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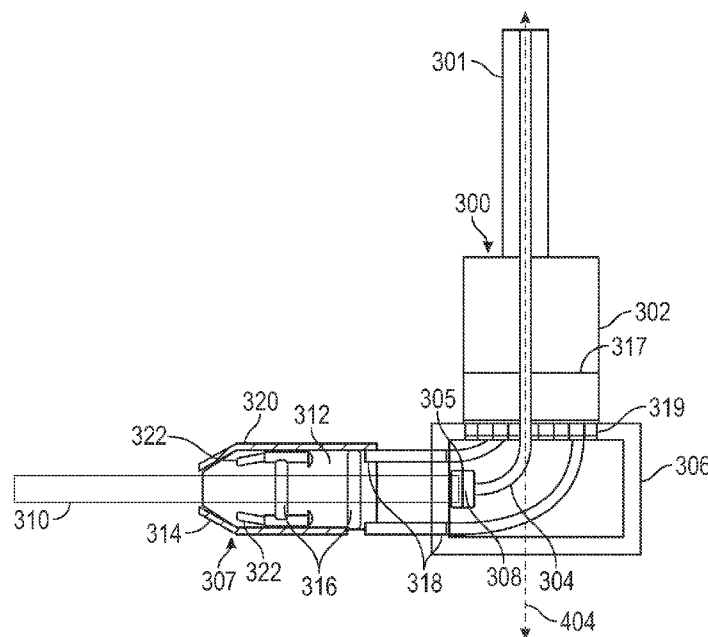


FIG. 2

(57) **Abstract:** Apparatus and methods for transverse fracturing are disclosed. The method may include lowering a laser cutting tool (300) into a wellbore drilled into a subsurface formation; where the laser cutting tool (300) includes a tool body (302), a rotating cutting head (306) positioned along the tool body (302), and an optical fiber (304) extending through the tool body (302) to the rotating cutting head (306). The method may further include directing a laser beam through the optical fiber (304) at a first power level to the rotating cutting head (306), directing the laser beam from the rotating cutting head (306) in a radially outward direction to cut into the wellbore, and rotating the rotating cutting head (306) while directing the laser beam in the radially outward direction from the rotating cutting head (306) to cut a first groove in the wellbore.

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TRANSVERSE FRACTURING

BACKGROUND

[0001] In the oil and gas industry fracturing operations are performed to establish communication between a formation and a wellbore for production. Fracturing technology relies on pumping high volumes of highly pressurized fracturing fluid down the wellbore to the formation, where the pressure of the fracturing fluid exceeds the formation breaking pressure, creating fractures. Fractures are stress dependent, such that propagation of fractures in the formation is controlled by stress orientation. As a result, fractures may propagate in directions that bypass of some hydrocarbons in the formation thereby reducing the rate of hydrocarbon production and/or the total hydrocarbon ultimately produced. A method of fracturing that prevents or reduces the amount of bypassed hydrocarbon is therefore desirable.

SUMMARY

[0002] 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.

[0003] In general, in one aspect, embodiments relate to a method, including lowering a laser cutting tool into a wellbore drilled into a subsurface formation; where the laser cutting tool includes a tool body, a rotating cutting head positioned along the tool body, and an optical fiber extending through the tool body to the rotating cutting head; directing a laser beam through the optical fiber at a first power level to the rotating cutting head, directing the laser beam from the rotating cutting head in a radially outward direction to cut into the wellbore, and rotating the rotating cutting head while directing the laser beam in the radially outward direction from the rotating cutting head to cut a first groove in the wellbore.

[0004] In general, in one aspect, embodiments relate to a laser cutting tool including a tool body having a central axis, an optical fiber extending through the tool body, a rotating cutting head provided coaxially along the tool body, and a motor configured

to rotate the rotating cutting head about the central axis independently from the tool body. The rotating cutting head includes a laser head disposed on a side of the rotating cutting head, the laser head comprising a laser exit, a rotational optics assembly positioned coaxially with an end of the optical fiber, the rotational optics assembly including a mirror facing the end of the optical fiber at an angle, an internal laser passageway extending in a radial direction between the rotational optics assembly and the laser exit, and an optical lens mounted transversely in the internal laser passageway.

[0005] In general, in one aspect, embodiments relate to a transverse fracturing system. The system includes a laser cutting tool, and a motor operatively connected to the laser cutting tool and configured to rotate the rotating cutting head about the central axis. The laser cutting tool includes a tool body having a central axis, and an optical fiber extending through the tool body, a rotating cutting head provided coaxially along the tool body, and a rotational optics assembly positioned coaxially with an end of the optical fiber, where the rotational optics assembly is rotatable with the rotating cutting head. The rotating cutting head is rotational about the central axis and includes a laser head disposed on a side of the rotating cutting head, the laser head comprising a laser exit, an internal laser passageway extending through the rotating cutting head to the laser exit, and an optical lens mounted transversely in the internal laser passageway.

[0006] Other aspects and advantages of the claimed subject matter will be apparent from the following description and the appended claims.

BRIEF DESCRIPTION OF DRAWINGS

[0007] Specific embodiments of the disclosed technology will now be described in detail with reference to the accompanying figures. Like elements in the various figures are denoted by like reference numerals for consistency. The size and relative positions of elements in the drawings are not necessarily drawn to scale. For example, the shapes of various elements and angles are not necessarily drawn to scale, and some of these elements may be arbitrarily enlarged and positioned to improve drawing legibility. Further, the particular shapes of the elements as drawn are not necessarily intended to convey any information regarding the actual shape of the particular elements and have been solely selected for ease of recognition in the drawing.

- [0008] FIG. 1 shows an exemplary hydraulic fracturing system.
- [0009] FIG. 2 shows a laser cutting tool in accordance with one or more embodiments.
- [0010] FIG. 3 shows a detailed view of components in a laser cutting tool in accordance with one or more embodiments.
- [0011] FIG. 4 shows a transverse fracturing system in accordance with one or more embodiments.
- [0012] FIGs. 5A – 5F show a rotating cutting head in accordance with one or more embodiments.
- [0013] FIG. 6 shows a transverse fracturing system in accordance with one or more embodiments.
- [0014] FIG. 7 shows a flowchart of a method in accordance with one or more embodiments.

DETAILED DESCRIPTION

- [0015] In the following detailed description of embodiments of the disclosure, numerous specific details are set forth in order to provide a more thorough understanding of the disclosure. However, it will be apparent to one of ordinary skill in the art that the disclosure may be practiced without these specific details. In other instances, well-known features have not been described in detail to avoid unnecessarily complicating the description.
- [0016] Throughout the application, ordinal numbers (e.g., first, second, third, etc.) may be used as an adjective for an element (i.e., any noun in the application). The use of ordinal numbers is not to imply or create any particular ordering of the elements nor to limit any element to being only a single element unless expressly disclosed, such as using the terms “before”, “after”, “single”, and other such terminology. Rather, the use of ordinal numbers is to distinguish between the elements. By way of an example, a first element is distinct from a second element, and the first element may encompass more than one element and succeed (or precede) the second element in an ordering of elements.

