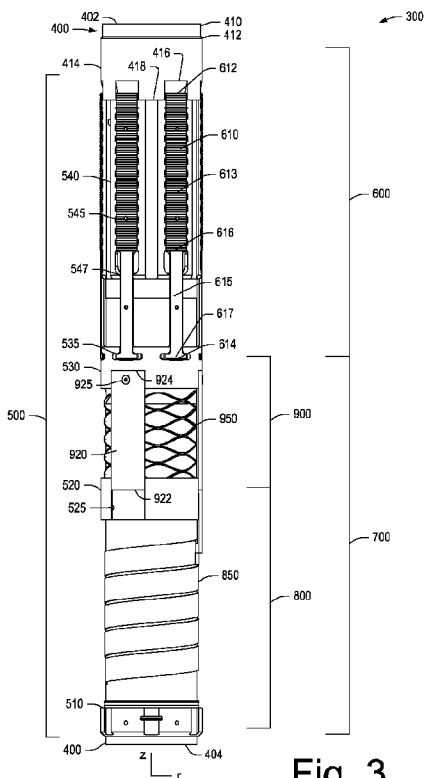




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(54) Title: HOOP STRESS HYDRAULIC TRIGGER



(57) Abstract: A system includes a tubular body that includes a longitudinal axis and a circumference that depends on circumferential stress of the tubular body; a helical strip that includes a turn number about a longitudinal axis that is substantially co-axial to the longitudinal axis of the tubular body where the turn number depends on the circumference of the tubular body; and a trigger lock component where the helical strip and the trigger lock component include a key and keyway pair that includes a latched state for a first circumferential stress of the tubular body and an unlatched state for a second circumferential stress of the tubular body.

Fig. 3

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HOOP STRESS HYDRAULIC TRIGGER

RELATED APPLICATION

[0001] This application claims the benefit of and priority to a US Provisional Patent Application having Serial No. 62/267,002, filed 14 December 2015, which is incorporated by reference herein.

BACKGROUND

[0002] Various types of equipment can be utilized in a subterranean environment. As an example, a liner hanger can be utilized to attach or hang one or more liners from an internal wall of a casing in a well in a subterranean environment.

SUMMARY

[0003] A system includes a tubular body that includes a longitudinal axis and a circumference that depends on circumferential stress of the tubular body; a helical strip that includes a turn number about a longitudinal axis that is substantially co-axial to the longitudinal axis of the tubular body where the turn number depends on the circumference of the tubular body; and a trigger lock component where the helical strip and the trigger lock component include a key and keyway pair that includes a latched state for a first circumferential stress of the tubular body and an unlatched state for a second circumferential stress of the tubular body. A method can include increasing fluid pressure in a tubular body disposed in a downhole, subterranean environment to increase circumferential stress of the tubular body; increasing a circumference of the tubular body responsive to the increase in circumferential stress; decreasing a number of turns of a helical strip wound about the tubular body; and, responsive to the decreasing of the number of turns, unlatching a component that is operatively coupled to the tubular body. Various other apparatuses, systems, methods, etc., are also disclosed.

[0004] This summary is provided to introduce a selection of concepts that are further described below in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

- [0005]** Features and advantages of the described implementations can be more readily understood by reference to the following description taken in conjunction with the accompanying drawings.
- [0006]** Fig. 1 illustrates examples of an environment, equipment and an assembly;
- [0007]** Fig. 2 illustrates an example of an assembly;
- [0008]** Fig. 3 illustrates an example a system that includes an example of a hoop stress hydraulic trigger;
- [0009]** Fig. 4 illustrates cross-sectional views of the system of Fig. 3 in an unactuated state and in an actuated state;
- [0010]** Fig. 5 illustrates an example of a portion of a hoop stress hydraulic trigger;
- [0011]** Fig. 6 illustrates an example of a tubular body and examples of equations;
- [0012]** Fig. 7 illustrates an example of an approximate plot of fractional increase in diameter of a tubular body with respect to pressure and an example of a method;
- [0013]** Fig. 8 illustrates perspective views of the system of Fig. 3;
- [0014]** Fig. 9 illustrates a cross-sectional view of an example of a roller mechanism; and
- [0015]** Fig. 10 illustrates cross-sectional views of examples of coatings.

DETAILED DESCRIPTION

[0016] The following description includes the best mode presently contemplated for practicing the described implementations. This description is not to be taken in a limiting sense, but rather is made merely for the purpose of describing the general principles of the implementations. The scope of the described implementations should be ascertained with reference to the issued claims.

[0017] As mentioned, various types of equipment can be utilized in a subterranean environment. An example of such equipment is a liner hanger, which may be utilized to attach or hang one or more liners from an internal wall of a casing in a well in a subterranean environment. A liner may be a string of casing in which the top does not extend to the surface but instead is suspended from inside another

casing string. As an example, a liner hanger may be used to attach or hang one or more liners from an internal wall of another casing string.

[0018] As an example, a method may include operating one or more components of a liner hanger system. As an example, a lower completion may be a portion of a well that is at least in part in a production zone or an injection zone. As an example, a liner hanger system may be implemented to perform one or more operations associated with a lower completion, for example, including setting one or more components of a lower completion, etc. As an example, a liner hanger system may anchor one or more components of a lower completion to a production casing string.

[0019] One or more pieces equipment, which may be an assembly or a system, can include one or more mechanisms that can be actuated. A mechanism may be actuated to transition from a first state to a second state. As an example, a mechanism may be actuated (e.g., actuable) via fluid pressure. For example, fluid pressure in a tubular (e.g., a tubular body) may be increased and/or decreased to actuate a mechanism. A mechanism may be a biased mechanism such as, for example, a spring-biased mechanism where potential energy stored in one or more springs can be released as kinetic energy to cause one or more components to move.

[0020] As an example, a mechanism may be actuated through a change in hoop stress, which may be referred to as circumferential stress. For example, a change in pressure in an interior region and/or an exterior region of a tubular body can cause a change in hoop stress of the tubular body that can increase or decrease a cross-sectional dimension (e.g., radius or diameter) of the tubular body. Where a helical strip (e.g., a spiral strip) is disposed about the tubular body or disposed interiorly to the tubular body, such a change in the cross-sectional dimension can cause the helical strip to change where a change in the helical strip can trigger a mechanism. As an example, where a liner hanger includes slips operatively coupled to a tubular body, an increase in pressure of the tubular body can cause a helical strip that is disposed about the tubular body to increase in diameter such that one or more portions of the helical strip move (e.g., due to a decrease in number of turns, total number of degrees from end to end, etc.). For example, an end of a helical strip can move where the end may include a latch portion that has a latched state and an unlatched state for the slips. In such an example, movement of the latch can cause

the liner hanger to transition from a latched state of the slips to an unlatched state of the slips. Such a mechanism can be fluid pressure actuatable and may be referred to as a hoop stress hydraulic trigger.

[0021] In mechanics, a cylinder stress is a stress distribution with rotational symmetry; that is, which remains unchanged if the stressed object is rotated about some fixed axis. Cylinder stress patterns can include: circumferential stress or hoop stress, as a normal stress in the tangential (azimuth) direction; axial stress, as a normal stress parallel to the axis of cylindrical symmetry; and radial stress, as a stress in directions coplanar with but perpendicular to the symmetry axis.

[0022] The term hoop stress has an etymology that is based in the tension applied to iron bands, or hoops, of a wooden barrel. Hoop stress is now synonymous with circumferential stress (e.g., stress associated with a perimeter of a body such as a tubular body). In a straight, closed pipe, force applied to the cylindrical pipe wall by a pressure differential can give rise to hoop stresses. A pipe may be “closed” due to an end cap, being in contact with material (e.g., rock, etc.), being pressurized by fluid at one end while having resistance to fluid flow at another end and/or along perforations, being plugged by one or more objects (e.g., balls, etc.) or other manner. As an example, a pipe, which can be a tubular body, can behave as a pressure vessel in that fluid pressure in the pipe can be increased or decreased by being in fluid communication with a pump or other equipment that can change fluid pressure. As an example, a pump or other equipment may change fluid pressure in a region about a pipe such that a pressure differential between an interior space and an exterior space of a pipe changes (e.g., increases or decreases).

[0023] As mentioned, a liner hanger can include a hoop stress hydraulic trigger or triggers. Liner hangers are tools that find use in oil and gas completions for hanging a liner in a casing. A liner hanger may be classified as being mechanical or hydraulic as to actuation of a setting mechanism (e.g., a slip-based setting mechanism).

[0024] A hydraulic set liner hanger can include a tubular body that includes one or more openings in its tubular wall such that fluid pressure can be communicated from an interior space to an exterior space and/or vice versa. A hydraulic set liner hanger can have an ability to prevent a liner hanger from premature setting while manipulating the tool string in to a well, which is a type of

risk that can exist for a mechanical set liner hanger. For example, fluid pressure may be controlled to assure that fluid pressure does not rise to a level sufficient to trigger an actuator of a setting mechanism (e.g., a slip-based setting mechanism). A mechanical set liner hanger can be without penetration(s) in a tubular body and, thus, without a seal stack to maintain pressure integrity.

[0025] As an example, a hoop stress hydraulic trigger can provide an ability to set a liner hanger hydraulically where a tubular body of the liner hanger is without a penetration or penetrations. Such an approach can reduce risk of premature setting of slips and can be controlled remotely, for example, via building of fluid pressure in an interior space (e.g., a lumen) of the tubular body where a pressure differential exists between the interior space and an exterior space that causes a desired amount of hoop stress to hydraulically activate a helical strip-based trigger.

[0026] As an example, a system that includes a hoop stress hydraulic trigger can include a tubular body that is without tubular wall penetration(s) (e.g., without a penetration through a body/liner string). As an example, energy to set slips of a liner hanger that includes a hoop stress hydraulic trigger can be stored as potential energy in a spring such as, for example, a wave spring with appropriate deflection/length characteristics. As an example, a sleeve that include seats slips can be pulled back to compress a wave spring where a trigger lock handle may be utilized to maintain the wave spring in a compressed (e.g., latched) state. In such an example, a trigger lock handle (e.g., a trigger lock component) can be set in place with a trigger, which can be a hoop stress hydraulic trigger. In such an example, the trigger can be a wound metal plate with a rectangular cross section, which may be shaped as a helical strip. In such an example, the width of the plate can be at least four times its thickness. Such a plate can be wound helically (e.g., also consider a helically cut spring with the aforementioned cross-section). An arrangement of components can include one end of the trigger interfaced with the trigger lock handle and the other end connected to the tubular body (e.g., fixed to avoid movement such that the trigger has a fixed end). As an example, a trigger can include at least four turns and can increase or decrease based on a change in the circumference of a tubular body of a liner hanger.

