted to linear mechanical lifting of the sucker rod string 24 via the screw mechanism. When the VFD is operating properly, gravitational lowering of the sucker rod string 24 during the downstroke thereof creates linear mechanical power that's converted to rearward mechanical torque at the PM motor 12/12' via the screw mechanism, from which electrical energy is created by the motor rotation and can be stored in the capacitors of the VFD's DC (Direct Current) bus.

However, in the event of a VFD problem condition that terminates the standby signal from the VFD to the brake controller, the brake switch 304 transitions to its closed conductive state, thereby connecting the brake resistor 306 to the terminals of the motor 12/12', as shown in Figure 8B. The absence of the expected standby signal by the brake controller thus serves as detection of a VFD problem condition by the brake controller. Power is now transferred upwardly through the system, as the linear mechanical power from the gravitationally falling of the sucker rod string 24 is converted into torque by the screw mechanism, and this torque generates electrical energy at the motor terminals, which is then transferred through the brake resistor 306 via the closed conductive state of the brake switch 304. The brake resistor 306 thus acts as a secondary, normally-disconnected load that is only connected to the motor terminals by closure of the brake switch 304 as a failsafe in the event of a detected VFD problem condition, whereby the resistance of the brake resistor 306 slows the reverse rotation of the motor, thus slowing the gravitational fall of the pump rod string 24 to safely lower same in a controlled manner.

In some embodiments, the electronic brake controller may be as a normally closed-relay that only opens the switch side of the relay in the presence of the standby signal from the VFD, whether the relay is solid state or mechanical. Accordingly, while the illustrated embodiment uses an electronic switch (i.e. solid state switch), a mechanical switch may alternatively be used. By using a normally-closed brake switch that only achieves and maintains its closed conductive state in the presence of an expected standby signal from the VFD, the brake resistor is automatically connected across the motor terminals not only in the instance of VFD-specific problem, but also in the instance of a system-wide power failure, regardless of whether the brake controller is powered solely by the VFD or by an alternative power source. Where the brake controller is a simple relay, it can rely solely on power from the VFD to operate (i.e. the standby signal from the VFD drives the control side of the relay). However, where additional functionality is desired in the brake controller, and additional circuitry or components are accordingly required (e.g. a micro-controller, one input of which receives the standby signal to monitor the VFD status, and an output of which controls the brake switch), the brake controller may be powered from a separate source that is

independent of the VFD. By using a normally-closed switch that requires an input signal to achieve and hold its open/non-conductive state, the brake switch will open in the event that power from either the VFD or an independent power source is lost.

The present invention encompasses use of any permanent magnet motor architecture, including both AC synchronous versions, and DC brushless versions of this technology. While permanent magnet motors provide the forgoing advantages, alternative low speed, high torque motors of any technology type can also be utilized.

The disclosed embodiments placing the motor in concentric alignment with the sucker rod, and thus likewise in concentric alignment with the wellhead, have the advantages of minimizing the footprint of the apparatus, providing the closest location to the sucker rod of the well head, and providing maximum torque effectiveness. A notable challenge of the screw technology is to hold the screw rod from twisting; thus transferring reaction torque of the screw to the frame without the torque being introduced into the sucker rod string, as is addressed herein by the various means of rotationally constraining the linearly displaceable screw component.

All embodiments will require instrumentation to aid in the control of the rotary screw linear motion generator, which may include position sensors (such as limit switches 92) or rotary sensors to map stroke limits, tension sensors to sense direct rod tension forces, and external control system hardware to manage these sensors. While the aforementioned limit switches 92 provide a simple solution for linear position sensors, other solutions could be as elaborate as linear encoders which identify the specific stroke position continuously, usually in a digital fashion. Likewise, rotary sensors could be as simple as rotation counting devices to identify the number of revolutions, or more elaboration solutions such as rotary encoders may be used to identify the precise shaft angular position any time. Strain gages can be utilized to sense both tension and compression in a load cell. This is a very precise means of measuring the tension in the rod string. This can help to optimize the utilization of the pump by altering the speed of the pump to optimize fluid flow in the well.

Since various modifications can be made in my invention as herein above described, and many apparently widely different embodiments of same made within the scope of the claims without departure from such scope, it is intended that all matter contained in the accompanying specification shall be interpreted as illustrative only and not in a limiting sense.

CLAIMS:

1. A linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a rotary screw device comprising:

a first rotary screw component; and

a second rotary screw component cooperatively mated with the first rotary screw component for linear displacement of said second rotary screw component along a longitudinal axis of said rotary screw device under relative rotation between said first and second rotary screw components about said longitudinal axis;

a drive source operatively coupled to said rotary screw device to drive said relative rotation between said first and second rotary screw components; and

a sucker rod connection carried by said second rotary screw component and arranged for coupling of the sucker rod thereto, whereby said linear displacement of said second rotary screw component drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis of the rotary screw device;

an anti-rotation arrangement for constraining rotation of the second rotary screw component around the longitudinal axis, said anti-rotation arrangement comprising:

a first anti-rotation element carried on the second rotary screw component; and

a second anti-rotation element attached to a stationary frame located at a longitudinal distance from said second rotary screw component, the first and second anti-rotation elements being keyed together to prevent relative rotation therebetween and one of said first and second anti-rotation elements being longitudinally extendable and collapsible to accommodate movement of the second rotary screw component toward and away from the stationary frame along the longitudinal axis.

2. The apparatus of claim 1 wherein the second anti-rotation element is extendable and collapsible.

3. The apparatus of claim 1 or 2 wherein said one of the first and second anti-rotation elements is telescopically extendable and collapsible.

4. The apparatus of claim 3 wherein said one of the first and second anti-rotation elements comprises a set of telescopically mated sleeves arranged to nest within one another in a collapsed state thereof.

5. The apparatus of claim 4 wherein the other of the first and second anti-

rotation elements is a solid shank that is mated within a smallest one of said telescopically mated sleeves in a keyed fashion preventing rotation therebetween.

6. The apparatus of any one of claims 1 to 5 wherein the first rotary screw component is a hollow outer rotary screw component of greater axial length than the second rotary screw component, and the second rotary screw component is an inner rotary screw component engaged to the hollow outer rotary screw component within a hollow interior thereof for longitudinal displacement back and forth therein.

7. The apparatus of claim 6 wherein the first anti-rotation element is a reduced-diameter longitudinal extension of the inner rotary screw component, the reduced-diameter longitudinal extension having an outer diameter lesser than an inner diameter of the hollow outer rotary screw component.

8. The apparatus of claim 7 wherein the reduced-diameter longitudinal extension of the inner rotary screw component is located at a topside thereof, and the second anti-rotation element is attached to the stationary frame at a location above the inner rotary screw component.

9. The apparatus of any preceding wherein the drive source comprises a motor, a stator of which is mounted in a fixed stationary position surrounding the first rotary screw component in concentric relation therewith around the longitudinal axis, the first rotary screw component defining a rotatably driven output of said motor, whereby operation of said motor linearly displaces the second rotary screw component along the longitudinal axis.

10. The apparatus of any one of claims 6 to 8 wherein the drive source comprises a motor, a stator of which is mounted a fixed stationary position surrounding the first rotary screw component in concentric relation therewith around the longitudinal axis, the first rotary screw component defining a rotatably driven output of said motor, whereby operation of said motor linearly displaces the second rotary screw component along the longitudinal axis.

11. The apparatus of any preceding claim wherein the first and second anti-rotation elements are aligned with the sucker rod connection of the second rotary screw component on the longitudinal axis.