- [0017] It is to be understood that the singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to “a fracture” includes reference to one or more of such fractures.
- [0018] Terms such as “approximately,” “substantially,” *etc.*, mean that the recited characteristic, parameter, or value need not be achieved exactly, but that deviations or variations, including for example, tolerances, measurement error, measurement accuracy limitations and other factors known to those of skill in the art, may occur in amounts that do not preclude the effect the characteristic was intended to provide.
- [0019] It is to be understood that one or more of the steps shown in the flowchart may be omitted, repeated, and/or performed in a different order than the order shown. Accordingly, the scope disclosed herein should not be considered limited to the specific arrangement of steps shown in the flowchart.
- [0020] In the following description of FIGs. 1 – 8, any component described with regard to a figure, in various embodiments disclosed herein, may be equivalent to one or more like-named components described with regard to any other figure. For brevity, descriptions of these components will not be repeated with regard to each figure. Thus, each and every embodiment of the components of each figure is incorporated by reference and assumed to be optionally present within every other figure having one or more like-named components. Additionally, in accordance with various embodiments disclosed herein, any description of the components of a figure is to be interpreted as an optional embodiment which may be implemented in addition to, in conjunction with, or in place of the embodiments described with regard to a corresponding like-named component in any other figure.
- [0021] In one aspect, embodiments disclosed herein relate to a method of creating transverse fractures within a formation using a laser cutting tool. More specifically, embodiments disclosed herein relate to using a rotating cutting head, which may emit a controlled laser beam, to create a circular, or approximately circular, transverse fracture within a formation. In another aspect, embodiments disclosed herein relate to a transverse fracturing system which may be deployed to a formation, and which may be powered from a surface location. The transverse fracturing system may

include a laser cutting tool with a rotating cutting head configured to create transverse fractures in a formation.

[0022] FIG. 1 shows an example of an exemplary hydraulic fracturing site (100) undergoing a hydraulic fracturing operation in accordance with one or more embodiments. The particular hydraulic fracturing operation and hydraulic fracturing site (100) shown is for illustration purposes only. The scope of this disclosure is intended to encompass any type of hydraulic fracturing site (100) and hydraulic fracturing operation. In general, a hydraulic fracturing operation includes two separate operations: a perforation operation and a pumping operation.

[0023] A hydraulic fracturing operation is performed in stages and on multiple wells that are geographically grouped. A singular well may have anywhere from one to in excess of forty stages. Typically, each stage includes one perforation operation, that may generate a plurality of adjacent perforations, and one pumping operation. While a perforation operation is occurring on one well, a pumping operation may be performed on the other well. As such, FIG. 1 shows an example hydraulic fracturing operation occurring on a first well (102) and a second well (104), each extending from the surface (105) to a formation (107). The first well (102) is depicted as undergoing the perforation operation and the second well (104) is shown as undergoing the pumping operation.

[0024] The first well (102) and the second well (104) are horizontal wells meaning that each well includes a vertical section and a diverging section. The diverging section is a section of the well that is drilled at least eighty degrees from vertical. However, fracturing operations may be performed on vertical wells and less deviated wells and the well trajectory illustrated in FIG. 1 is not intended to limit the claimed invention in any way. The first well (102) is capped by a first frac tree (106) and the second well (104) is capped by a second frac tree (108). A frac tree (106, 108) is similar to a production tree but is specifically installed for the hydraulic fracturing operation. Frac trees (106, 108) tend to have larger bores and higher-pressure ratings than a production tree would have. Further, hydraulic fracturing operations require abrasive materials being pumped into the well at high pressures, so the frac tree (106, 108) is designed to handle a higher rate of erosion.

[0025] The first well (102) and the second well (104) are shown as requiring four stages, as an example. Both the first well (102) and the second well (104) have undergone three stages and are undergoing the fourth stage. The second well (104) has already undergone the fourth stage perforation operation and is currently undergoing the fourth stage pumping operation. The first well (102) is undergoing the fourth stage perforating operation and has yet to undergo the fourth stage pumping operation.

[0026] The perforating operation includes installing a wireline blow out preventor (BOP) (110) onto the first frac tree (106). A wireline BOP (110) is similar to a drilling BOP; however, a wireline BOP (110) has seals designed to close around (or shear) wireline (112) rather than drill pipe. A lubricator (114) is connected to the opposite end of the wireline BOP (110). A lubricator (114) is a long, high-pressure pipe used to equalize between downhole pressure and atmosphere pressure in order to run downhole tools, such as a perforating gun (116), into the well.

[0027] The perforating gun (116) is lowered into the first well (102) using the lubricator (114), wireline (112), and fluid pressure. In accordance with one or more embodiments, the perforating gun (116) is equipped with explosives and a frac plug (118) prior to being deployed in the first well (102). The wireline (112) is connected to a spool (120) often located on a wireline truck (122). Electronics (not pictured) included in the wireline truck (122) are used to control the unspooling/spooling of the wireline (112) and are used to send and receive messages along the wireline (112). The electronics may also be connected, wired or wirelessly, to a monitoring system (124) that is used to monitor and control the various operations being performed on the hydraulic fracturing site (100).

[0028] When the perforating gun (116) reaches a predetermined depth, a message is sent along the wireline (112) to set the frac plug (118) to seal the section of the well in the stage being performed. After the frac plug (118) is set, another message is sent through the wireline (112) to detonate the explosives, as shown in FIG. 1. The explosives create perforations in the casing (126) and in the surrounding formation. There may be more than one set of explosives on a singular perforation gun (116), each detonated by a distinct message. Multiple sets of explosives are used to perforate

different depths along the casing (126) for a singular stage. Further, the frac plug (118) may be set separately from the perforation operation without departing from the scope of the disclosure herein.

[0029] As explained above, FIG. 1 shows the second well (104) undergoing the pumping operation after the fourth stage perforating operation has already been performed and perforations are left behind in the casing (126) and the surrounding formation. A pumping operation includes pumping a frac fluid (128) into the perforations in order to propagate the perforations and create fractures (142) in the surrounding formation. The frac fluid (128) often comprises a certain percentage of water, proppant, and chemicals.

[0030] FIG. 1 shows chemical storage containers (130), water storage containers (132), and proppant storage containers (134) located on the hydraulic fracturing site (100). Frac lines (136) and transport belts (not pictured) transport the chemicals, proppant, and water from the storage containers (130, 132, 134) into a frac blender (138). A plurality of sensors (not pictured) is located throughout this equipment to send signals to the monitoring system (124). The monitoring system (124) may be used to control the volume of water, chemicals, and proppant used in the pumping operation.

[0031] The frac blender (138) blends the water, chemicals, and proppant to become the frac fluid (128). The frac fluid (128) is transported to one or more frac pumps, often pump trucks (140), to be pumped through the second frac tree (108) into the second well (104). Each pump truck (140) includes a pump designed to pump the frac fluid (128) at a certain pressure. More than one pump truck (140) may be used at a time to increase the pressure of the frac fluid (128) being pumped into the second well (104). The frac fluid (128) is transported from the pump truck (140) to the second frac tree (108) using a plurality of frac lines (136).

[0032] The fluid pressure propagates and creates the fractures (142) while the proppant props open the fractures (142) once the pressure is released. Different chemicals may be used to lower friction pressure, prevent corrosion, etc. The pumping operation may be designed to last a certain length of time to ensure the fractures (142) have propagated enough. Further the frac fluid (128) may have different make ups

throughout the pumping operation to optimize the pumping operation without departing from the scope of the disclosure herein.