[0027] As an example, surfaces that can contact (e.g., trigger and trigger lock, trigger and tubular body, etc.) may be manufactured and/or treated to have a desired surface and/or surface finish, which may be, for example, low friction to facilitate

accurate setting. As an example, a polytetrafluoroethylene (PTFE) and/or another type of fluoropolymer may be utilized as a layer, a coating, etc., to reduce friction between two components. As an example, one or more rolling elements (e.g., ball bearings, roller bearings, etc.) may be utilized to reduce friction between two components. As an example, nitriding may be utilized to treat a surface to form a nitrided surface. A treatment such as nitriding may increase surface hardness, improves resistance to one or more of wear, fatigue and corrosion, and/or lower coefficient of friction.

[0028] As an example, one or more components may be coated at least in part with a XYLAN™ fluoropolymeric and binder coating (Whitford Corporation, West Chester, Pennsylvania), for example, to reduce friction, improve wear resistance, to protect a metal from corrosion, etc. As an example, fluoropolymers can include one or more of PTFE, fluorinated ethylene propylene (FEP) and perfluoroalkoxy alkanes (PFA).

[0029] As an example, a trigger can be covered at least in part by a sleeve (e.g., an annular cylinder) to protect it from rough conditions downhole (e.g., debris, other components, etc.). Such a sleeve may be treated (e.g., nitrided, surface coated, etc.) to provide desired surface properties (e.g., surface finish, friction coefficient, etc.).

[0030] As an example, contact surfaces between a trigger and a trigger lock (e.g., a trigger lock component) can have a hook angle (e.g., consider a shallow angle of about 3 degrees to about 5 degrees) that aims to hold in place and reduce risk (e.g., prevent) premature release of the trigger lock from the trigger. As an example, a trigger lock can be guided through a slot to constrain rotation along the axis of a tubular body. As an example, a sleeve that holds slips can have a lock ring to assist slip movement (e.g., to be limited to movement in one direction).

[0031] As mentioned, a trigger can be a hoop stress-based trigger where pressurization of a tubular body of a liner hanger results in radial growth due to hoop stress. In such an example, due to this radial growth, there will be change in circumference (e.g., perimeter) of the tubular body.

[0032] As an example, a change in circumference of a tubular body can be utilized to trigger the setting of a liner hanger. Turns can be provided in a strip of a trigger to magnify a circumference change. For example, if a circumference change for one turn is about 0.050 inch (e.g., about 1.27 mm), then, for five turns, the

change can be magnified to about 0.250 inch (e.g., about 6.35 mm) circumferentially. Such movement can be effectively utilized to trigger slips of a liner hanger.

[0033] A trigger lock can be operatively coupled to a tubular body in a manner such that it is fixed or otherwise limited in rotation (e.g., azimuthal) movement with respect to a trigger such that when the trigger moves, the trigger lock is released. A trigger lock can be fixed such that it does not move circumferentially where the trigger can move losing contact with the trigger lock. In an unlatched or unlocked state, the trigger lock can release potential energy stored in a spring (e.g., a slip deployment spring that can effectively cause setting the slips).

[0034] A method can include positioning a liner hanger downhole to a desired depth and pressurizing the liner to a pressure sufficient to activate the trigger (e.g., consider fluid pressure of about 1500 psi to about 3000 psi or about 10 MPa to about 20 MPa) to set the hanger.

[0035] As an example, a method can include positioning a running tool at a location (e.g., a liner hanger/packer running tool). In such a method, the running tool load carrying location can be located to be below the trigger section of a liner hanger. Such positioning can allow a liner hanger to be practically tensionless. For example, a hoop stress hydraulic trigger can experience hoop stress without experiencing a substantial amount of other stress.

[0036] Figs. 1 and 2 show an example of an environment 100, an example of a portion of a completion 101, an example of equipment 120 and examples of assemblies 150 and 250, which may be part of a liner hanger system. As an example, the equipment 120 may include a rig, a turntable, a pump, drilling equipment, pumping equipment, equipment for deploying an assembly, a part of an assembly, etc. As an example, the equipment 120 may include one or more controllers 122. As an example, a controller may include one or more processors, memory and instructions stored in memory that are executable by a processor, for example, to control one or more pieces of equipment (e.g., motors, pumps, sensors, etc.). As an example, the equipment 120 may be deployed at least in part at a well site and, optionally, in part at a remote site.

[0037] Fig. 1 shows an environment 100 that includes a subterranean formation into which a bore 102 extends where a tool 112 such as, for example, a drill string is disposed in the bore 102. As an example, the bore 102 may be defined

in part by an angle (\ominus); noting that while the bore 102 is shown as being deviated, it may be vertical (e.g., or include one or more vertical sections along with one or more deviated sections). As shown in an enlarged view with respect to an r, z coordinate system (e.g., a cylindrical coordinate system), a portion of the bore 102 includes casings 104-1 and 104-2 having casing shoes 106-1 and 106-2. As shown, cement annuli 103-1 and 103-2 are disposed between the bore 102 and the casings 104-1 and 104-2. Cement such as the cement annuli 103-1 and 103-2 can support and protect casings such as the casings 104-1 and 104-2 and when cement is disposed throughout various portions of a wellbore such as the wellbore 102, cement may help achieve zonal isolation.

[0038] In the example of Fig. 1, the bore 102 has been drilled in sections or segments beginning with a large diameter section (see, e.g., r_1) followed by an intermediate diameter section (see, e.g., r_2) and a smaller diameter section (see, e.g., r_3). As an example, a large diameter section may be a surface casing section, which may be three or more feet in diameter and extend down several hundred feet to several thousand feet. A surface casing section may aim to prevent washout of loose unconsolidated formations. As to an intermediate casing section, it may aim to isolate and protect high pressure zones, guard against lost circulation zones, etc. As an example, intermediate casing may be set at about 6000 feet (e.g., about 2000 m) and extend lower with one or more intermediate casing portions of decreasing diameter (e.g., in a range from about thirteen to about five inches in diameter). A so-called production casing section may extend below an intermediate casing section and, upon completion, be the longest running section within a wellbore (e.g., a production casing section may be thousands of feet in length). As an example, production casing may be located in a target zone where the casing is perforated for flow of fluid into a bore of the casing.

[0039] As mentioned, a liner may be a casing (e.g., a completion component). As mentioned, a liner may be installed via a liner hanger system. As an example, a liner hanger system may include various features such as, for example, one or more of the features of the assembly 150 and/or the assembly 250 of Figs. 1 and 2.

[0040] As shown in Fig. 1, the assembly 150 can include a pump down plug 160, a setting ball 162, a handling sub with a junk bonnet and setting tool extension 164, a rotating dog assembly (RDA) 166, an extension(s) 168, a mechanical running

tool 172, a hydraulic running tool 174, a hydromechanical running tool 176, a retrievable cementing bushing 180, a slick joint assembly 182 and/or a liner wiper plug 184.

[0041] As shown in Fig. 2, the assembly 250 can include a liner top packer with a polished bore receptacle (PBR) 252, a coupling(s) 254, a mechanical liner hanger 262, a hydraulic liner hanger 264, a hydraulic liner hanger 266, a liner(s) 270, a landing collar with a ball seat 272, a landing collar without a ball seat 274, a float collar 276, a liner joint or joints 278 and/or 280, a float shoe 282 and/or a reamer float shoe 284.

[0042] As an example, a method can include setting a liner hanger, releasing a running tool, cementing a liner and setting a liner top packer. As an example, a method can include pumping heavy fluid (e.g., cement) down an annulus from a point above a liner hanger and a liner top packer. In such an example, stress on a formation may be reduced when compared to a method that pumps heavy fluid (e.g., cement) up such an annulus. For example, stress may be reduced as back pressure developed during pumping may be contained in between a casing and a landing string.

[0043] As an example, a liner hanger can include a hold down slip that aims to prevent a liner from moving up during a cementing operation or, for example, when loading exists due to fluid pressure (e.g., well kicking) of a formation. For deep offshore wells, loading due to well kicking can be substantial. As an example, a liner hanger can include multiple sets of hold down components. For example, a liner hanger can include two hold down assemblies with separate sets of slips.

[0044] As an example, an assembly such as the assembly 150 or the assembly 250 can include a trigger and trigger lock component where the trigger can be a helical strip. As an example, a trigger lock component can be a helical strip or another type of component. As mentioned, a helical strip positioned exterior to or interior to a tubular body (e.g., an annular cylinder, etc.) can increase or decrease in a number of turns (e.g., total number of degrees) in response to a change in a circumference of a tubular body, which can be due to a change in circumferential stress of the tubular body. Such a change can allow for unlocking of the trigger lock component and the trigger (e.g., unlatching, disengagement, etc.).

[0045] Fig. 3 shows an example of a system 300 that includes a tubular body 400 (e.g., a pipe), components 500 operatively coupled to the tubular body 400, a

set of slips 600 and an actuation mechanism 700 that includes a hoop stress hydraulic trigger portion 800 and a spring portion 900 that can be latched and unlatched via a trigger lock component 920 interacting with the hoop stress hydraulic trigger portion 800.

[0046] As to the components 500, these include a first annular component 510, a second annular component 520, a third annular component 530 and a fourth annular component 540. Such components may be assemblies that operatively couple to the tubular body 400 in a fixed manner or in a movable manner.

[0047] As shown in Fig. 3, the tubular body 400 includes opposing ends 402 and 404, which may be at axial positions other than those illustrated in Fig. 3, for example, the tubular body 400 may be longer than in the example illustrated in Fig. 3. The tubular body 400 includes a portion 410 with a length at a first diameter that defines a shoulder 412 that steps to a portion 414 with a length at a second, larger diameter, where recesses 416 in the portion extend to another shoulder 418.

[0048] As shown the recesses 416 accommodate ends 612 of the slips 610. As shown, the slips 610 have axial lengths defined between opposing ends 612 and 614. Each of the slips 610 includes a grip portion 613 that extends between one of the ends 612 and a juncture 616 with a stem portion 615. Each of the stem portions 615 includes a T-shaped portion 617 at the end 614.

[0049] As shown in Fig. 3, the annular component 540 includes grooved recesses 545 that seat the slips 610, which can include mating grooves such that the slips 610 are guided during deployment, axially upwardly and radially outwardly. The annular component 540 also includes slots 547 that seat the stem portions 615 of the slips 610. The annular component 530 includes recesses 535 that seat the T-shaped portions 617 at the ends 614 of the slips 610. In the example of Fig. 3, the annular component 530 is axially translatable to apply force to the slips 610 such that the slips 610 can be deployed (e.g., to engage an inner surface of casing, etc.).