12. A linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a rotary screw device comprising:

a first rotary screw component; and

a second rotary screw component cooperatively mated with the first rotary

screw component for linear displacement of said second rotary screw component along a longitudinal axis of said rotary screw device under relative rotation between said first and second rotary screw components about said longitudinal axis;

a drive source operatively coupled to said rotary screw device to drive said relative rotation between said first and second rotary screw components; and

a sucker rod connection carried by said second rotary screw component and arranged for coupling of the sucker rod thereto, whereby said linear displacement of said second rotary screw component drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis of the rotary screw device;

wherein the drive source comprises a motor, a stator of which is mounted a fixed stationary position surrounding the first rotary screw component in concentric relation therewith around the longitudinal axis, the first rotary screw component defining a rotatably driven output of said motor, whereby operation of said motor linearly displaces the second rotary screw component along the longitudinal axis.

13. The apparatus of claim 12 wherein the first rotary screw component is a hollow outer rotary screw component of greater axial length than the second rotary screw component, and the second rotary screw component is an inner rotary screw component engaged to the hollow outer rotary screw component within a hollow interior thereof for longitudinal displacement back and forth therein.

14. A linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a rotary screw device comprising:

a first rotary screw component; and

a second rotary screw component cooperatively mated with the first rotary screw component for linear displacement of said second rotary screw component along a longitudinal axis of said rotary screw device under relative rotation between said first and second rotary screw components about said longitudinal axis;

a drive source operatively coupled to said rotary screw device to drive said relative rotation between said first and second rotary screw components; and

a sucker rod connection carried by said second rotary screw component and arranged for coupling of the sucker rod thereto, whereby said linear displacement of said second rotary screw component drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis of the rotary screw device;

wherein the first rotary screw component is a hollow outer rotary screw component of greater axial length than the second rotary screw component, and the second rotary screw component is an inner rotary screw component engaged to the hollow outer rotary screw component within a hollow interior thereof for longitudinal displacement back and forth therein.

15. The apparatus of claim 13 or 14 comprising an anti-rotation arrangement for constraining rotation of the inner rotary screw component about the longitudinal axis, said anti-rotation arrangement comprising at least one guide rod passing longitudinally through the inner rotary screw component inside the hollow interior of the hollow outer rotary screw component at a respective position spaced radially outward from the longitudinal axis to thereby block rotation of the inner rotary screw component about said longitudinal axis.

16. The apparatus of claim 15 wherein the at least one guide rod is fixed at both upper and lower ends thereof.

17. The apparatus of claim 10 or 13 wherein the hollow outer rotary screw component exceeds the stator in axial length, and the hollow outer rotary screw reaches further upwardly than downwardly from said stator.

18. The apparatus of any one of claims 10 and 13 to 17 wherein the rotary screw mechanism is a sealed unit of which the hollow outer rotary screw component is sealed closed at opposing upper and lower ends thereof and contains a sealing/lubricating medium therein.

19. A linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a rotary screw device comprising:

a first rotary screw component; and

a second rotary screw component cooperatively mated with the first rotary screw component for linear displacement of said second rotary screw component along a longitudinal axis of said rotary screw device under relative rotation between said first and second rotary screw components about said longitudinal axis;

a drive source operatively coupled to said rotary screw device to drive said relative rotation between said first and second rotary screw components; and

a sucker rod connection carried by said second rotary screw component and arranged for coupling of the sucker rod thereto, whereby said linear displacement of said second rotary screw drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis of the rotary screw device;

wherein the first rotary screw component is one of a pair of parallel externally-

threaded rotary screw components that are each engaged through a respective axial bore in the second rotary screw component, and the drive source is arranged to drive simultaneous rotation of said pair of parallel externally-threaded rotary screw components, whereby the first rotary screw component is linearly displaced along the pair of parallel externally-threaded rotary screw components during said simultaneous rotation thereof; and

wherein the drive source comprises a motor operatively coupled to the pair of parallel externally-threaded rotary screw components and residing in alignment with the sucker rod connection on the second rotary screw component so as to center the motor in alignment with the sucker rod.

20. The apparatus of claim 19 wherein the pair of parallel externally-threaded rotary screw components are radially equidistant from a common axis shared by the motor and the sucker rod connection on the second rotary screw component.

21. The apparatus of claim 19 or 20 wherein an output shaft of the motor carries a central gear engaged by a pair of respective drive gears attached to the pair of parallel externally-threaded rotary screw components.

22. A linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a linear motion generator having an output component arranged for linear displacement under driven operation of said linear motion generator; and

a sucker rod connection carried by said output component of the linear motion generator and connected or connectable to the sucker rod to drive linear movement thereof under said driven operation of the linear motion generator;

a movable base component on which the linear motion generator is carried;

a stationary base component mounted or mountable in an elevated position over a wellhead; and

a movable connection between the movable base component and the stationary base component booth to enable movement of the movable base component between a working position in which the linear motion generator stands atop the movable base component in an operating position aligned over the wellhead, and a maintenance position in which the linear motion generator is at least partially withdrawn from its operating position over the wellhead.

23. The apparatus of claim 22 wherein the movable connection is a pivotal connection.

24. The apparatus of claim 23 wherein the pivotal connection defines a

horizontal pivot axis about which the movable base component is pivotal relative to the stationary base component to tilt the linear motion generator laterally out of the operating position.

25. The apparatus of any one of claims 22 to 24 wherein the movable base component comprises a slot therein that intersects an outer periphery of the movable base component at an open end of said slot, and that terminates at a closed inner end of the slot near which the sucker rod reaches through the slot in the working position of the movable base component.

26. The apparatus of claim 25 further comprising a housing having at least one hinged segment movable between a closed position cooperating with the base and one or more other segments to enclose components of the linear motion generator within an interior space of the housing above the base, and an open position revealing access to said interior space, wherein the open position of the at least one hinged segment opens up the interior space of the housing at the open end of the slot.

27. The apparatus of any one of claims 22 to 26 wherein the stationary base component resides at an upper end of a booth that is mounted, or arranged for mounting to, the wellhead in a position accommodating passage of the sucker rod upwardly through the booth from the wellhead to the sucker rod connection while providing access to a stuffing box situated atop the wellhead through open side areas of the booth.

28. The apparatus of any one of claims 22 to 27 further comprising a drive source providing a source of input power to the linear motion generator, said drive source being carried on the movable base component and being movable together with the linear motion generator into and out of the operational position aligned over the wellhead.

29. The apparatus of claim 28 wherein the drive source is a motor whose rotational axis coincides with a longitudinal axis of the linear motion generator, and the sucker rod connection also resides on the longitudinal axis in order to position the motor directly overhead of the sucker rod on the longitudinal axis in the working position of the movable base component.

30. A linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a drive source comprising a motor;

a rotary screw mechanism comprising:

an externally threaded shaft rotatably driven by the motor about a central longitudinal axis of said externally threaded shaft, on which the motor is also centered;

a carriage having:

an internally threaded bore at which the carriage is operably engaged with the externally threaded shaft for linear displacement of the carriage along said longitudinal axis under driven rotation of the externally threaded shaft by the motor;

a sucker rod connection carried on said carriage at a location radially outward from the externally threaded shaft to one side thereof for coupling of the sucker rod to said carriage, whereby said linear displacement of said carriage drives linear motion of the sucker rod in a longitudinal direction parallel to the longitudinal axis at a position offset outwardly therefrom; and

a linear guide standing upright in a stationary position at a radial distance outward from the externally threaded shaft, the carriage being slidably engaged with said linear guide to constrain the carriage against rotation about the longitudinal axis.

31. The apparatus of claim 30 wherein the linear guide and the sucker rod connection are radially offset from the externally threaded shaft in a same direction.

32. The apparatus of claim 30 or 31 wherein the linear guide is situated further radially outward from the externally threaded shaft than the sucker rod connection.