[0033] Through the fracturing process shown in FIG. 1, a number of fractures (142) may extend from the wellbore into the formation (107). The propagation of the fractures (142) is dependent on stress orientation. Accordingly, the fractures (142) may propagate in multiple directions, such that one or more bypassed zones (204) are created in a somewhat randomized pattern. A bypassed zone (204) may refer to a region in which hydrocarbons within the formation (107) are bypassed by fractures (142), such that the full production potential of the formation (107) is not achieved.

[0034] According to embodiments of the present disclosure, fracture bypassed zones may be prevented by using a laser cutting tool disclosed herein to form relatively uniform cuts through a surrounding formation. As described in more detail below, a laser cutting tool according to embodiments of the present disclosure may include one or more rotating cutting heads designed to direct a laser beam outwardly from the rotating cutting head as the rotating cutting head rotates within a well. In such manner, the laser beam may travel linearly into a surrounding formation as the rotating cutting head rotates, thereby forming a cut into the surrounding formation along a single plane transverse to the wellbore. Thus, unlike fractures (142) formed by conventional fracturing processes (e.g., by perforation guns (116)), which extend in multiple directions according to surrounding formation characteristics (e.g., stress concentrations, heterogeneities, and physical discontinuities in the rock), cuts formed by a laser cutting tool may be controlled in a single direction. According to embodiments of the present disclosure, a laser cutting tool may be lowered into a well to form cuts through a surrounding formation in the alternative to forming conventional fractures. In some embodiments, a laser cutting tool may be used to form cuts through a surrounding formation after forming conventional fractures (142), such as in the first well (102) shown in FIG. 1 to cut through one or more bypassed zones (204).

[0035] FIG. 2 shows a laser cutting tool (300) in accordance with one or more embodiments. The laser cutting tool (300) includes a tool body (302) having a rotating cutting head (306) designed to direct a laser beam radially outwardly from the laser cutting tool (300). In the embodiment shown, the rotating cutting head (306) is shown

in an enlarged and cross-sectional view in order to shown internal components and details of the rotating cutting head (306). However, in one or more embodiments, a rotating cutting head may have an outer diameter approximately the same size as the tool body (e.g., where the rotating cutting head outer diameter is within 5 percent of the tool body outer diameter). In one or more embodiments, additional rotating cutting heads may be axially spaced apart along the tool body (302) and coaxially aligned.

[0036] The tool body (302) may be connected at an axial end to a wireline or coiled tubing (301) to be lowered into a well. In one or more embodiments, the tool body (302) may be configured to withstand high temperatures and high pressures, such as those typically associated with the fracturing process at a formation (107). An optical fiber (304) extends through the tool body (302) to the rotating cutting head (306), where an end of the optical fiber (304) may be connected to and/or held within the rotating cutting head (306). The optical fiber (304) may be configured to receive a laser beam and to emit the laser beam. In one or more embodiments, the laser beam may be generated at the surface and delivered to a rotating cutting head (306) via the optical fiber (304). In other embodiments, the laser beam may be generated in-situ at a downhole location.

[0037] A mechanical gear (319) may be secured between the rotating cutting head (306) and the tool body (302) to rotate the rotating cutting head (306) relative to the tool body (302) about a central axis (404). In one or more embodiments, the mechanical gear may be rotated by a motor (317) that is hydraulically or electrically powered. In some embodiments, such motor (317) may be provided in the tool body (302) and connected to a gear assembly (including one or more gears (319)) in the rotating cutting head to rotate the rotating cutting head (306). The rotating cutting head (306) may be coaxially aligned with the tool body (302), such that the rotating cutting head (306) may rotate about the central axis (404) of the tool body (302).

[0038] Further, according to embodiments of the present disclosure, a rotational optics assembly (313), such as shown in FIG. 3, may be provided in the rotating cutting head (306) to allow continuous transmission of a laser beam (311) from the optical fiber (304) through transmission components in the rotating cutting head (306) as the rotating cutting head (306) rotates about the central axis (404). As shown in FIG. 3,

a rotational optics assembly (313) may be positioned proximate to an end of the optical fiber (304) and may include one or more mirrors (315) oriented to reflect and transmit the laser beam (311) at an angle relative to the direction of transmission from the optical fiber (304). For example, a mirror (315) in the rotational optics assembly (313) may be oriented to transmit the laser beam (311) at an angle between 80 and 100 degrees (e.g., perpendicularly) from the direction of transmission from the end of the optical fiber (304).

[0039] In one or more embodiments, a rotational optics assembly (313) may be triangularly positioned between an end of the optical fiber (304) and an optical lens (308) in the rotating cutting head (306), where the rotational optics assembly (313) is configured to direct the laser beam (311) transmitted from the optical fiber (304) at an angle to the optical lens (308). Additionally, the rotational optics assembly (313) may be fixed within the rotating cutting head (306) in an axially aligned position with the optical fiber (304), such that the laser beam (311) may be continuously directed from the optical fiber (304) to the rotational optics assembly (313) as the rotating cutting head (306) (and thus also the rotational optics assembly (313)) rotates about the central axis (404). One skilled in the art may appreciate that various types and configurations of rotational optics assemblies may be used to transmit a laser beam from an optical fiber (304) at an angle to an optical lens (308) to allow the laser beam to be directed in a radial outward direction from the rotating cutting head (306) as the rotating cutting head (306) rotates about its central axis (404).

[0040] In some embodiments, a rotating cutting head (306) may be rotated with the tool body (302) about a common central axis (404). In such embodiments, a rotational optics assembly may be provided at a point of relative rotation between the rotating laser cutting tool and the laser beam source to allow transmission of the laser beam from a non-rotating portion of the optical fiber to a rotating portion of the optical fiber (304) as the entire laser cutting tool (300) rotates. For example, a laser cutting tool may be connected at an axial end to a downhole motor, where the rotational optics assembly may be provided at the axial end of the laser cutting tool. In such embodiments, the rotational optics assembly may be positioned proximate an axial end of a non-rotating optical fiber and configured to direct a laser beam from the non-rotating optical fiber to a coaxial rotating optical fiber that extends through and rotates

with the laser cutting tool. For example, a laser beam may pass through the rotational optics assembly from a non-rotating optical fiber to a coaxial rotating optical fiber. As shown in FIG. 2, when a rotational optics assembly is provided between a non-rotating optical fiber and a coaxial portion of a rotating optical fiber, a rotating cutting head (306) may include an optical lens (308) installed at an end of the rotating optical fiber (304) to receive a laser beam (311) being transmitted through the optical fiber (304).

[0041] According to embodiments of the present disclosure, a rotational optics assembly may be configured to direct a laser beam from a non-rotating optical fiber at an angle outwardly from the optical fiber central axis or coaxial with the optical fiber central axis, depending on whether a laser cutting tool is designed to have a rotating cutting head that rotates independently from the tool body, or is designed to rotate entirely (where the rotating cutting head and tool body rotate together). A rotational optics assembly may be held in the laser cutting tool to rotate with the rotating cutting head (either when the rotating cutting head rotates independently from the tool body or when the rotating cutting head rotates with the tool body). The rotational optics assembly may be allowed to rotate while also receiving a laser beam emitted from an end of a non-rotating optical fiber by holding the rotational optics assembly axially aligned with the end of the non-rotating optical fiber but disjointed from the end of the non-rotating optical fiber (e.g., disconnected but adjacent to the optical fiber end or axially spaced apart from the optical fiber end, as shown in FIG. 3).