[0050] The trigger lock component 920, which includes opposing ends 922 and 924, is fixed to the annular component 530 via a bolt 925 or other component or components. As shown in Fig. 3, the annular component 530 is spring biased by the spring 950 such that upon release (e.g., unlatching) of the trigger lock component 920, the annular component 530 can translate axially upwardly to apply force to the slips 610 to translate the slips 610 with respect to the recesses 545 of the annular component 540, which may be a series of individual bodies operatively coupled to

the tubular body 400. The annular component 520 includes a slot 525 in which the trigger lock component 920 can axially translate, for example, upon released of the trigger lock component 920. As an example, a sleeve may be disposed about the spring 950 to protect the spring 950 (e.g., during transport of the system 300, etc.).

[0051] As shown in Fig. 3, the hoop stress hydraulic trigger portion 800 includes a helical strip 850 that can latch the trigger lock component 920 and that can move responsive to hoop stress of the tubular body 400 to unlatch the trigger lock component 920. Upon unlatching of the trigger lock component 920, potential energy stored in the spring 950 can be converted into kinetic energy to cause the annular component 530 to translate axially upwardly, with reference to the illustration of Fig. 3, which causes the slips 610 to translate axially upwardly and radially outwardly such that the grip portions 613 of the slips 610 can contact and grip a surface of casing in which the system 300 is disposed. In such an example, hoop stress as generated via fluid pressure (e.g., hydraulic pressure) can trigger setting of the slips 610 against a surface to secure the system 300 at an axial location in a subterranean environment.

[0052] In the example of Fig. 3, the helical strip 850 can be referred to as a trigger or, for example, a hoop stress hydraulic trigger; noting that hydraulic refers to fluid such as a substantially incompressible fluid that can exert pressure on the tubular body 400.

[0053] As an example, a system can include a tubular body that includes a longitudinal axis and a circumference that depends on circumferential stress of the tubular body; a helical strip that includes a turn number about a longitudinal axis that is substantially co-axial to the longitudinal axis of the tubular body where the turn number depends on the circumference of the tubular body; and a trigger lock component where the helical strip and the trigger lock component include a key and keyway pair that includes a latched state for a first circumferential stress of the tubular body and an unlatched state for a second circumferential stress of the tubular body. For example, the a system 300 includes the tubular body 400 that includes a longitudinal axis (z-axis) and a circumference that depends on circumferential stress of the tubular body 400; the helical strip 850 that includes a turn number about a longitudinal axis that is substantially co-axial to the longitudinal axis (z-axis) of the tubular body 400 where the turn number depends on the circumference of the tubular body 400; and the trigger lock component 920 where the helical strip 850 and

the trigger lock component 920 can include a key and keyway pair that includes a latched state for a first circumferential stress of the tubular body 400 and an unlatched state for a second circumferential stress of the tubular body 400.

[0054] As an example, the system 300 may be oriented substantially aligned with gravity (e.g., in a vertical portion of a borehole) or at an angle with respect to gravity (e.g., in a deviated or horizontal portion of a borehole).

[0055] Fig. 4 shows two cross-sectional views of the system 300 where the cross-sectional view to the left side is of the system 300 in an undeployed state with respect to the slips 610 and where the cross-section view to the right side is of the system 300 in a deployed state with respect to the slips 610. The undeployed state corresponds to the helical strip 850 being engaged with respect to the trigger lock component 920 such that the spring 950 is in a compressed state that stores potential energy. The deployed state corresponds to the helical strip 850 being disengaged with respect to the trigger lock component 920 such that the spring 950 is in a less compressed state with lesser stored potential energy, which may be an uncompressed state with no stored potential energy.

[0056] Fig. 4 also show three pressures, P_0 , P_1 and P_2 , where P_2 is greater than P_1 and where P_0 is a pressure in an exterior region, exterior to the bore of the tubular body 400. In such an example, P_2 can be sufficient to generate hoop stress in a portion of the tubular body 400 that is at least in part axially extensive with the helical strip 850 such that the helical strip 850 experiences the circumferential expansion of the tubular body 400 and, in response, increases its circumference which acts to reduce its total end-to-end angular turn. For example, where the helical strip 850 has four turns, it may decrease to less than four turns in response to a circumferential increase in the tubular body 400. Such a decrease can be sufficient to cause an end of the helical strip 850 to move a distance with respect to the trigger lock component 920 where that distance frees the trigger lock component 920 for movement driven by conversion of potential energy to kinetic energy of the spring 950. As mentioned, the trigger lock component 920 can be attached (e.g., or integral) to the annular component 530, which seats the T-shaped portions 617 of the slips 610. Thus, upon release of the trigger lock component 920, the spring 950 can drive the annular component 530 axially to apply force to the T-shaped portions 617 of the slips 610 to thereby deploy the slips 610.

[0057] As shown in Fig. 4, various components of the system 300 can move axially while various other components of the system 300 can remain substantially stationary. The amount of axial movement of various components can correspond to an amount of axial movement of the slips 610.

[0058] In Fig. 4, a sleeve 890 is shown as being a cover that can cover at least a portion of the helical strip 850. The sleeve 890 can reduce risk of intrusion of material between portions of the helical strip 850. As shown in Fig. 4, the sleeve 890 may be releasably latched to the annular component 510. In a latched state of the sleeve 890, contact between the sleeve 890 and the annular component 510 may help reduce risk of debris entering a space or spaces between the helical strip 850 and the sleeve 890 and/or between the helical strip 850 and the tubular body 400. Such an arrangement of components can help to protect the helical strip 850, as a hoop stress hydraulic trigger, during positioning of the system 300 in a downhole, subterranean environment. As shown in Fig. 3, once the helical strip 850 has performed its function (e.g., release of the trigger lock component 920), contact may no longer exist directly between the sleeve 890 and the annular component 510 (e.g., fluid may enter a space between an inner surface of the sleeve 890 and an outer surface of the tubular body 400).

[0059] Fig. 5 shows a perspective view of an example of the helical strip 850 and the trigger lock component 920 in a latched state and in an unlatched state. As shown in Fig. 5, the helical strip 850 includes ends 852 and 854 where the end 854 includes various key and/or keyway features 856 and 857 and the trigger lock component 920 includes ends 922 and 924 where the end 922 includes various key and/or keyway features 926 and 927. In such an example, a pair or pairs of key and keyway features can be utilized to latch the trigger lock component 920 to the helical strip 850. As shown, the key feature 856 and the keyway feature 927 form one pair while the key feature 926 and the keyway feature 857 form another pair. Actuation of the helical strip 850, due to an increase in circumference of a tubular body that has a longitudinal axis that is substantially co-axial to a longitudinal axis of the helical strip 850, causes the key 856 and the keyway 857 to move away from the keyway 927 and the key 926 such that the trigger lock component 920 can transition from a latched to an unlatched state.

[0060] In the example of Fig. 5, the end 852 of the helical strip 850 can be fixed such that the end 854 experiences movement responsive to an increase in

circumference of a tubular body. For example, the end 852 may include an opening that can receive a bolt that may be bolted into the tubular body 400 (e.g., without penetrating the tubular body 400). As an example, the end 852 may be fixed to an annular component that is attached to the tubular body 400.

[0061] As an example, a key and keyway pair can be a latch and keeper pair, which can be a fastener that can be used to join two or more components together while allowing for their separation, for example, by a trigger, which may move the latch, the keeper or the latch and the keeper. As an example, two helical strips may be disposed about a tubular body and may be joined at ends via one or more key and keyway pairs where each of the helical strips can retract in response to an increase in circumference of the tubular body due to an increase in circumferential stress.

[0062] Fig. 5 shows various dimensions as to the helical strip 850 and as to the trigger lock component 920. The helical strip 850 includes a strip width z_w and a strip thickness Δr_s . In helical form, the helical strip 850 also includes a gap width z_g as defined by spacing between a helical edge of the helical strip 850. The thickness and/or the width may be relatively constant from the end 852 to the end 854, for example, by manufacturing the helical strip 850 from a length of a stock piece of material having a specified thickness and width (e.g., a lineal strip). As an example, the gap may be relatively constant from the end 852 to the end 854. As an example, the end 854 of the helical strip 850 can be machined to form one or more features. For example, a cutting tool may remove material to form the key 856 and may remove material to form the keyway 857, which may be an undercut at the end 854 that extends inwardly a distance from the end 854 sufficient to receive the key 926 of the trigger lock component 920. As to a number of turns, the helical strip 850 has more than four turns where the end 852 is at about 225 degrees and where the end 854 is at about 90 degrees. Thus, a total number of turns may be calculated from a number of degrees, which can be, for example, 4 turns multiplied by 360 degrees per turn plus 225 degrees for the end 852 minus 90 degrees for the end 854 for a total of about 1,575 degrees, which is about 4.375 turns.

[0063] In the example of Fig. 5, the trigger lock component 920 includes a length z_L . As an example, the trigger lock component 920 may have a curvature such as a curvature of a section of an annular cylinder specified by a radius from a

longitudinal axis of the annular cylinder. In such an example, the trigger lock component 920 may be defined by an arc width, which may be specified as a number of degrees (e.g., as in a slice of a pie). For example, the trigger lock component 920 can span an arc width of about a few degrees to about 45 degrees. As an example, the trigger lock component 920 may be manufactured from a piece of stock material such as, for example, a lineal strip. As an example, the trigger lock component 920 can include features that are machined into a piece of stock material that may be a shaped piece of stock material. As shown in the example of Fig. 5, the trigger lock component 920 includes a notch 929 that extends axially to the key 926, which may be of an arc width of a stock piece of material, as appropriately shaped. In such an example, the notch 929 can define a depth of the key 926. As an example, the trigger lock component 920 may be formed of a piece of stock material that has a thickness such as the thickness Δr_T . In such an example, the material may be thinned in one direction (e.g., via machining) to form the keyway 927 and be thinned in another direction (e.g., via machining) to form the key 926. In such an example, the key 926 and the keyway 927 may be formed to mate with the key 856 and the keyway 857 of the helical strip 850.