33. The apparatus of any one of claims 1 to 21 and 28 to 32 wherein the drive source comprises a permanent magnet motor.

34. The apparatus of any one of claims 22 to 29 wherein the linear motion generator comprises a rotary screw device.

35. The apparatus of any one of claims 1 to 21, 30 to 32 and 34 wherein the rotary screw device is a lead screw device.

36. The apparatus of any one of claims 1 to 21, 30 to 32 and 34 wherein the rotary screw device is a ball screw device.

37. The apparatus of any one of claims 1 to 21, 30 to 33 and 35 wherein the rotary screw device is a roller screw device.

38. A linear sucker rod top drive apparatus for effecting linear motion of a sucker rod of a downhole pump, said apparatus comprising:

a linear motion generator having an output component arranged for linear displacement under driven operation of said linear motion generator; and

a permanent magnet motor operably coupled to the linear motion to drive operation of the linear motion generator during at least an upstroke thereof, with rotational movement of the permanent magnet motor being linked to the linear motion generator in both the upstroke thereof and a downstroke thereof;

a variable frequency drive connected to the permanent magnet motor to normally

control operation thereof;

a secondary electrical load that is independent of an operative state of the variable frequency drive and is arranged for selective connection to terminals of the permanent magnet motor thereof to apply a voltage across said terminals of the permanent magnet motor to the secondary load; and

a failsafe mechanism operable to connect the secondary load to the terminals of the permanent magnet motor in response to a problem condition with the variable frequency drive;

wherein connection of the secondary load across the terminals of the permanent magnet creates a braking effect on rotation of the motor during the downstroke of the linear motion generator, thereby slowing a gravitationally induced lowering of the sucker rod during a downstroke thereof.

39. The apparatus of claim 38 wherein the failsafe comprises a brake controller comprising a brake switch arranged to automatically switch into a conductive state in response to the problem condition of the variable frequency drive.

40. The apparatus of claim 38 comprising a brake controller having an input for detecting a status the VFD, and a switch configured to switch between conductive and non-conductive states between the secondary load and the terminals of the motor in response to a change in said status of the VFD.

41. The apparatus of claim 40 wherein the VFD is configured to normally and continuously send a standby signal to the brake controller during normal operation of said VFD, and the brake controller is configured to maintain the non-conductive state of the switch in the presence of said standby signal and switch into and hold the conductive state in the absence of said standby signal.

42. The apparatus of claim 40 or 41 wherein the switch is a normally closed switch.

43. The apparatus of claim 41 wherein the brake controller comprises a relay that defines the switch and whose control side is driven by the standby signal from the VFD.