[0042] In one or more embodiments, the optical lens (308) may be configured to shape, size, and/or orient the laser beam (311) from the optical fiber into a controlled laser beam (310), which may be directed through an internal laser passageway (312) and out of an exit (314) (an opening) provided through a laser head (307) on the rotating cutting head (306). For example, the optical lens (308) may shape the laser beam as either collimated, where the controlled laser beam (310) may have the same diameter as the laser beam, or focused, where the controlled laser beam (310) may have a smaller diameter than the laser beam.

[0043] The internal laser passageway (312) may extend through the rotating cutting head (306) in a radial direction between the central axis (404) of the laser cutting tool

(300) and the exit (314) in the laser head (307). The laser head (307) (and exit (314)) is provided around a side of the rotating cutting head (306), such that as the rotating cutting head (306) is rotated, the laser head (307) of the rotating cutting head moves circumferentially around the laser cutting tool (300).

[0044] One or more cover lenses (316) may be arranged within the internal laser passageway (312) to transverse the internal laser passageway, e.g., including an outer cover lens located relatively closer to the exit (314) and an inner cover lens located relatively farther from the exit (314) of the rotating cutting head. The one or more cover lenses (316) may be arranged perpendicular to the controlled laser beam (310). In one or more embodiments, cover lenses (316) may be spaced at least 2" apart from one another and from the optical lens (308). In one or more embodiments, the cover lenses (316) may be configured to protect the optical lens (308) and the optical fiber (304) from back reflection, dust, and debris.

[0045] An internal purging system (318) may be integrally formed with the rotating cutting head (306) and used to cool the optical lens (308) and the one or more cover lenses (316). The internal purging system (318) may include fluid openings oriented to direct a fluid onto the optical lens (308) and the cover lenses (316). Additional fluid nozzles (320) may be directed towards the cover lenses (316). In one or more embodiments, the additional fluid nozzles (320) may inject fluid parallel to the laser beam emitted from the rotating cutting head (306). Further, the number of additional fluid nozzles (320) may be selected to produce a desired flow rate. One or more external fluid nozzles (322) may be coupled to the circular laser tool (300) and may be positioned at the exit (314) of the rotating cutting head (306). The external fluid nozzles (322) may be configured to clear a path for the controlled laser beam (310) emitted by the rotating cutting head (306). More specifically, the external fluid nozzles (322) may clear any debris from the path of the controlled laser beam (310).

[0046] In one or more embodiments, the external fluid nozzles (322) may inject a gas or a liquid. The gas used, for example, may be an inert gas, such as nitrogen. The fluid source supplying the gas or liquid may be located at the surface. A flow path from the fluid source to the nozzles (320, 322, 318) in the rotating cutting head (306) may be provided through coiled tubing (301), the tool body (302), and the rotating cutting head (306) via fluidly connected passages through the assembly. In one or

more embodiments, a laser cutting tool (300) may include one or more annular flow paths, which may fluidly connect flow passages between the tool body (302) and a rotating cutting head (306) while also allowing the rotating cutting head (306) to rotate relative to the tool body (302). In some embodiments, an entire laser cutting tool (300) may rotate (rotating the rotating cutting head (306) together with the tool body (302)). In such embodiments, one or more annular flow paths may fluidly connect flow passages between the laser cutting tool (300) and the coiled tubing (301) while also allowing the laser cutting tool to rotate.

[0047] In one or more embodiments, the fluid nozzles (320) and the external fluid nozzles (322) may inject either the same fluid or a different fluid depending on the application. For example, in embodiments where different fluids are used, the fluid nozzles (320) may inject a lighter fluid which can penetrate deeper into the formation and the external fluid nozzles (322) may inject a heavier fluid to control pressure in the wellbore (202).

[0048] Turning now to FIG. 4, FIG. 4 shows a laser cutting tool (400) in accordance with one or more embodiments deployed in a well (303). The well (303) may extend from the surface (105) to a formation (107). In one or more embodiments, the well (303) may be a vertical, horizontal, or other directional well. In horizontal wells, as shown in FIG. 4, there may be a primary wellbore (802) which may extend into the ground in a substantially vertical direction and a lateral section (804) which may diverge from the primary wellbore (802) at a kick-off point at an angle until the lateral section (804) is substantially horizontal. In one or more embodiments, the angle of the lateral section (804) may change by less than 10° per 30 meters (100 feet) of distance covered by the lateral section (804). In the embodiment shown, the laser cutting tool (400) is positioned in the lateral section (804) of a well (400). However, laser cutting tools according to embodiments of the present disclosure may be operated in other directional or vertical sections of a well.

[0049] The laser cutting tool (400) may be powered from the surface (105) by a laser power generator (406). In one or more embodiments, the laser power generator (406) may be a diesel generator configured to provide electric power to generate laser energy. The laser cutting tool (400) may have more than one rotating cutting head (306) arranged along a tool body (302). In one or more embodiments, multiple

rotating cutting heads (306) may be powered by the same optical fiber (304). Each rotating cutting head (306) may be separated by a spacing (402). In some embodiments, the rotating cutting heads (306) may be evenly spaced. In other embodiments, the spacing (402) may vary depending on the formation (107) and production operations. In one or more embodiments, each rotating cutting head (306) may rotate about central axis (404) of the laser cutting tool (400). In one or more embodiments, the rotating cutting heads (306) may be centrally positioned within the wellbore (202) using a centralizer (not pictured) positioned along the tool body (302). In one or more embodiments, the laser cutting tool (400) may be pushed (*e.g.*, on coiled tubing or lowered on a wireline) or pulled (*e.g.*, on a borehole-tractor) from one depth to another.

[0050] When positioned in a selected location of the well (303), a laser beam may be generated by the laser power generator (406) and directed through the optical fiber (304) (which may be split into one or more portions to allow rotation of part of the optical fiber) to one or more of the rotating cutting heads (306) of the laser cutting tool (400). The laser beam may be focused through the rotating cutting head (306) into a controlled laser beam (310), which may be directed in a radially outward direction from an exit (314) of the rotating cutting head (306) into the formation (107) around the well (303). The controlled laser beam (310) may be continuously emitted from the rotating cutting head (306) in the radially outward direction as the rotating cutting head (306) rotates about the central axis (404). In such manner, the controlled laser beam (310) may form a controlled cut through the formation (107) along a plane transverse to the well (303).

[0051] For example, FIGs. 5A – 5F show a rotating cutting head (306) in accordance with one or more embodiments in various rotational configurations about the central axis (404) of the laser cutting tool (400) during a transverse fracturing operation. Initially, as shown in FIG. 5A, the rotating cutting head (306) may emit the controlled laser beam (310) in one direction. In one or more embodiments, the laser cutting tool (400) may be used in either open hole or cased hole environments. Specifically, the laser cutting tool (400) may emit a laser beam (310) at a first power level with an intensity high enough to cut through a casing. A first hole (502) may be created in the formation, as shown in FIG. 5B. The rotating cutting head (306) may then rotate

about the central axis (404) of the laser cutting tool (300), such that a first circular hole (504) is created in the formation (107) when the rotating cutting head (306) has rotated 360°, as shown in FIG. 5C. The rotating cutting head (306) may rotate either clockwise or counter-clockwise.