[0064] In the example of Fig. 5, various surfaces are disposed at an angle or angles. Such angles may be determined by an angle of the helical strip 850. A helical strip may be defined mathematically by one or more parameters of a helix. A helix, sometimes called a coil, is a curve for which the tangent makes a constant angle with a fixed line. The shortest path between two points on a cylinder (one not directly above the other) is a fractional turn of a helix, as can be seen by cutting the cylinder along one of its sides, flattening it out, and noting that a straight line connecting the points becomes helical upon re-wrapping (noting that squirrels chasing one another up and around tree trunks tend to follow helical paths).

[0065] As an example, a tubular body may be conical in shape and a helical strip may be conical in shape. In such an example, the helical strip may be of a lesser diameter where the tubular body is of a lesser diameter and may be a greater diameter where the tubular body is of a greater diameter. In such an example, hoop stress can increase the diameters of the conically shaped tubular body, which can cause the conically shaped helical strip to shorten with respect to its turns.

[0066] As an example, a helical strip may be defined in part by a helix angle, which can be an angle between a helix and an axial line on its right, circular cylinder or cone. A helix angle can reference the axis of a cylinder, distinguishing it from the lead angle, which references a line perpendicular to the axis. The helix angle can be the geometric complement of the lead angle. The helix angle can be measured in degrees.

[0067] Fig. 5 shows a plot 1500 that includes various parameters such as a helix radius r_H , a helix angle α and a helix axial dimension Δz . One or more of such parameters may be selected to define a helical strip. As mentioned, a number of turns can be a parameter that defines a helical strip. As an example, a helix angle may be selected to achieve a desired amount of friction between one or more key and keyway pairs for latching of a helical strip to a trigger lock component. As an example, an angle may be a shallow angle (e.g., less than about 10 degrees) such that key and keyway features engage with minimal risk of unintended slippage (e.g., slipping that could prematurely disengage the features when subjected to a biasing force).

[0068] As an example, a helical strip may be defined by various parameters where potential energy stored by a spring may be taken into account. For example, a helix angle may be selected and dimensions of key and keyway features to assure that contact between the key and keyway features is sufficient at the helix angle to withstand an amount of force exerted by the spring when the spring is in a compressed state. Such features may be dimensioned to account for an amount of hoop stress and corresponding increase in circumference of a tubular body about which a helical strip is wound.

[0069] As mentioned, a helical strip may be utilized within a tubular body such that the helical strip increases in its diameter upon an increase in circumference of the tubular body. For example, where a helical strip is in contact with an inner surface of a tubular body and exerts some amount of force, an increase in fluid pressure in the interior space of the tubular body can increase the circumference of the tubular body and release some of the force (e.g., potential to kinetic energy) of the helical strip as it expands in cross-section and correspondingly decreases in number of turns. As an example, where a helical strip is wound about an outer surface of a tubular body, some amount of force may be applied to the helical strip

upon an increase in circumference of the tubular body such that the helical strip stores potential energy.

[0070] Fig. 6 shows a diagram of an example of a portion of the tubular body 400 with respect to various parameters as well as a series of equations 1600, which are reproduced below:

$$\begin{aligned}\varepsilon_C &= \frac{1}{E}(\sigma_C - \nu\sigma_L) \\ \sigma_L &= \frac{pD}{4t} \\ \sigma_C &= \frac{pD}{2t} \\ \varepsilon_C = \varepsilon_D &= \frac{\Delta D}{D} = \frac{1}{E}\left(\frac{pD}{2t} - \nu\frac{pD}{4t}\right) = \frac{pD}{4tE}(2 - \nu)\end{aligned}$$

where E is the Young's modulus of material of a tubular body, ν is Poisson's ratio of material of a tubular body, D is a diameter of a tubular body, t is a wall thickness of a tubular body, σ_C and σ_L are stresses and ε_C and ε_D are strains.

[0071] As to Poisson's ratio, it is a ratio of transverse strain to axial strain (e.g., amount of transversal expansion divided by the amount of axial compression, for small values of these changes). As to the Young's modulus, also known as the elastic modulus, it is a measure of stiffness of a solid material and a mechanical property of linear elastic solid materials. The Young's modulus defines the relationship between stress (force per unit area) and strain (proportional deformation) in a material.

[0072] The foregoing equations include equations for circumferential strain (ε_C) of a tubular body such as the tubular body 400 where $\frac{\Delta D}{D}$ may be estimated for a given pressure experienced by the tubular body 400. As an example, a desired increase in a diameter of a tubular body may be about 0.050 inch (e.g., about 1.27 mm). For example, a diameter of a tubular body may be of the order of about 1 inch (e.g., 25 mm) to about 20 inches (e.g., about 500 mm). As an example, a tubular body or a portion or portions thereof may be dimensioned (see, e.g., the dimensions in Fig. 6) and made from a material to achieve a desired amount or amounts of circumferential change with respect to a helical strip or helical strips.

[0073] As an example, a tubular body may be made of steel. As an example, a mild (0.3 carbon) steel, normalized with small amounts of manganese may be utilized. As an example, strength of steel may be increased with quenching and/or tempering.

[0074] As an example, a tubular body may be made of a polymeric material. As an example, a tubular body may be made of a fiber material (e.g., fiberglass, etc.). As an example, a helical strip may be made of a metal, an alloy, a polymeric material and/or a fiber material (e.g., fiberglass, etc.). As an example, a material can be selected to operate at fluid pressures associated with an operation or operations. For example, a material can be selected based at least in part on a yield stress being sufficient to withstand operational fluid pressures.

[0075] As an example, a material of a helical strip and a material of a tubular body may be selected to avoid reactions therebetween, which may result in changes to surface finishes, corrosion, bonding, etc.

[0076] As an example, for various types of steel or titanium materials, Poisson's ratio is in a range from about 0.25 to about 0.35; noting that nickel alloys may be higher (e.g., above 0.35). As an example, for steel (e.g., ASTM-A36), a Young's modulus may be about 200 GPa and for a titanium material (e.g., titanium or titanium alloy), a Young's modulus may be about 100 to about 120 GPa. As shown in the equations 1600 of Fig. 6, a larger Young's modulus results in a lesser amount of circumferential strain for a given pressure, diameter and thickness. Thus, a titanium material may provide for a greater change for a given pressure (e.g., pressure differential) when compared to steel (e.g., a steel material).

[0077] Fig. 7 shows an example plot 1705 and example of a method 1710. The plot 1705 shows an approximate relationship between increases in diameter of a tubular body versus pressures experienced by the tubular body (e.g., fluid pressure in an interior space as may be referenced with respect to a static pressure in an exterior space). As shown in Fig. 7, as the pressure increases, diameter increases (e.g., circumference increases). As an example, a system may be built such that a target pressure (P_T) is a trigger pressure for a hoop stress hydraulic trigger.

[0078] The method 1710 of Fig. 7 includes an increase block 1712 for increasing fluid pressure in a tube, an increase block 1714 for increasing a diameter of the tube, a decrease block 1716 for decreasing turns of a helix (e.g., by a

fractional amount) and a trigger block 1718 for triggering a mechanism responsive to the decreasing of the turns of the helix.

[0079] As an example, the method 1710 may involve an increase in fluid pressure from a first fluid pressure to a second fluid pressure. For example, consider increasing from a first fluid pressure of about 2,000 psi (e.g., about 14 MPa) to a second fluid pressure of about 4,000 psi (e.g., about 28 MPa), which may be at or above a trigger pressure.

[0080] As an example, a method can include increasing pressure in a manner that includes plugging one or more openings, passages, etc. of a tubular body or a conduit, etc., which may be in fluid communication with the tubular body. As mentioned, a tubular body may act as a pressure vessel or part of a pressure vessel. As an example, a pump, which may be a surface pump or a downhole pump (e.g., consider an electric submersible pump) may be utilized to change pressure in a bore of a tubular body (e.g., a lumen) and/or in an exterior region of a tubular body such that circumferential stress of the tubular body changes, which may, change in a manner sufficient to have a helical strip trigger release a trigger lock component.

[0081] As mentioned, a tubular body may be made of a fiberglass material that may have a fiber weave with a relatively low Young's modulus compared to a metal or metal alloy. In such an example, the tubular body may change in circumference in an amount sufficient to cause a helical strip trigger to release a trigger lock component at a pressure (e.g., pressure differential) that is less than that of a similarly dimensioned metal or metal alloy tubular body. In such an example, a pump to increase fluid pressure for a fiberglass tubular body may be sized to be of a lesser size than a pump to increase fluid pressure for the metal or metal alloy tubular body.

[0082] As an example, a source of fluid pressure can be a formation fluid pressure. For example, consider a tubular body that is plugged at one end and exposed to formation fluid pressure at another end (e.g., or along wall perforations, etc.). In such an example, formation fluid pressure may build in the tubular body to a level sufficient to cause a helical strip trigger to release a trigger lock component.

[0083] Fig. 8 shows two perspective views of a portion of the system 300. The views of Fig. 8 show the system 300 with the sleeve 890 covering part of the helical strip 850 and part of the trigger lock component 920 and show the system 300 without the sleeve 890 (e.g., or with the sleeve 890 slide downwardly) where the

end 854 of the helical strip 850 and where the end 922 of the trigger lock component 920 can be seen.

[0084] As an example, a method can include compressing the spring 950 by axially translating the annular component 530 toward the helical strip 850 to thereby engage the helical strip 850 and the trigger lock component 920 and secure the spring 950 in a compressed state that stores potential energy. Such a method can include increasing fluid pressure in the bore of the tubular body 400 to expand its circumference to thereby cause the helical strip 850 to decrease in total number of degrees of turn and release the trigger lock component 920 such that the spring 950 can act as a deployment mechanism that drives the annular component 530 axially away from the helical strip 850 to deploy the slips 610.

[0085] As an example, a helical strip may be positioned to one side or to another side of a spring-biased mechanism. For example, a helical strip may be positioned above the annular component 530, which may be latched by a portion of the helical strip that moves in response to circumferential expansion of the tubular body to release the annular component 530 for deployment of the slips 610. In such an example, the annular component 530 can include one or more keys and/or one or more keyways that cooperate with one or more keyways and/or one or more keys of the helical strip.

[0086] Fig. 9 shows a cross-sectional view of an example arrangement of the helical strip 850 with respect to the tubular body 400 where a rolling element 858 (e.g., a ball bearing) is disposed therebetween as set into one or more raceways. For example, the helical strip 850 can include a raceway and/or the tubular body 400 can include a raceway. In such an example, the rolling element 858 or a plurality of rolling elements can reduce friction to help assure that an increase in circumference of the tubular body 400 causes a change in the helical strip 850. In such an example, the rolling element 858 may be made of a steel or other material. As an example, a rolling element can be made of a hard material (e.g., a stainless steel or other hard material). As an example, a rolling element may be utilized as part of a hook, which may be formed by a key and keyway pair. For example, a portion of a key and/or a portion of a keyway may include one or more rolling elements set in a raceway.