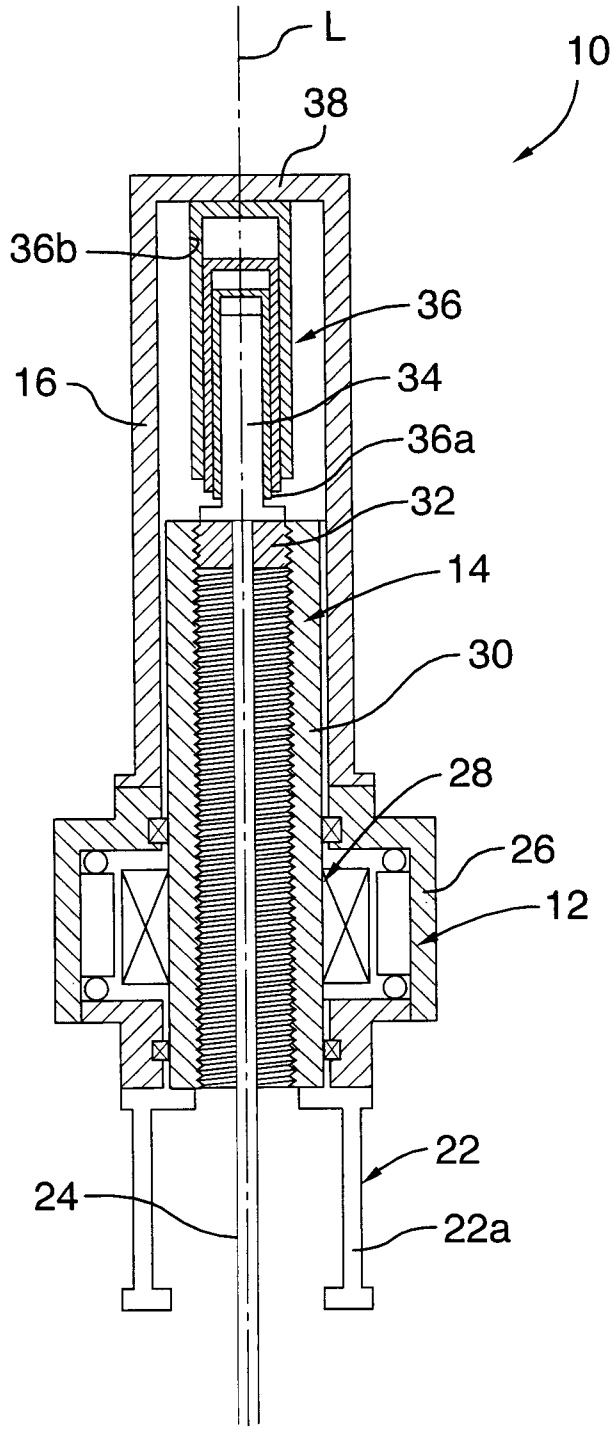


FIG.1

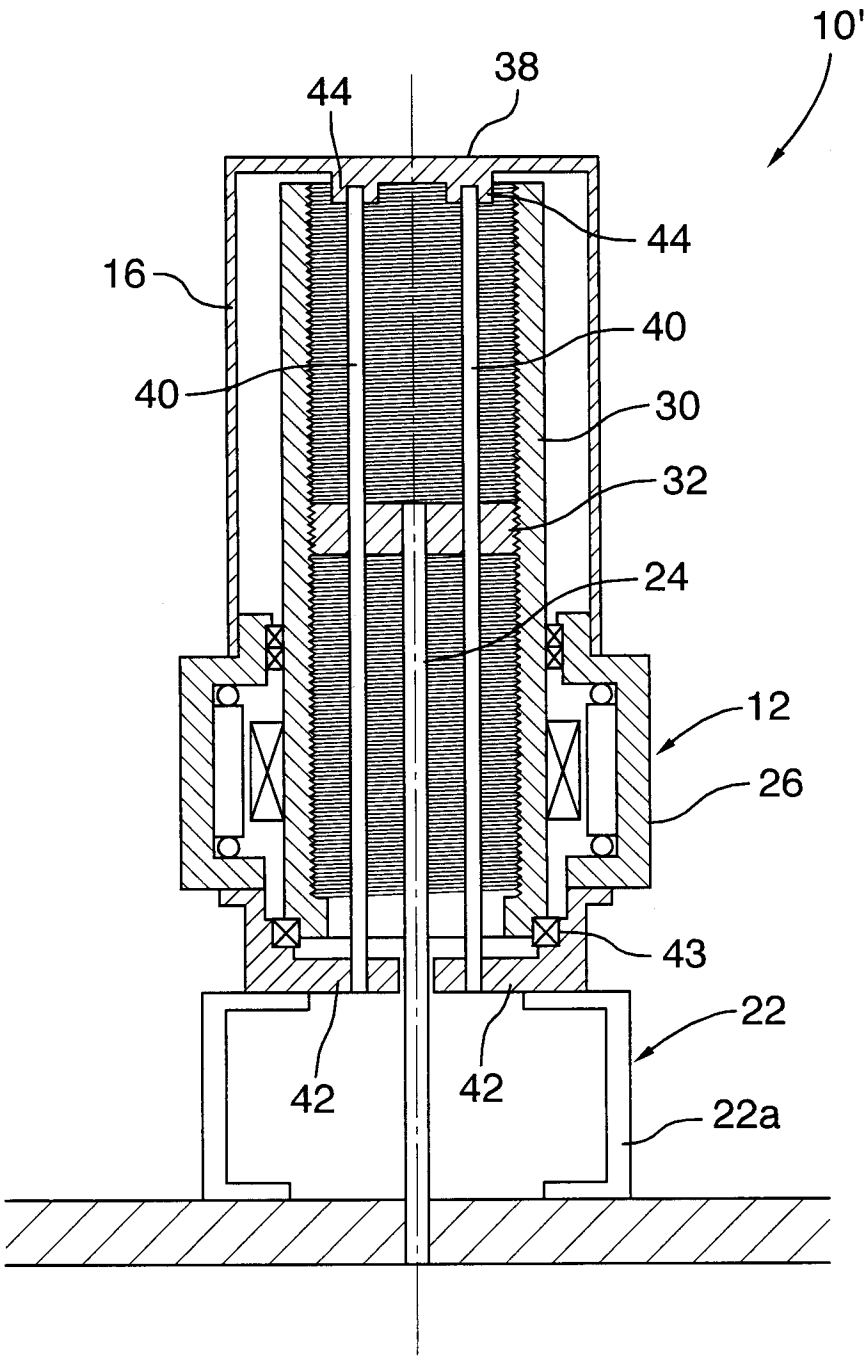


FIG.2

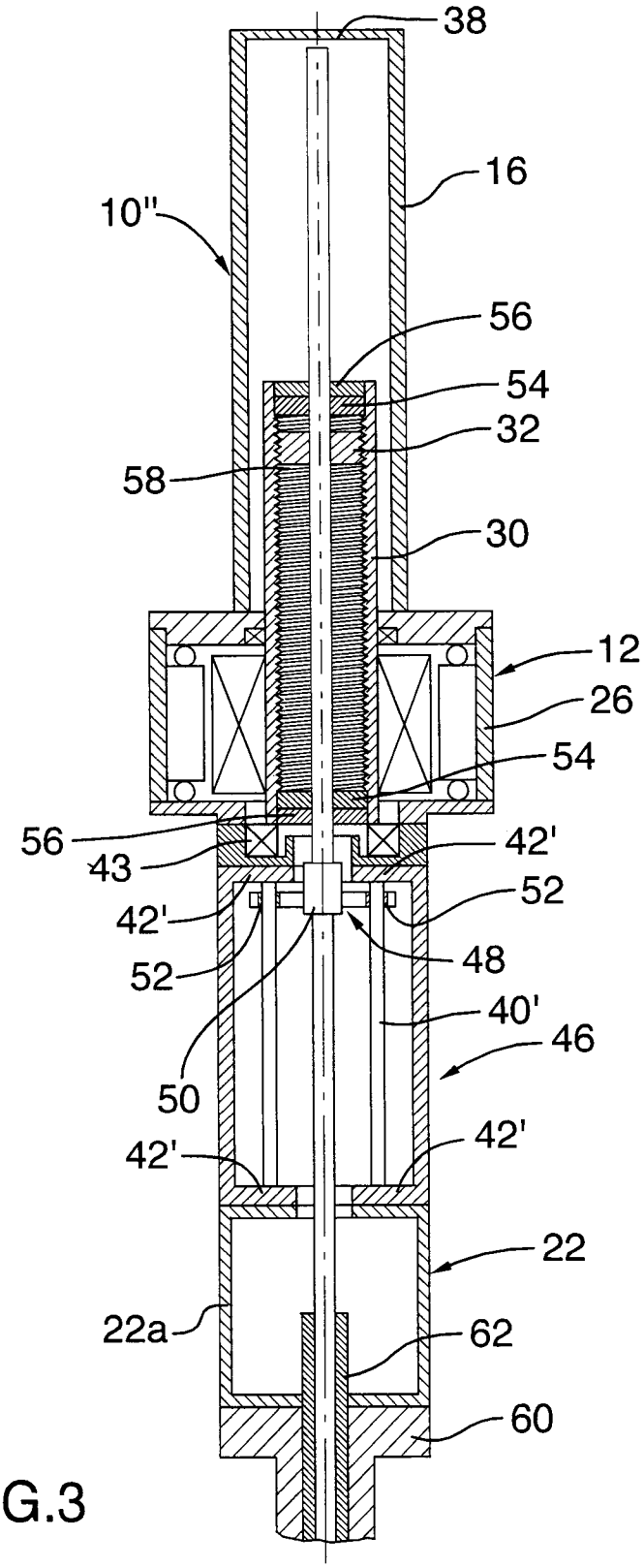

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10"
56
54
32
58
30
12
26
54
56
43
42'
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42'
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52
40'
46
50
42'
42'
22
22a
62
60