[0052] Once the first circular hole (504) has been created, the power of the controlled laser beam (310) may increase to a second power level greater than the first power level to create a second hole (506), as shown in FIG. 5D. The second hole (506) may have a larger diameter than the first hole (502). Moving to FIG. 5E, the rotating cutting head (306) may then rotate about the central axis (404) for a second time. As a result, once the rotating cutting head (306) has rotated 360°, a second circular hole (508) may be created, as shown in FIG. 5F. The process shown in FIGs. 5A – 5F may be repeated by creating circular holes with increasing diameters until a desired depth is achieved.

[0053] Once the desired depth has been achieved through the process shown in FIGs. 5A – 5F, one or more transverse fractures (602) may be created in the formation (107), as shown in FIG. 6. In contrast to traditional fractures formed by hydraulic fracturing, transverse fractures (602) may extend continuously around the entire circumference of the well to form an annular opening through the formation (107). The circular, or disc-like, shape of the transverse fractures (602) may avoid any bypassed zones (204) (shown in FIG. 2) that would otherwise occur between conventionally formed fractures. Transverse fractures (602) may allow for increased flow (604) of hydrocarbons from the formation (107) into the wellbore (202). In one or more embodiments, for example, transverse fractures (602) may extend up to 30 meters (100 feet) into the formation (107).

[0054] FIG. 7 depicts a flowchart in accordance with one or more embodiments. More specifically, FIG. 7 depicts a flowchart 700 of a method of creating a transverse fracture in a formation. Further, one or more blocks in FIG. 7 may be performed by one or more components as described in FIG. 1 – 6. While the various blocks in FIG. 7 are presented and described sequentially, one of ordinary skill in the art will appreciate that some or all of the blocks may be executed in different orders, may be combined, may be omitted, and some or all of the blocks may be executed in parallel. Furthermore, the blocks may be performed actively or passively.

[0055] Initially in step S702, a laser cutting tool (300, 400) may be suspended in a borehole or a wellbore (202). In particular, the laser cutting tool (300, 400) may be lowered from a wellhead at the surface (105) into a well (such as the first well (102) or the second well (104)) to a subsurface formation (107). Specifically, the laser cutting tool (300, 400) may be lowered down the wellbore (202) to a desired fracturing location within the formation (107). In one or more embodiments, the laser cutting tool (300, 400) may include an optical fiber (304) with a first end (305), where the first end (305) is disposed in a rotating cutting head (306).

[0056] In step S704, a groove may be cut into the wall of the wellbore (202) using the laser cutting tool (300, 400). This may involve directing a laser beam from the first end (305) of the optical fiber (304). The laser beam may be generated by a laser with a first power level, where the laser is powered by a laser power generator (406) located at the surface (105) of the earth and transmitted downhole through an optical fiber enabled coiled tubing, onto which a tool body (302) may be secured. The laser beam may be received by an optical fiber (304), which may extend through the tool body (302). In one or more embodiments, the laser power generator (406) may supply a variable power to the laser cutting tool (300, 400), such that a lower power may first be supplied, following by a higher power. The laser may be connected to a second end of the optical fiber (304) and directed toward a wall of the wellbore (202).

[0057] A controlled laser beam (310) may be created using the laser cutting tool (300, 400). The intensity of the controlled laser beam (310) may depend on the intensity of the power supplied by the laser power generator (406). In one or more embodiments, creating the controlled laser beam (310) may include emitting a laser beam from the first end (305) of the optical fiber (304) into an optical lens (308), and shaping and sizing the laser beam using the optical lens (308) to produce the controlled laser beam (310).

[0058] In one or more embodiments, the groove may be, for example, the first hole (502). More specifically, the groove may be cut by rotating the rotating cutting head (306) while directing the laser beam from the first end (305) of the optical fiber (304) against the wall of the wellbore (202). The rotating cutting head (306) may be rotated either clockwise or counter-clockwise. A 360° rotation of the rotating cutting head

(306) around the central axis (404) of the laser cutting tool (300, 400) may create the first circular hole (504). The first circular hole (504) may form the beginning of a transverse fracture (602). Cutting the groove may also include, for example, focusing the laser beam on the wall of the wellbore using an optical lens (308). Additionally, fluid may be pumped through at least one external fluid nozzle (322) to flush any debris or dust particles from the groove. This fluid may be, for example, a transparent fluid.

[0059] The method may further include increasing the power of the laser from the first power level to a second power level, where the second power level is greater than the first power level. The laser beam may then be directed from the first end (305) of the optical fiber (304) towards the wall of the wellbore. As such, the groove in the wall of the wellbore may be enlarged (along the first circular hole (504) path) using the laser beam.

[0060] The method described above may be repeated until a final circular hole is created and the transverse fracture (602) reaches a desired depth, where the diameter of the final circular hole is equal to the desired depth. Transverse fractures (602) may allow for radial flow of hydrocarbons from the formation (107) into the wellbore (202). Further, transverse fractures (602) may maximize flow (64) due to a larger reservoir contact than in traditional hydraulic fractures.

[0061] Embodiments of the present disclosure may provide at least one of the following advantages. Traditional hydraulic fracturing operations are characterized by propagating fractures, the formation of which is largely dependent on stress orientation. As such, there are many bypassed zones which exist, meaning that a significant volume of hydrocarbon potential within formation is not produced. Embodiments of the present disclosure employ a laser cutting tool for the creation of circular transverse fractures. Circular transverse fractures can be created and sized to a desired depth, covering all areas within a formation, effectively eradicating any bypassed zones which may have existed with the use of traditional methods. Further, creation of circular transverse fractures may increase flow from the formation to the wellbore due to maximized reservoir contact. Use of a high power laser, such as the controlled laser beam described herein, is a non-damaging technology which provides suitable stimulation for formation rock samples. This technology is waterless, has a

small footprint, and does not require any chemicals, unlike traditional fracturing operations.

[0062] Although only a few example embodiments have been described in detail above, those skilled in the art will readily appreciate that many modifications are possible in the example embodiments without materially departing from this invention. Accordingly, all such modifications are intended to be included within the scope of this disclosure as defined in the following claims.

CLAIMS

What is claimed:

1. A method, comprising:
 - lowering a laser cutting tool (300, 400) into a wellbore (202, 802) drilled into a subsurface formation (107), wherein the laser cutting tool (300, 400) comprises:
 - a tool body (302);
 - a rotating cutting head (306) positioned along the tool body (302); and
 - an optical fiber (304) extending through the tool body (302) to the rotating cutting head (306);
 - directing a laser beam (311) through the optical fiber (304) at a first power level to the rotating cutting head (306);
 - directing the laser beam (311) from the rotating cutting head (306) in a radially outward direction to cut into the wellbore (202, 802); and
 - rotating the rotating cutting head (306) while directing the laser beam (311) in the radially outward direction from the rotating cutting head (306) to cut a first groove in the wellbore (202, 802).
2. The method of claim 1, further comprising:
 - increasing a laser power of the laser beam (311) from the first power level to a second power level; and
 - while rotating the rotating cutting head (306), directing the laser beam (311) from the rotating cutting head (306) at the second power level into the first groove to enlarge the first groove.
3. The method of claim 1 or 2, further comprising directing the laser beam (311) through an optical lens (308) inside the rotating cutting head (306) to focus the laser beam (311) on the wellbore (202, 802).
4. The method of any one of claims 1 to 3, further comprising pumping a fluid through at least one external fluid nozzle (322) on the rotating cutting head (306) around the laser beam (311) as the laser beam (311) exits the rotating cutting head (306).
5. The method of claim 4, wherein the fluid is a transparent fluid.