[0087] Fig. 10 shows a series of cross-sectional views of examples of arrangements of the helical strip 850 with respect to the tubular body 400 where one or more coatings and/or one or more layers may be utilized.

[0088] As an example, the helical strip 850 can be coated and/or surface treated to form a surface layer 859 that may be of desirable properties with respect to a surface of the tubular body 400. For example, the helical strip 850 can be coated with a polymeric material, which may be a fluoropolymeric material (e.g., PTFE, etc.). As an example, the helical strip 850 may be a material that is nitrided. Nitriding is a process that diffuses nitrogen into a surface of a metal (e.g., or metal alloy) to create a case-hardened surface. As an example, nitriding may be applied to low-carbon, low-alloy steels and/or medium and high-carbon steels, titanium, aluminum and molybdenum.

[0089] In another arrangement, the tubular body 400 is shown as including a coating and/or a surface treatment to form a surface layer 409 that may be of desirable properties with respect to a surface of the helical strip 850. For example, the tubular body 400 can be coated with a polymeric material, which may be a fluoropolymeric material (e.g., PTFE, FEP, PFA, etc.). As an example, the tubular body 400 may be a material that is nitrided. Nitriding is a process that diffuses nitrogen into a surface of a metal (e.g., or metal alloy) to create a case-hardened surface. As an example, nitriding may be applied to low-carbon, low-alloy steels and/or medium and high-carbon steels, titanium, aluminum and molybdenum.

[0090] In yet another arrangement, the helical strip 850 includes one or more surface layers 859-1 and 859-2 and the tubular body 400 can include the surface layer 409. As an example, a sleeve such as the sleeve 890 can include a surface layer that faces the helical strip 850.

[0091] As an example, one or more surface layers may be utilized to provide desired friction characteristics that can help to assure movement of a helical strip in response to hoop stress of a tubular body that causes the tubular body to increase in circumference.

[0092] As an example, surface equipment may be utilized to initiate one or more actuation processes. In such an example, surface equipment may be utilized to increase fluid pressure in a tubular body.

[0093] As an example, a system can include a tubular body that includes a longitudinal axis and a circumference that depends on circumferential stress of the

tubular body; a helical strip that includes a turn number about a longitudinal axis that is substantially co-axial to the longitudinal axis of the tubular body where the turn number depends on the circumference of the tubular body; and a trigger lock component where the helical strip and the trigger lock component include a key and keyway pair that includes a latched state for a first circumferential stress of the tubular body and an unlatched state for a second circumferential stress of the tubular body. In such an example, the second circumferential stress of the tubular body can exceed the first circumferential stress of the tubular body.

[0094] As an example, a helical strip can include a turn number that is at least 2 (e.g., two turns). As an example, a helical strip can be specified by including a number of degrees. For example, a turn can be 360 degrees such that two turns is 720 degrees, etc.

[0095] As an example, for a transition of a tubular body from a first circumferential stress of a tubular body to a second circumferential stress of the tubular body, a turn number of a helical strip can decrease by a fraction of a turn, which may correspond to a number of degrees about a longitudinal axis of a helical strip.

[0096] As an example, a tubular body can be a tubular body of a liner hanger. As an example, a system can include slips that can be in an undeployed state that corresponds to a latched state and a deployed state that corresponds to an unlatched state of a helical strip with respect to a trigger lock component.

[0097] As an example, a system can include a spring that biases a trigger lock component that can be latched to a helical strip where movement of the helical strip releases (e.g., unlatches) the trigger lock component such that the spring can convert potential energy to kinetic energy. As an example, a spring can be an annular wave spring that is disposed about a tubular body.

[0098] As an example, a helical strip can include a keyway and a trigger lock component can include a key where the key can be received at least in part by the keyway. As an example, a helical strip can include a key and a trigger lock component can include a keyway where the key can be received at least in part by the keyway.

[0099] As an example, a tubular body can include opposing ends and an axial distance between the opposing ends. In such an example, the tubular body may be

provided where it does not include an opening between the opposing ends. As an example, a tubular body can form at least a portion of a pressure vessel.

[00100] As an example, a first circumferential stress of a tubular body can correspond to a first fluid pressure and a second circumferential stress of the tubular body corresponds to a second fluid pressure. As an example, a second circumferential stress of a tubular body can correspond to a fluid pressure that is equal to or greater than a trigger pressure that triggers a transition from a latched state to an unlatched state where, for example, such a transition actuates a mechanism (e.g., a slip deployment mechanism, etc.).

[00101] As an example, a method can include increasing fluid pressure in a tubular body disposed in a downhole, subterranean environment to increase circumferential stress of the tubular body; increasing a circumference of the tubular body responsive to the increase in circumferential stress; decreasing a number of turns of a helical strip wound about the tubular body; and responsive to the decreasing of the number of turns, unlatching a component that is operatively coupled to the tubular body. In such an example, decreasing can decrease the number of turns by a fraction of a turn (e.g., less than one turn, which may be optionally give in degrees about a longitudinal axis of the helical strip). As an example, the component that is unlatched can be biased by a spring where unlatching allows the spring to convert potential energy to kinetic energy. As an example, a component can be a slip latch that, in an unlatched state, releases slips for deployment. As an example, a tubular body can be a tubular body of a liner hanger. As an example, a tubular body can include opposing ends and an axial distance between the opposing ends and where the tubular body does not include an opening between the opposing ends.

[00102] As an example, a method can include latching a component to a helical strip. Such a method can include compressing a spring or springs where latching of the component allows the spring or springs to store potential energy that can be converted to kinetic energy upon movement of the helical strip, which can be responsive to hoop stress of a tubular body that changes the circumference of the tubular body and thereby the diameter of the helical strip.

[00103] Although only a few examples have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the examples. Accordingly, all such modifications are intended to be included within

the scope of this disclosure as defined in the following claims. In the claims, means-plus-function clauses are intended to cover the structures described herein as performing the recited function and not only structural equivalents, but also equivalent structures. Thus, although a nail and a screw may not be structural equivalents in that a nail employs a cylindrical surface to secure wooden parts together, whereas a screw employs a helical surface, in the environment of fastening wooden parts, a nail and a screw may be equivalent structures. It is the express intention of the applicant not to invoke 35 U.S.C. § 112, paragraph 6 for any limitations of any of the claims herein, except for those in which the claim expressly uses the words “means for” together with an associated function.

CLAIMS

What is claimed is:

1. A system comprising:
 - a tubular body that comprises a longitudinal axis and a circumference that depends on circumferential stress of the tubular body;
 - a helical strip that comprises a turn number about a longitudinal axis that is substantially co-axial to the longitudinal axis of the tubular body wherein the turn number depends on the circumference of the tubular body; and
 - a trigger lock component wherein the helical strip and the trigger lock component comprise a key and keyway pair that comprises a latched state for a first circumferential stress of the tubular body and an unlatched state for a second circumferential stress of the tubular body.
2. The system of claim 1 wherein the second circumferential stress of the tubular body exceeds the first circumferential stress of the tubular body.
3. The system of claim 1 wherein the turn number comprises at least 2 turns.
4. The system of claim 1 wherein, for a transition from the first circumferential stress of the tubular body to the second circumferential stress of the tubular body, the turn number decreases by a fraction of a turn.
5. The system of claim 1 wherein the tubular body comprises a tubular body of a liner hanger.
6. The system of claim 1 comprising slips that comprise an undepolyed state that corresponds to the latched state and a deployed state that corresponds to the unlatched state.
7. The system of claim 1 comprising a spring that biases the trigger lock component.

8. The system of claim 7 wherein the spring comprises an annular wave spring that is disposed about the tubular body.
9. The system of claim 1 wherein the helical strip comprises a keyway and wherein the trigger lock component comprises a key.
10. The system of claim 1 wherein the helical strip comprises a key and wherein the trigger lock component comprises a keyway.
11. The system of claim 1 wherein the tubular body comprises opposing ends and an axial distance between the opposing ends.
12. The system of claim 11 wherein the tubular body does not include an opening between the opposing ends.
13. The system of claim 1 wherein the tubular body forms at least a portion of a pressure vessel.
14. The system of claim 1 wherein the first circumferential stress of the tubular body corresponds to a first fluid pressure and wherein the second circumferential stress of the tubular body corresponds to a second fluid pressure.
15. The system of claim 1 wherein the second circumferential stress of the tubular body corresponds to a fluid pressure that is equal to or greater than a trigger pressure that triggers a transition from the latched state to the unlatched state.
16. A method comprising:
 - increasing fluid pressure in a tubular body disposed in a downhole, subterranean environment to increase circumferential stress of the tubular body;
 - increasing a circumference of the tubular body responsive to the increase in circumferential stress;
 - decreasing a number of turns of a helical strip wound about the tubular body;and

responsive to the decreasing of the number of turns, unlatching a component that is operatively coupled to the tubular body.

17. The method of claim 16 wherein the component is biased by a spring.
18. The method of claim 16 wherein the component is a slip latch that, in an unlatched state, releases slips for deployment.
19. The method of claim 16 wherein the tubular body comprises a tubular body of a liner hanger.
20. The method of claim 16 wherein the tubular body comprises opposing ends and an axial distance between the opposing ends and wherein the tubular body does not include an opening between the opposing ends.