FIG.3

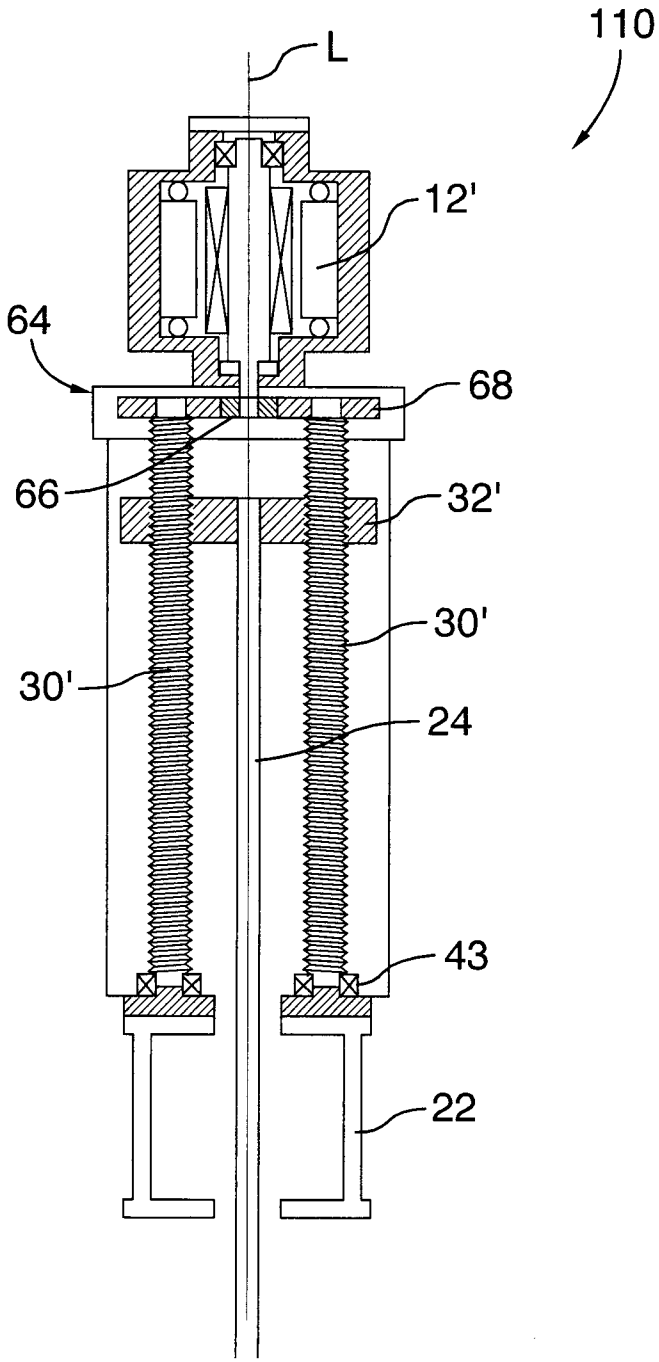


FIG.4

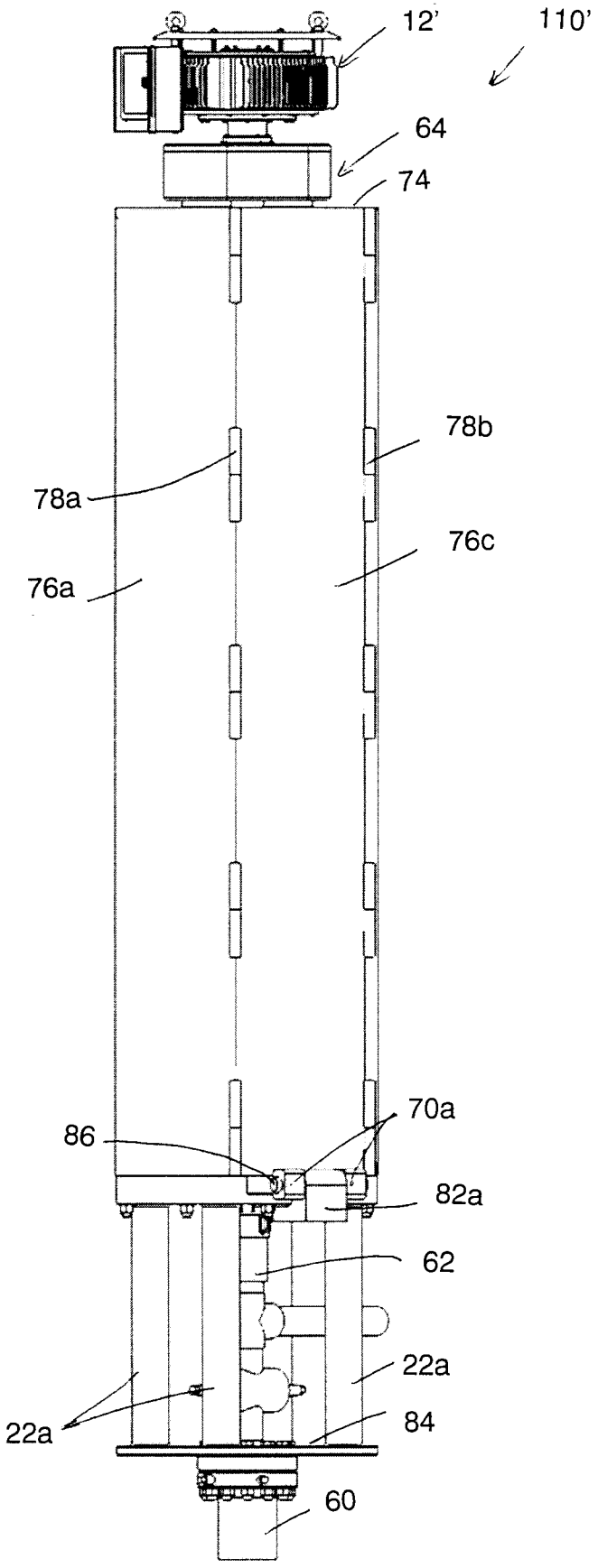


FIGURE 5A

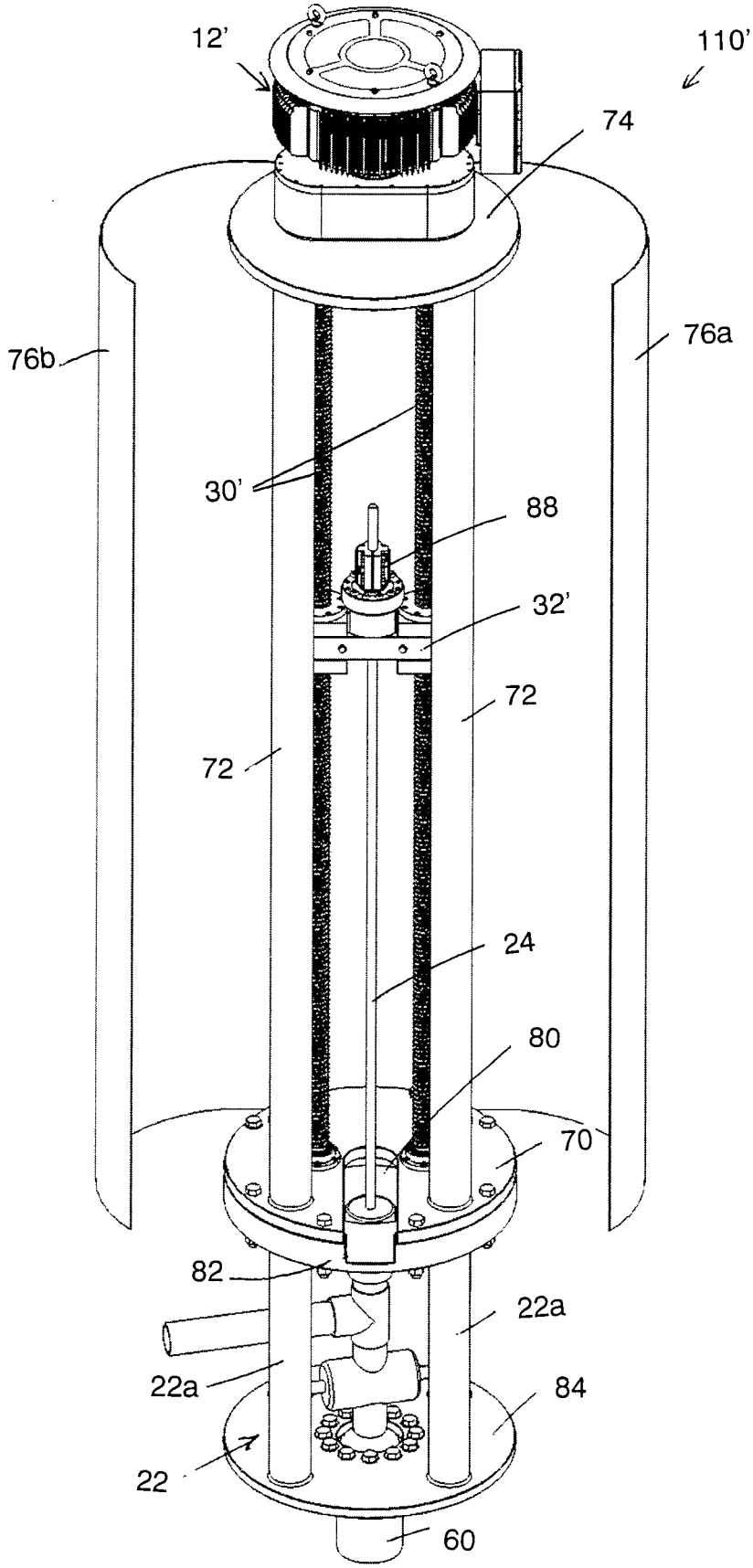


FIGURE 5B

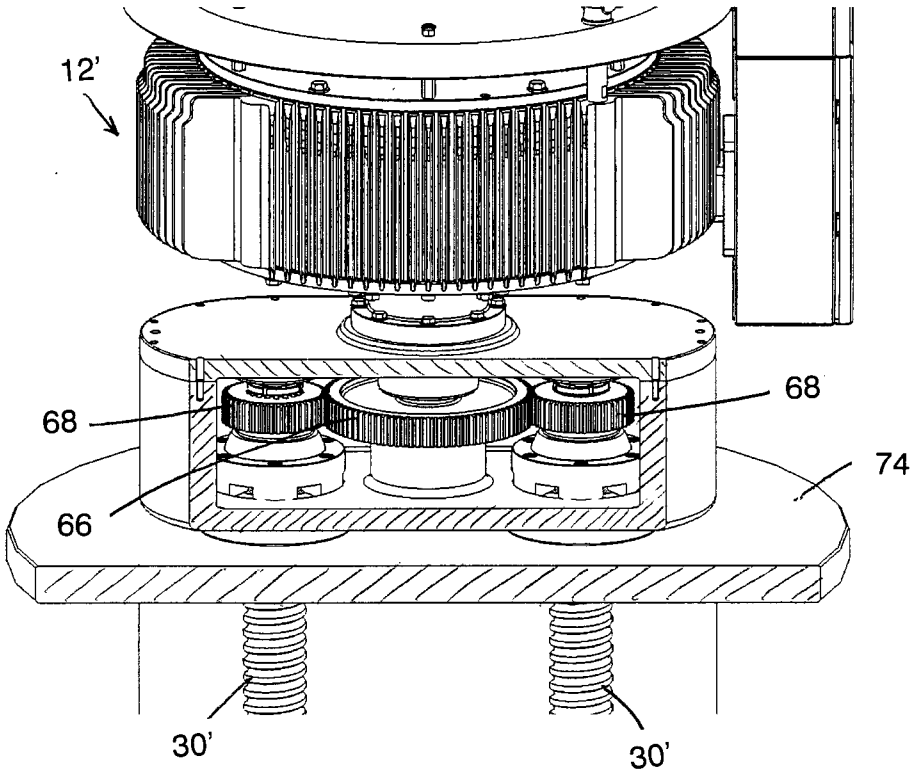