6. The method of any one of claims 1 to 5, further comprising generating the laser beam (311) from a laser generator (406) at a surface around the wellbore (202, 802), wherein the optical fiber (304) is connected to the laser generator.
7. The method of any one of claims 1 to 6, wherein an additional rotating cutting head is positioned along the tool body (302) and connected to the optical fiber (304), the method further comprising:
 - directing the laser beam (311) from the optical fiber (304) concurrently to both the rotating cutting head (306) and the additional rotating cutting head; and
 - concurrently directing the laser beam (311) out of the rotating cutting head (306) and the additional rotating cutting head into the wellbore (202, 802) to cut a second groove into the wellbore while the first groove is being cut.
8. The method of any one of claims 1 to 7, wherein the laser cutting tool (300, 400) is lowered into the wellbore (202, 802) at the end of a coiled tubing (301).
9. A laser cutting tool (300, 400), comprising:
 - a tool body (302) having a central axis (404);
 - an optical fiber (304) extending through the tool body (302);
 - a rotating cutting head (306) provided coaxially along the tool body (302), the rotating cutting head (306) comprising:
 - a laser head (307) disposed on a side of the rotating cutting head (306), the laser head (307) comprising a laser exit (314);
 - a rotational optics assembly (313) positioned coaxially with an end of the optical fiber (304), the rotational optics assembly (313) comprising a mirror (315) facing the end of the optical fiber (304) at an angle;
 - an internal laser passageway (312) extending in a radial direction between the rotational optics assembly (313) and the laser exit (314); and
 - an optical lens (308) mounted transversely in the internal laser passageway (312); and
 - a motor (317) configured to rotate the rotating cutting head (306) about the central axis independently from the tool body (302).

10. The laser cutting tool of claim 9, further comprising a second rotating cutting head provided coaxially along the tool body (302) and axially spaced apart from the rotating cutting head (306).
11. The laser cutting tool of claim 9 or 10, wherein the optical lens (308) is configured to focus a laser beam (311) emitted from the optical fiber (304) to a controlled laser beam (310) having a diameter smaller than the laser beam (311).
12. The laser cutting tool of any one of claims 9 to 11, further comprising an external fluid nozzle (322) positioned around the laser head (307) and oriented to direct a fluid out of the external fluid nozzle (322) in a direction substantially parallel with the internal laser passageway (312).
13. The laser cutting tool of any one of claims 9 to 12, further comprising at least one cover lens (316) held in the internal laser passageway (312) between the laser exit (314) and the optical lens (308), wherein the at least one cover lens (316) transverses the internal laser passageway (312).
14. The laser cutting tool of claim 13, further comprising an internal purging system (318) comprising at least one fluid passage having fluid openings oriented to direct a fluid onto the optical lens (308) and the at least one cover lens (316).
15. A transverse fracturing system, comprising:
 - a laser cutting tool (300, 400), the laser cutting tool comprising:
 - a tool body (302) having a central axis (404);
 - an optical fiber (304) extending through the tool body (302);
 - a rotating cutting head (306) provided coaxially along the tool body (302), wherein the rotating cutting head (306) is rotational about the central axis (404), the rotating cutting head (306) comprising:
 - a laser head (307) disposed on a side of the rotating cutting head (306), the laser head (307) comprising a laser exit (314);
 - an internal laser passageway (312) extending through the rotating cutting head (306) to the laser exit (314); and
 - an optical lens (308) mounted transversely in the internal laser passageway (312); and

- a rotational optics assembly (313) positioned coaxially with an end of the optical fiber (304), wherein the rotational optics assembly (313) is rotatable with the rotating cutting head (306); and
- a motor (317) operatively connected to the laser cutting tool (300, 400) and configured to rotate the rotating cutting head (306) about the central axis (404).
16. The transverse fracturing system of claim 15, wherein the laser cutting tool (300, 400) is connected at an end of a coiled tubing (301) extending from a surface of a well (303) into the well (303).
17. The transverse fracturing system of claim 16, further comprising a laser power generator (406) located at the surface of the well (303), wherein the laser power generator (406) is connected to the optical fiber (304) through the coiled tubing (301).
18. The transverse fracturing system of any one of claims 15 to 17, further comprising:
an internal purging system (318) provided in the rotating cutting head (306), the internal purging system (318) comprising at least one fluid passage having fluid openings oriented to direct a fluid onto the optical lens (308); and
a fluid source fluidly connected to the internal purging system (318).
19. The transverse fracturing system of any one of claims 15 to 18, wherein the motor (317) is connected at an axial end of the laser cutting tool (300, 400) and configured to rotate the tool body (302) with the rotating cutting head (306), and wherein the rotational optics assembly (313) is positioned at the axial end of the laser cutting tool (300, 400).
20. The transverse fracturing system of any one of claims 15 to 18, wherein the motor (317) is connected to the tool body (302) and configured to rotate the rotating cutting head (306) independently from the tool body (302), and wherein the rotational optics assembly (313) is held within the rotating cutting head (306) and configured to receive a laser beam (311) emitted from the end of the optical fiber (304) as the rotational optics assembly (313) rotates with the rotating cutting head (306).