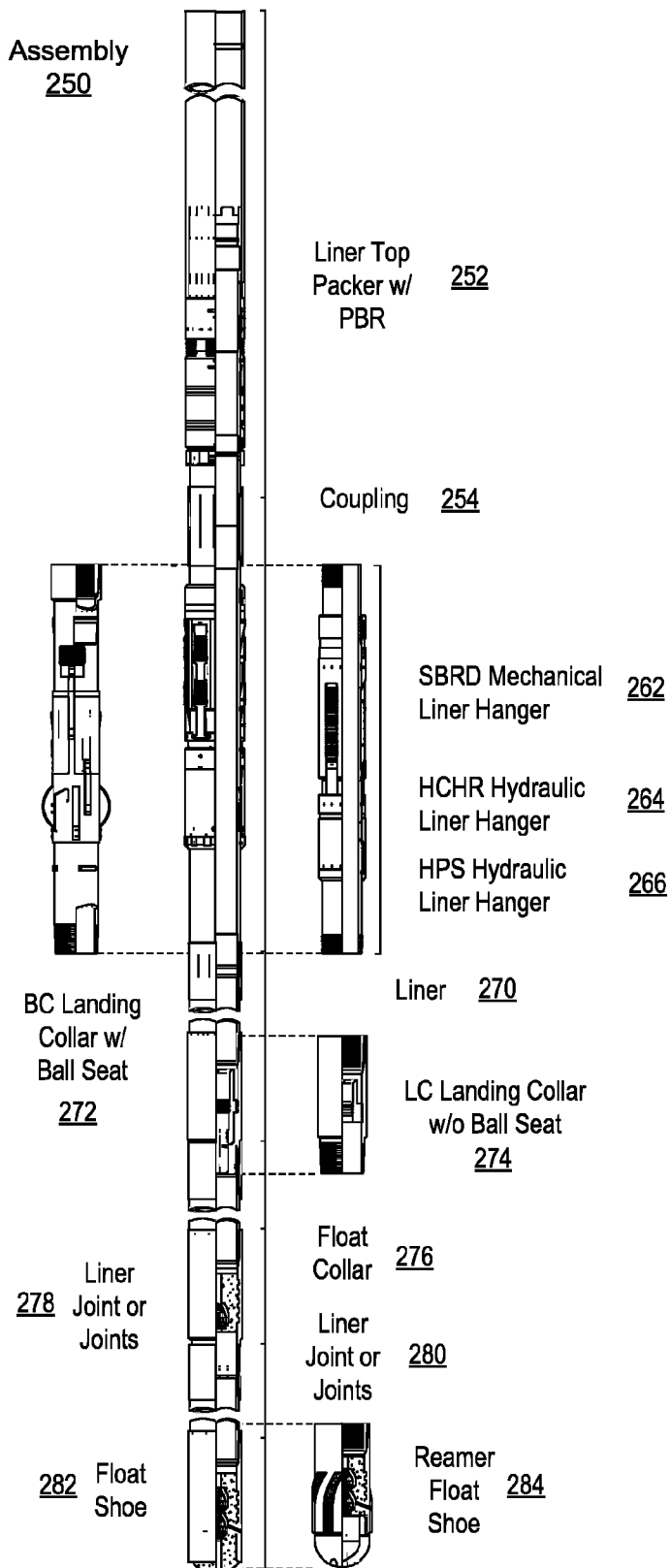


Fig. 2

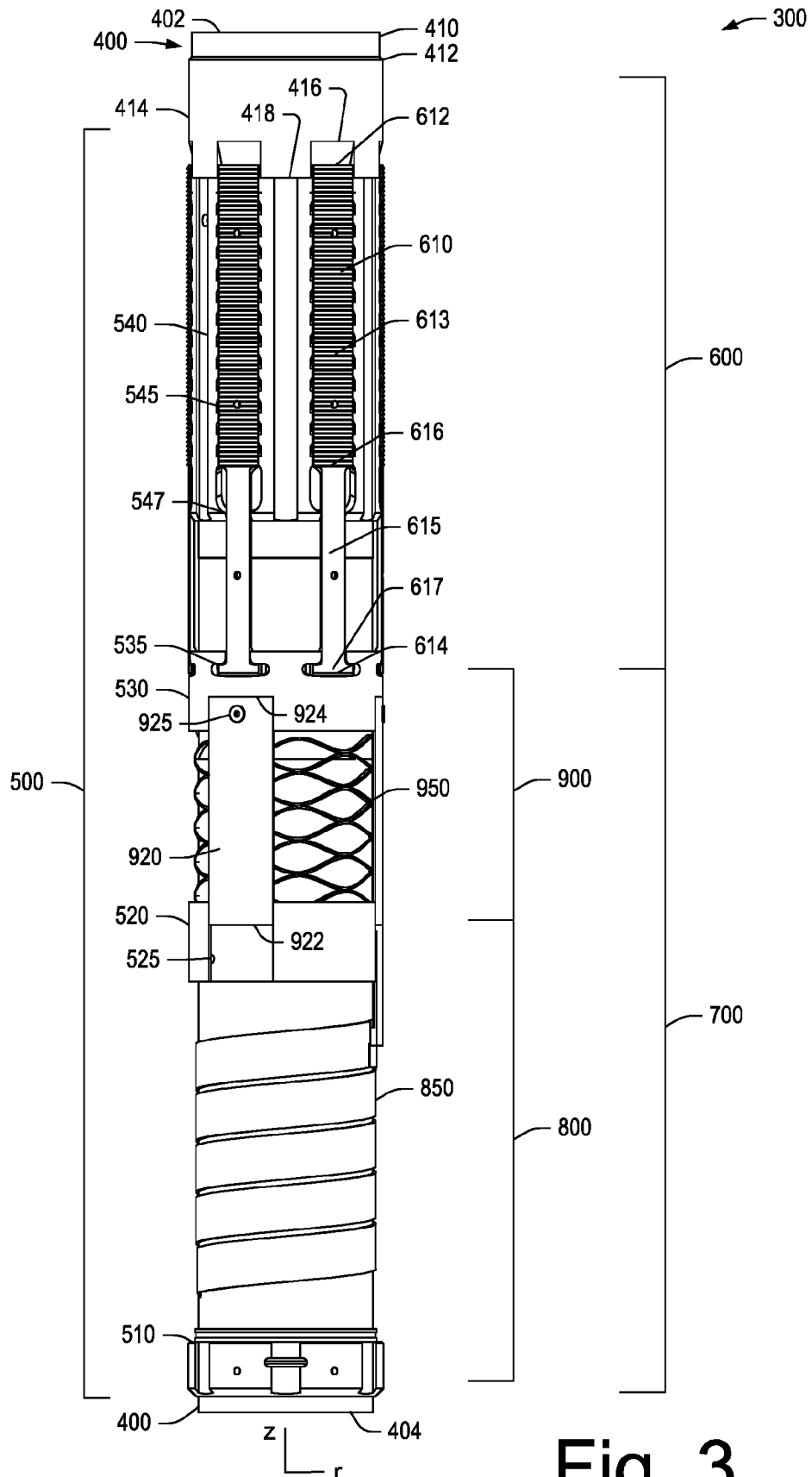


Fig. 3

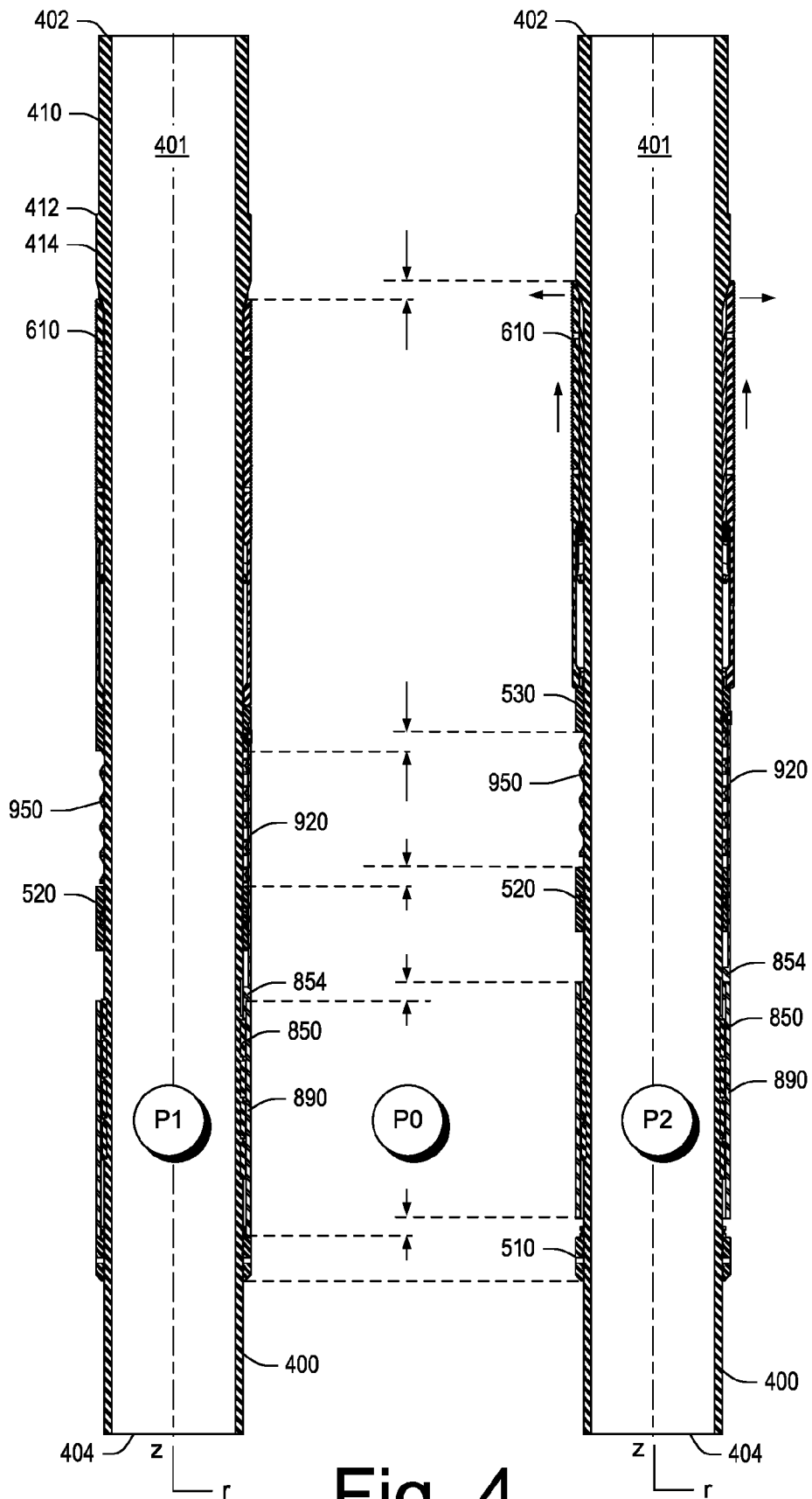


Fig. 4

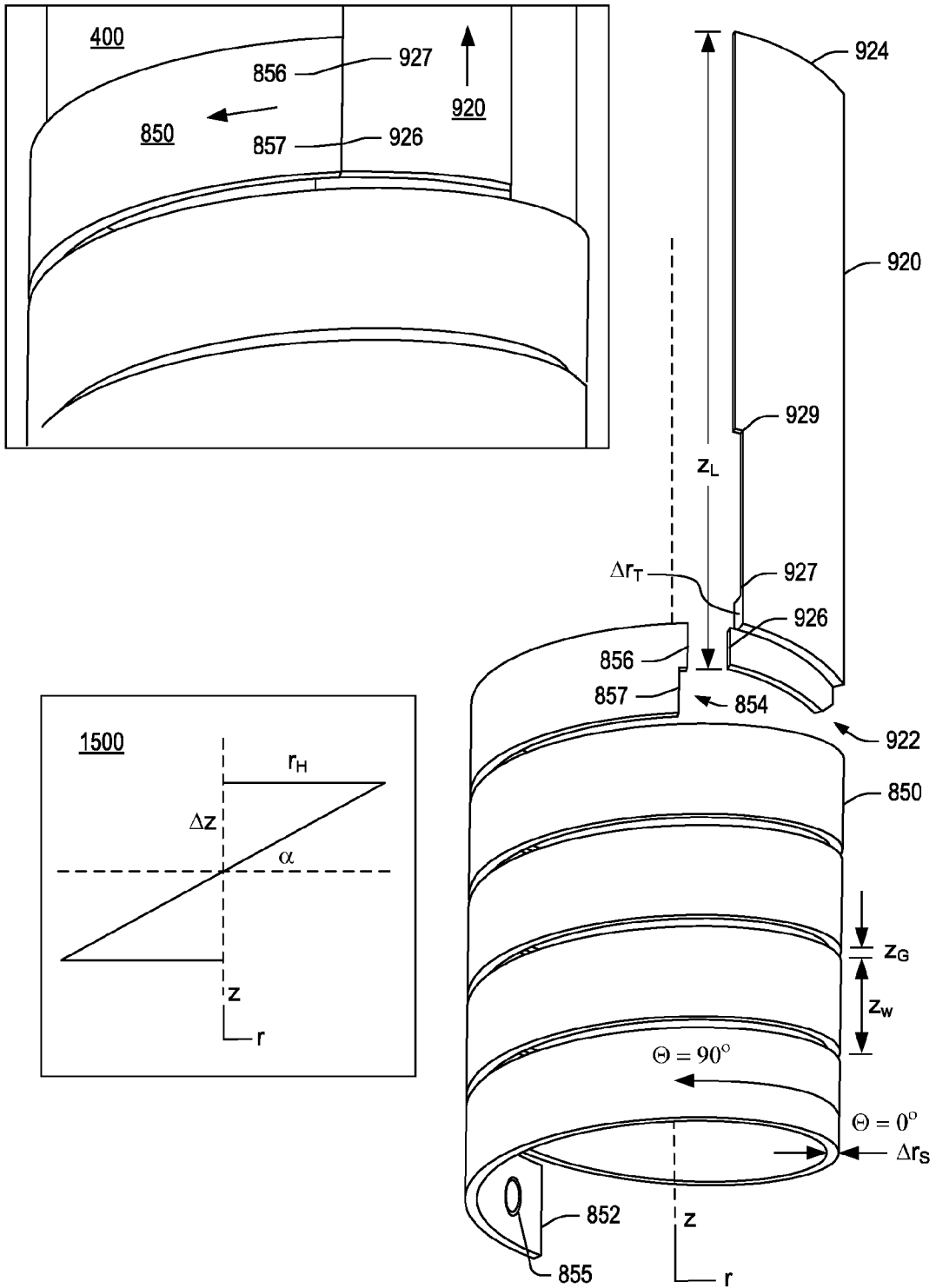
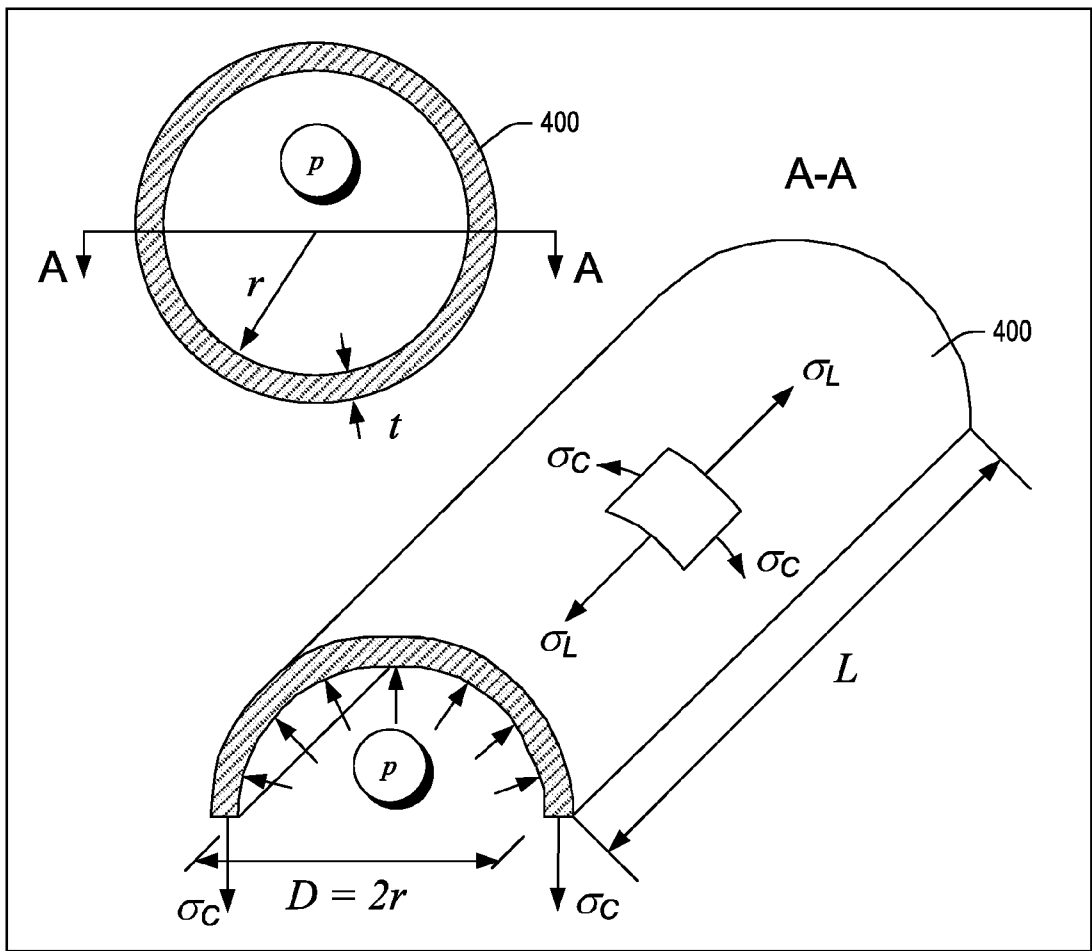


Fig. 5



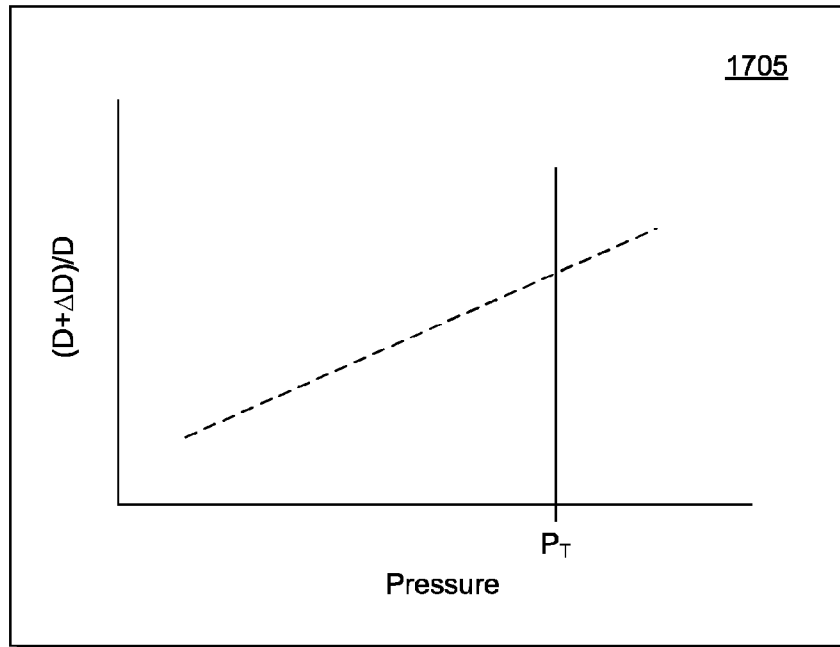
$$\varepsilon_C = \frac{1}{E} (\sigma_C - \nu \sigma_L) \quad 1600$$

$$\sigma_L = \frac{pD}{4t}$$

$$\sigma_C = \frac{pD}{2t}$$

$$\varepsilon_C = \varepsilon_D = \frac{\Delta D}{D} = \frac{1}{E} \left(\frac{pD}{2t} - \nu \frac{pD}{4t} \right) = \frac{pD}{4tE} (2 - \nu)$$