FIGURE 5C

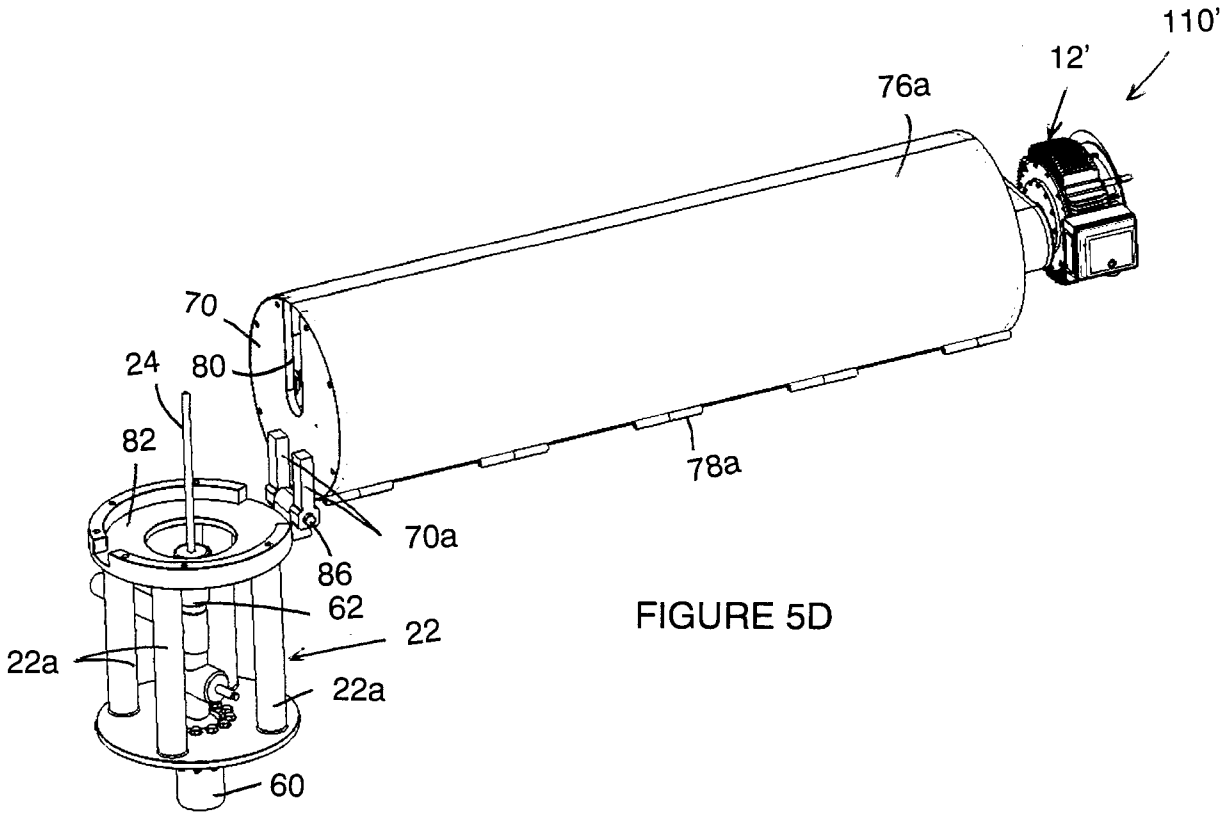


FIGURE 5D

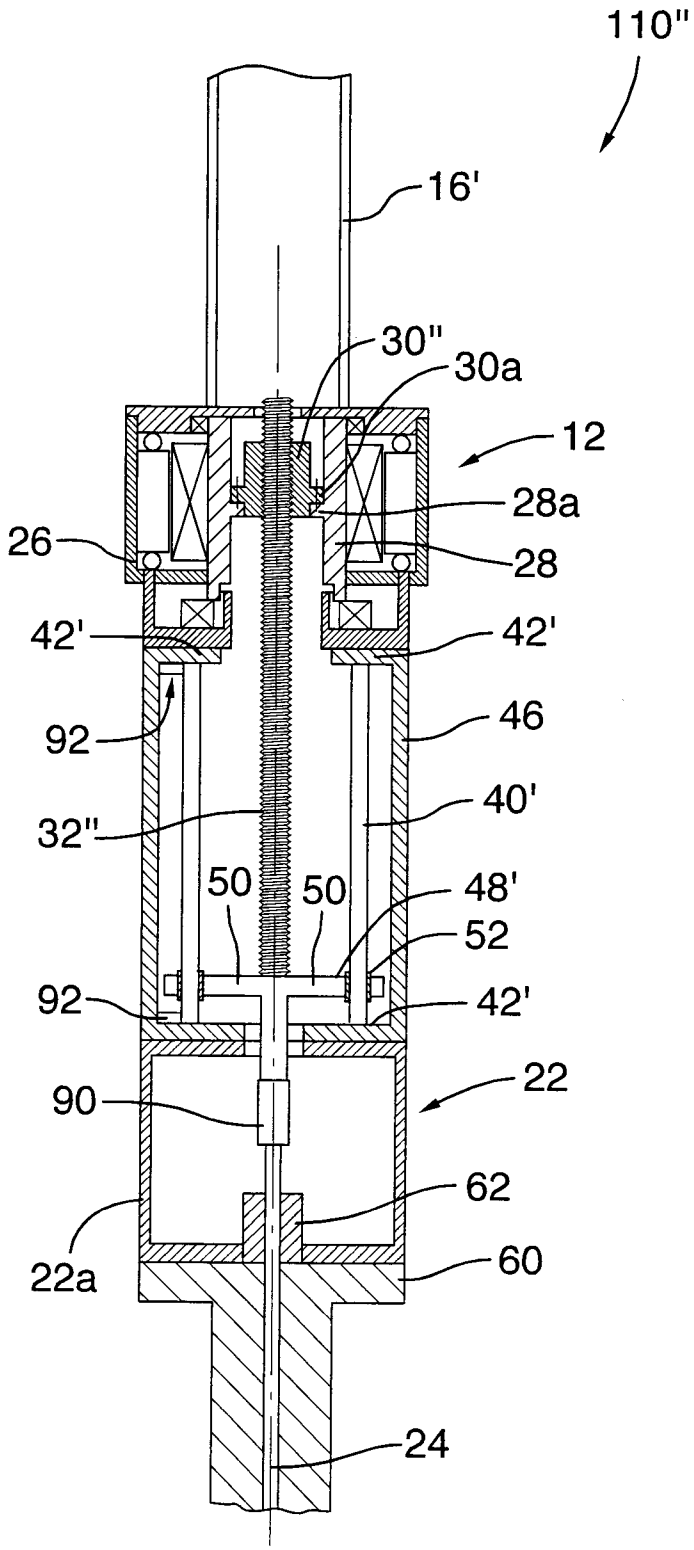

110"
16'
30"
30a
12
28a
26
28
42'
42'
92
46
40'
32"
50
50
48'
52
92
42'
22
90
62
60
22a
24