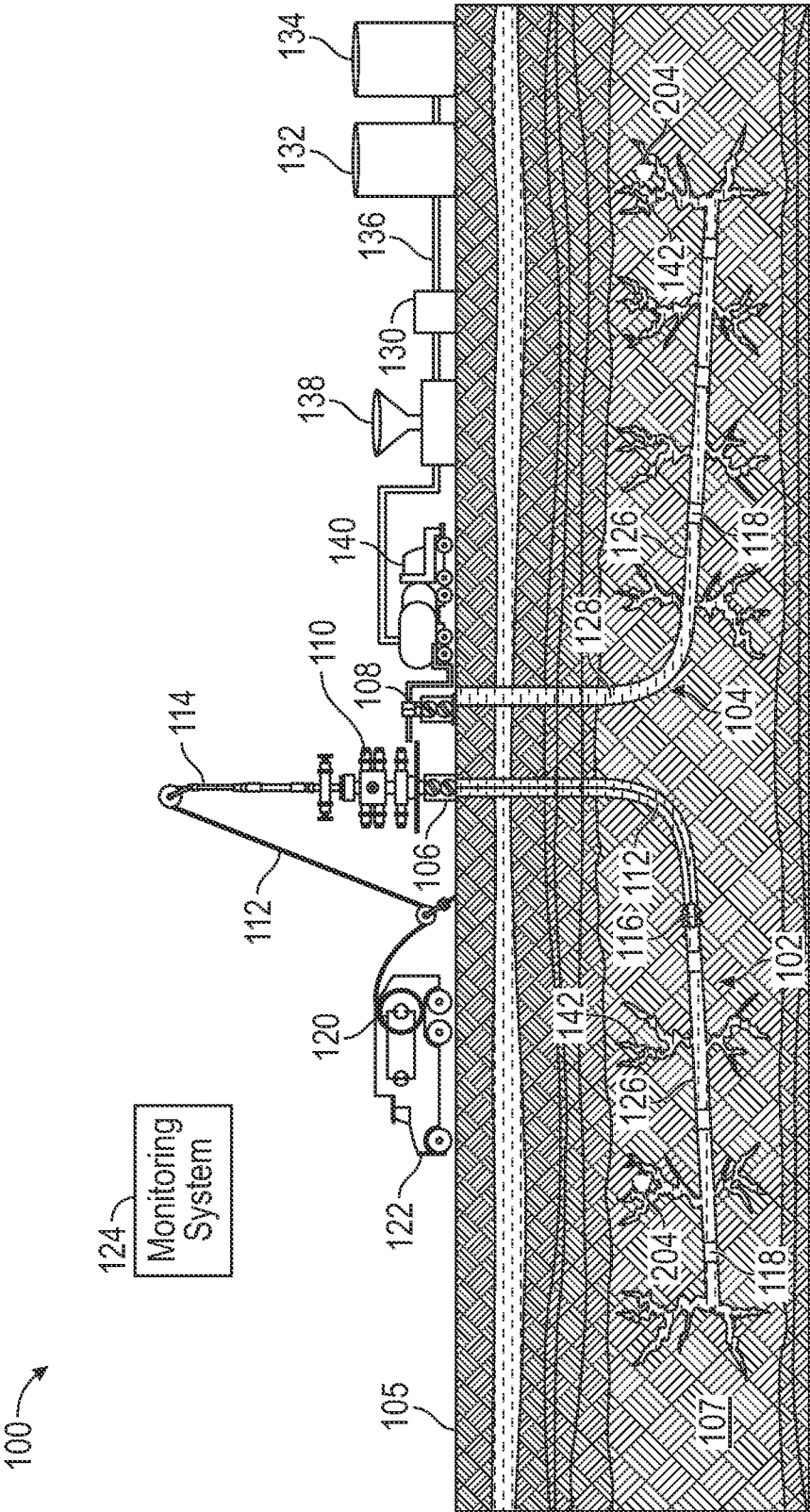


FIG. 1

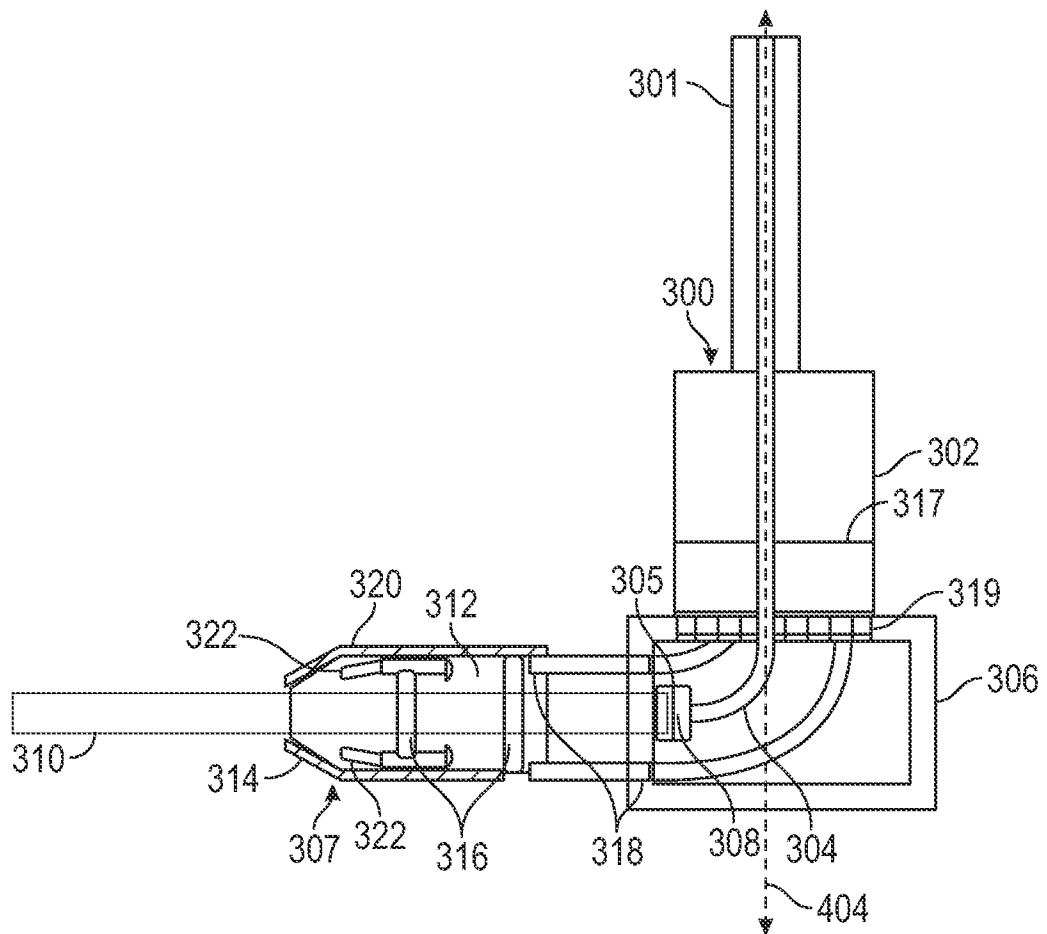


FIG. 2

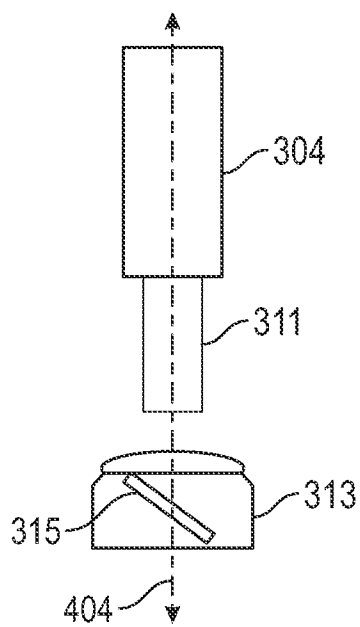


FIG. 3

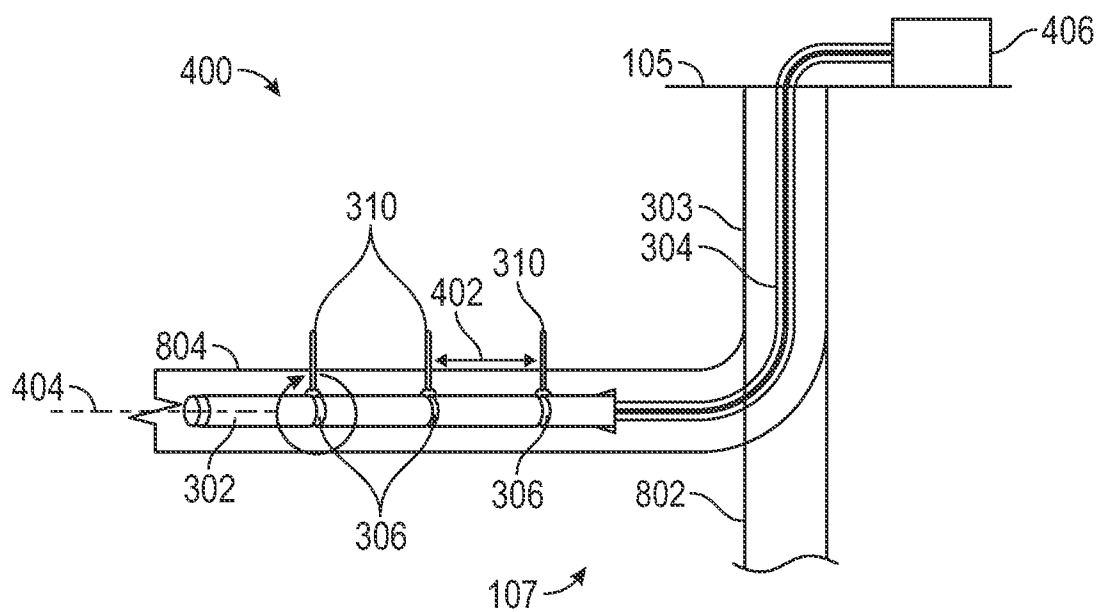


FIG. 4

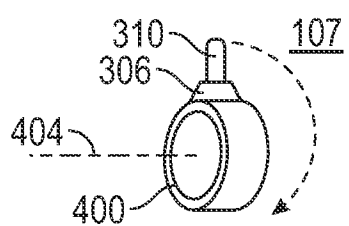


FIG. 5A

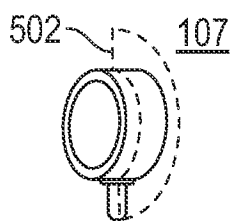


FIG. 5B

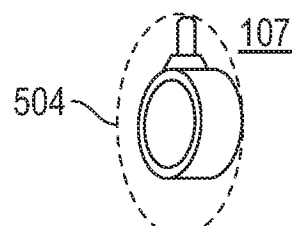


FIG. 5C

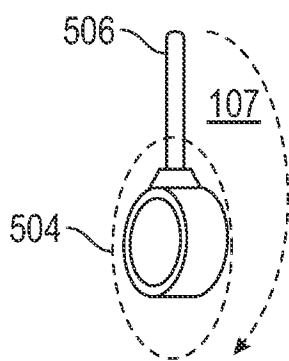


FIG. 5D

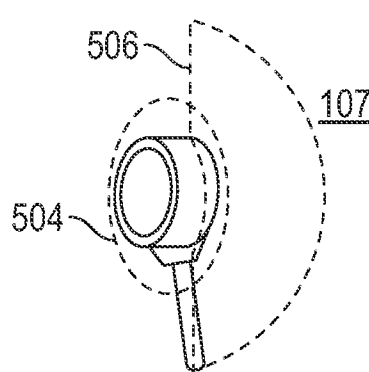


FIG. 5E

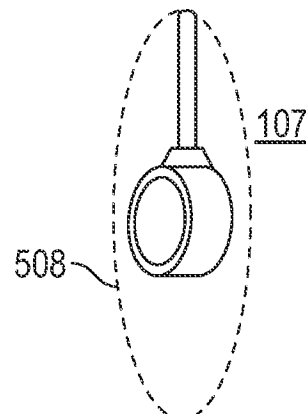


FIG. 5F

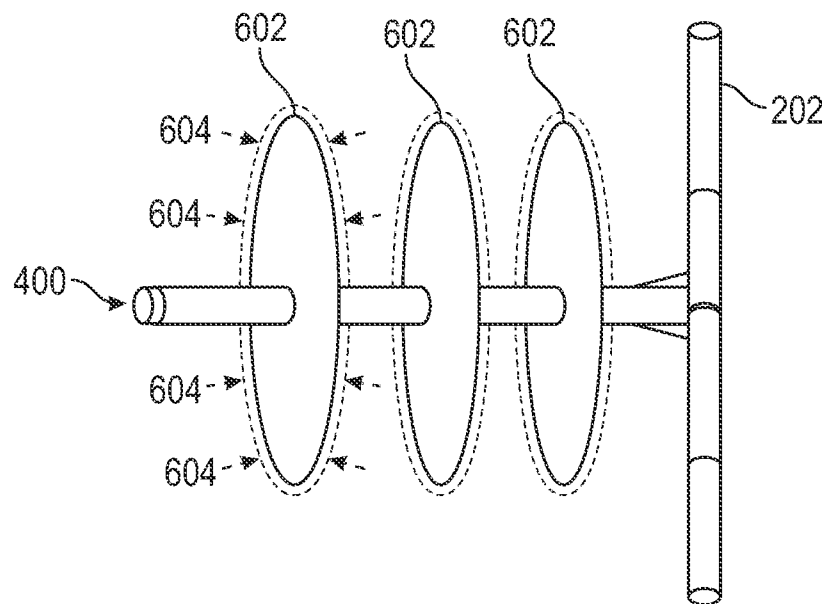


FIG. 6

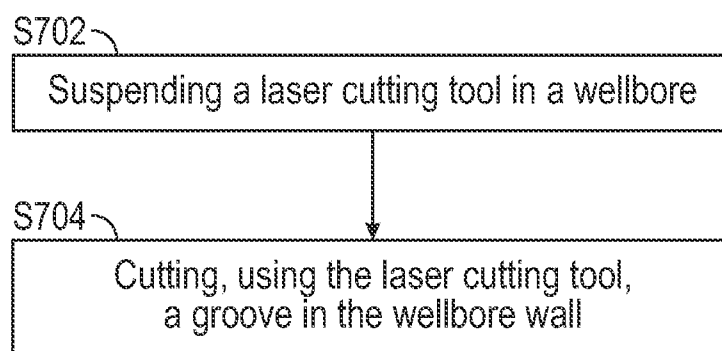


FIG. 7

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2024/035434

A. CLASSIFICATION OF SUBJECT MATTER

INV. E21B43/26

ADD.

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

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

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

EPO-Internal**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2020/232309 A1 (DEUTCH PAUL D [US] ET AL) 23 July 2020 (2020-07-23)	1, 3, 4, 6-13, 15-17, 19, 20
Y	paragraph [0201] - paragraph [0217];	5, 14, 18
A	figures 17-19	2

Y	US 2020/392794 A1 (AL OBAID OMAR MOHAMMED [SA] ET AL) 17 December 2020 (2020-12-17)	5, 14, 18
	paragraph [0035] - paragraph [0045]	



Further documents are listed in the continuation of Box C.



See patent family annex.

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"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

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"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

11 September 2024

Date of mailing of the international search report

20/09/2024

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2024/035434

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2020232309 A1	23-07-2020	CA 2891500 A1	22-05-2014
		US 2015129203 A1	14-05-2015
		US 2019040726 A1	07-02-2019
		US 2020232309 A1	23-07-2020
		WO 2014078663 A2	22-05-2014

US 2020392794 A1	17-12-2020	CN 114207246 A	18-03-2022
		EP 3966426 A1	16-03-2022
		US 2020392794 A1	17-12-2020
		WO 2020250022 A1	17-12-2020