Fig. 6



Method 1710

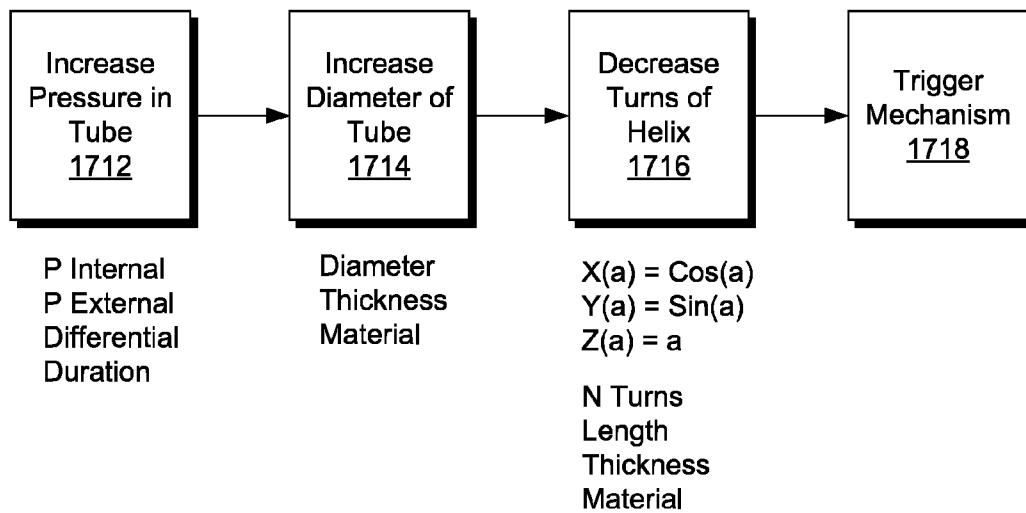


Fig. 7

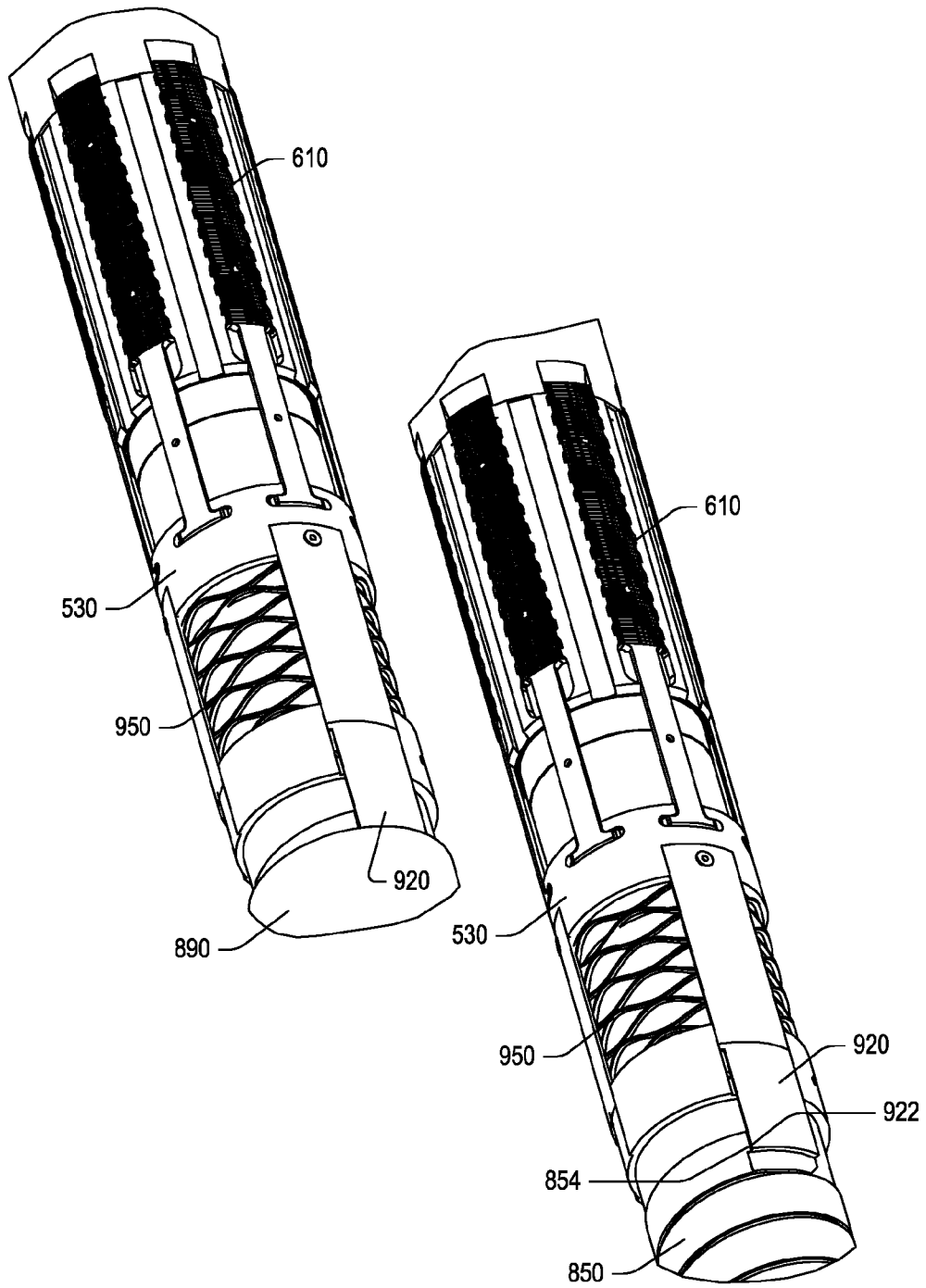


Fig. 8

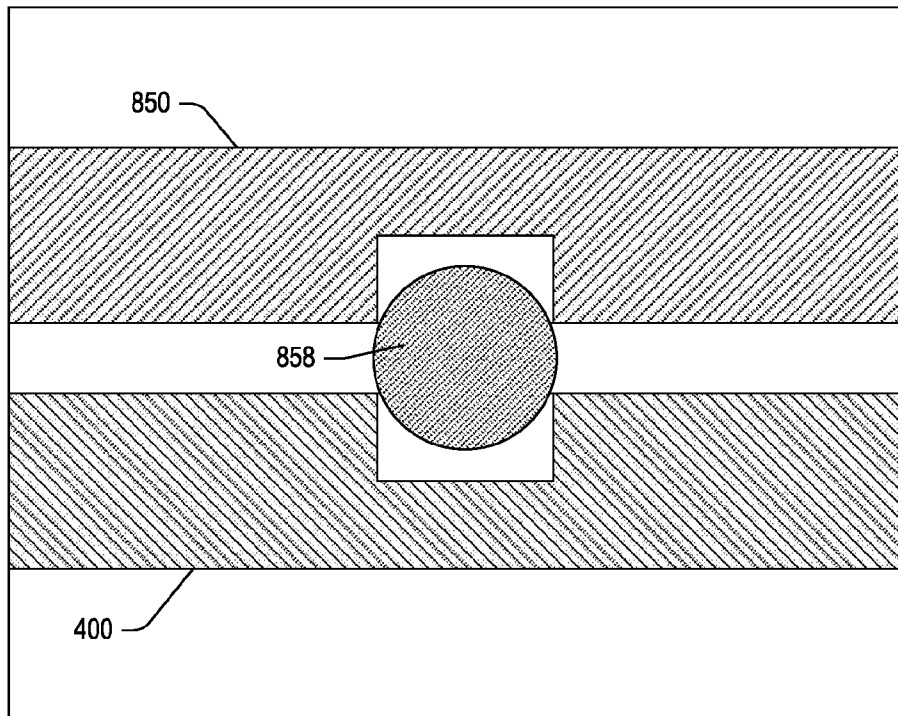


Fig. 9

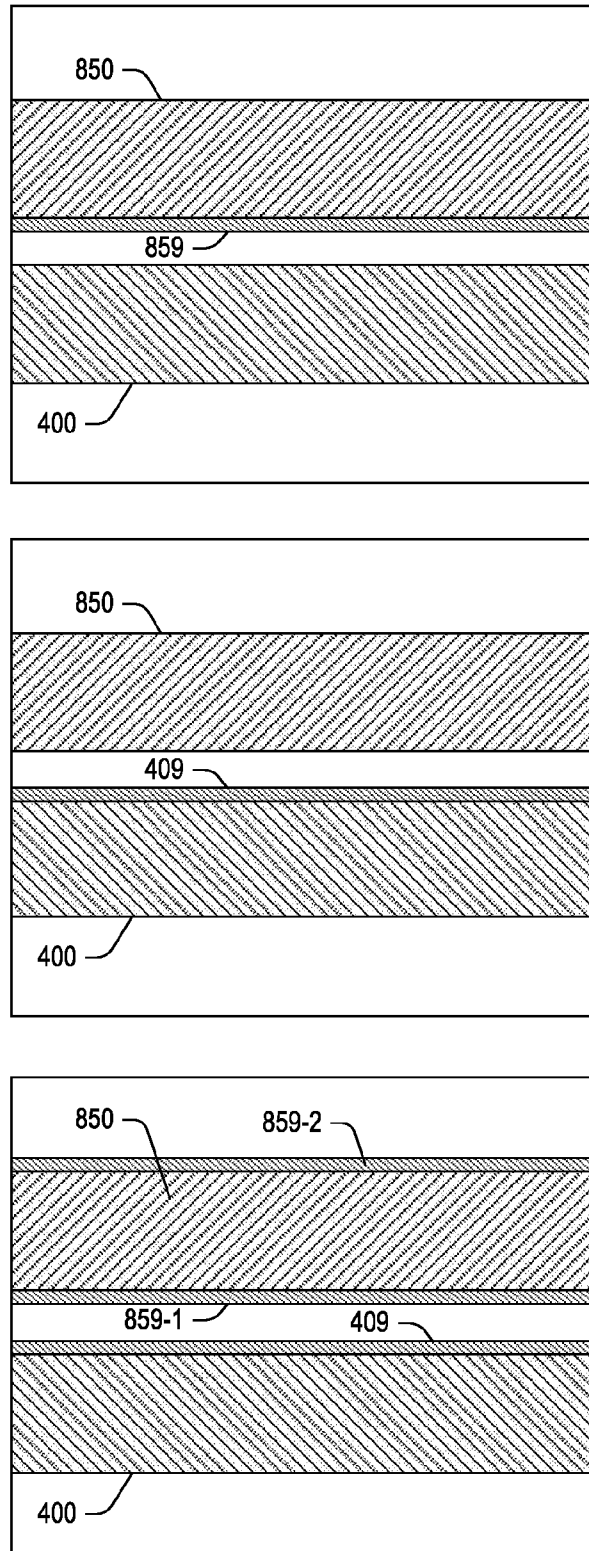


Fig. 10

A. CLASSIFICATION OF SUBJECT MATTER**E21B 43/10(2006.01)i, E21B 23/00(2006.01)i, E21B 17/00(2006.01)i**

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)

E21B 43/10; E21B 23/04; H04H 9/00; G01V 3/00; E21B 23/00; E21B 34/10; E21B 34/16; E21B 17/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

eKOMPASS(KIPO internal) & keywords: hoop stress, circumferential, actuator, lock, key, slip, spring, and latch

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5226494 A (RUBBO et al.) 13 July 1993 See column 6, lines 33 - 47, column 7, lines 36 - 46, column 8, lines 19 - 68, claim 7, and figures 2A-3C.	1-20
A	US 2014-0116715 A1 (GENERAL ELECTRIC COMPANY) 01 May 2014 See paragraphs [0023]-[0024], [0032] and figures 1, 5.	1-20
A	WO 98-45732 A1 (CARSTENSEN et al.) 15 October 1998 See page 21, lines 16 - 29 and figures 19-20.	1-20
A	US 2005-0263292 A1 (BRADDICK, BRITT O.) 01 December 2005 See paragraphs [0033]-[0044] and figures 1A-1B.	1-20
A	US 2004-0194954 A1 (CRAM et al.) 07 October 2004 See paragraphs [0029]-[0031] and figures 1-3.	1-20

 Further documents are listed in the continuation of Box C. See patent family annex.

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"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

15 February 2017 (15.02.2017)

Date of mailing of the international search report

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2016/063717

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