FIG.6

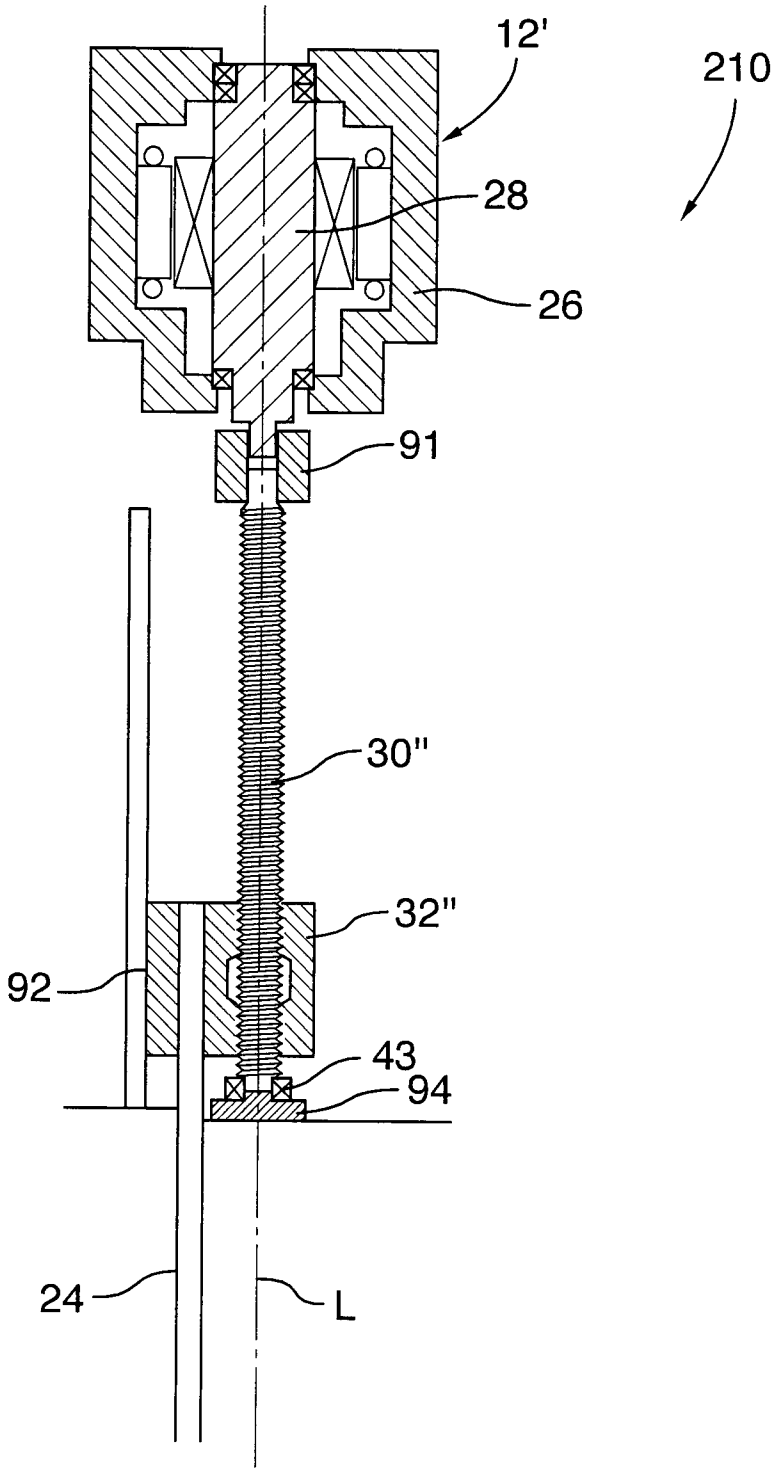


FIG.7

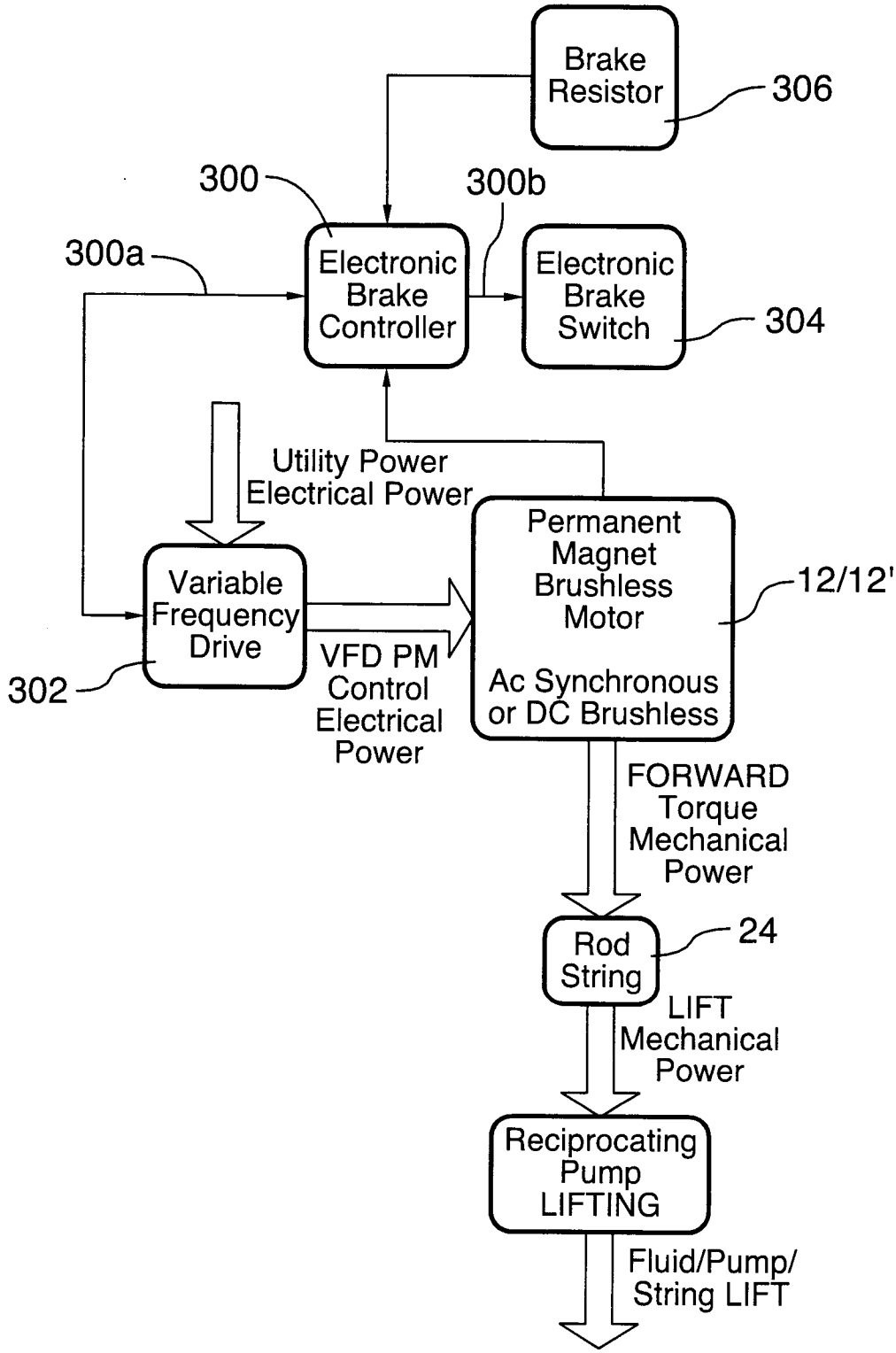

Brake Resistor
306
300
300b
300a
Electronic Brake Controller
Electronic Brake Switch
304
Utility Power Electrical Power
Permanent Magnet Brushless Motor
12/12'
Variable Frequency Drive
302
VFD PM Control Electrical Power
Ac Synchronous or DC Brushless
FORWARD Torque Mechanical Power
Rod String
24
LIFT Mechanical Power
Reciprocating Pump LIFTING
Fluid/Pump/ String LIFT

FIG.8A

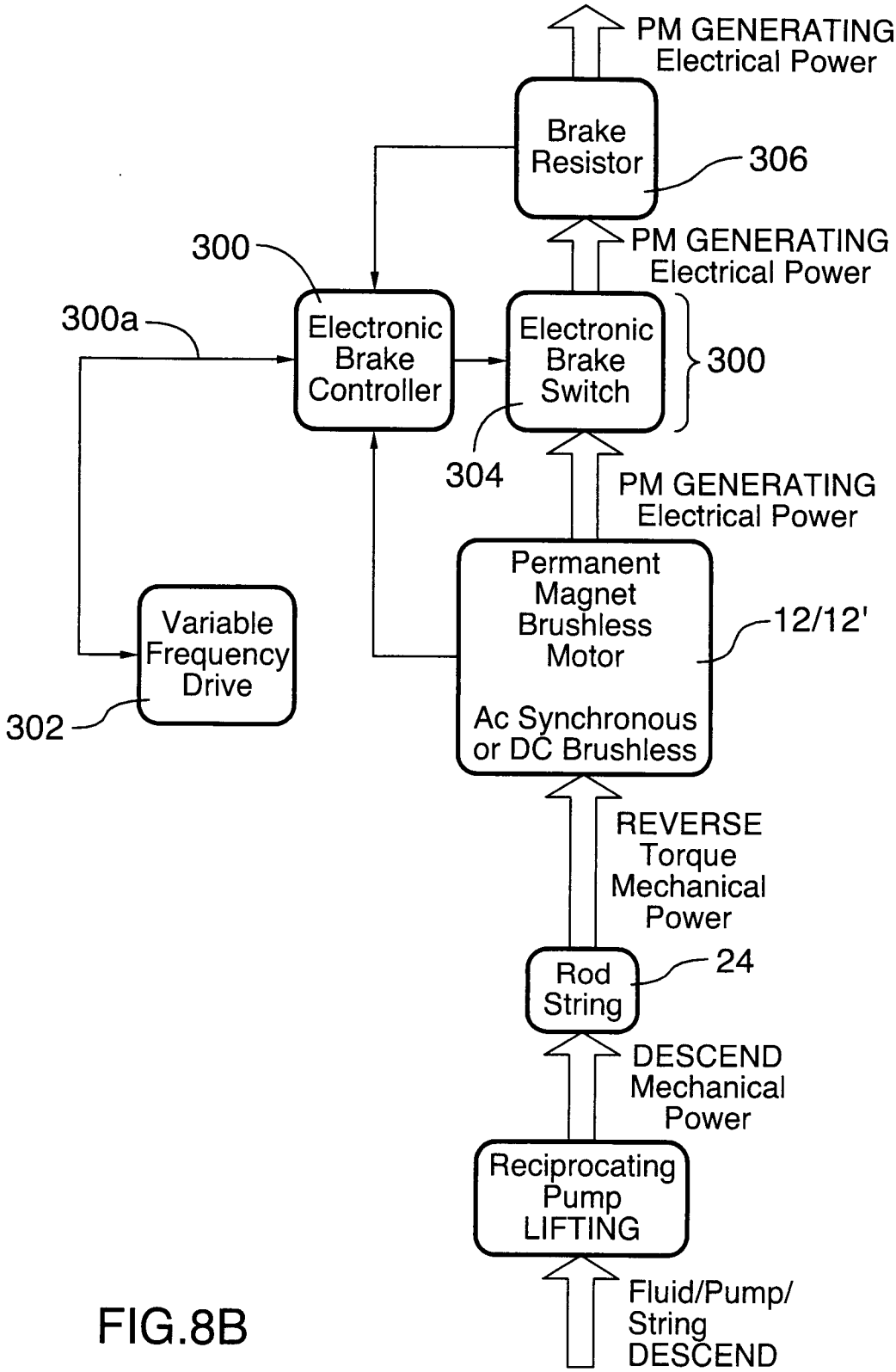

PM GENERATING
Electrical Power
Brake
Resistor
306
300
PM GENERATING
Electrical Power
300a
Electronic
Brake
Controller
Electronic
Brake
Switch
300
304
PM GENERATING
Electrical Power
Permanent
Magnet
Brushless
Motor
12/12'
Ac Synchronous
or DC Brushless
Variable
Frequency
Drive
302
REVERSE
Torque
Mechanical
Power
Rod
String
24
DESCEND
Mechanical
Power
Reciprocating
Pump
LIFTING
Fluid/Pump/
String
DESCEND

FIG.8B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2017/050622

A. CLASSIFICATION OF SUBJECT MATTER
IPC: ***F04B 47/02*** (2006.01) , ***F04B 47/04*** (2006.01) , ***F04B 49/06*** (2006.01) , ***F16H 19/02*** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC: ***F04B 47/02*** (2006.01) , ***F04B 47/04*** (2006.01) , ***F04B 49/06*** (2006.01) , ***F16H 19/02*** (2006.01)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NONE

Electronic database(s) consulted during the international search (name of database(s) and, where practicable, search terms used)
Questel (ORBIT), keywords: rotary screw, sucker rod, pump, drive, screw, reciprocate, anti-rotation, linear actuator, lead screw, roller screw, ball screw, *and like terms*

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5404767 A (SUTHERLAND, J), 11 April 1995 (11-04-1995)	19-21, 33, 35-37
A	US 2014105759 A1 (HENRY, J et al.), 17 April 2014 (17-04-2014)	1-18

☐ Further documents are listed in the continuation of Box C.

☑ See patent family annex.

*	Special categories of cited documents:
"A"	document defining the general state of the art which is not considered to be of particular relevance
"E"	earlier application or patent but published on or after the international filing date
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O"	document referring to an oral disclosure, use, exhibition or other means
"P"	document published prior to the international filing date but later than the priority date claimed
"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&"	document member of the same patent family

Date of the actual completion of the international search 31 August 2017 (31-08-2017)	Date of mailing of the international search report 15 September 2017 (15-09-2017)
Name and mailing address of the ISA/CA Canadian Intellectual Property Office Place du Portage I, C114 - 1st Floor, Box PCT 50 Victoria Street Gatineau, Quebec K1A 0C9 Facsimile No.: 819-953-2476	Authorized officer Daniel Burwell (819) 639-7833

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CA2017/050622

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of the first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claim Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claim Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claim Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Group A: Claims 1 to 21, 33; and 35 to 37 when dependent on one of claims 1 to 21

Group B: Claims 22 to 29 and 34; and 35 to 37 when dependent on claim 34

Group C: Claims 30 to 32; and 33 and 35 to 37 when dependent on one of claims 30 to 32

Group D: Claims 38 to 43

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claim Nos.:

4. ☑ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim Nos.:

1 to 21, 33 and 35 to 37

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CA2017/050622

Patent Document Cited in Search Report	Publication Date	Patent Family Member(s)	Publication Date
US5404767A	11 April 1995 (11-04-1995)	None	
US2014105759A1	17 April 2014 (17-04-2014)	US2014105759A1	17 April 2014 (17-04-2014)
		US9447788B2	20 September 2016 (20-09-2016)
		CA2829684A1	02 April 2014 (02-04-2014)