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Lafleur

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(54) **GAUGE SENSOR FOR DOWNHOLE PRESSURE/TEMPERATURE MONITORING OF ESP INTAKE PRESSURE AND DISCHARGE TEMPERATURE**

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E21B 47/01 (2012.01)
E21B 47/06 (2012.01)
E21B 47/07 (2012.01)

(52) **U.S. Cl.**
CPC ***E21B 47/01*** (2013.01); ***E21B 47/00*** (2013.01); ***E21B 47/06*** (2013.01); ***E21B 47/07*** (2020.05)

(58) **Field of Classification Search**
CPC E21B 47/07; E21B 23/03; E21B 43/128; E21B 47/008; E21B 47/01; G01D 11/245
See application file for complete search history.

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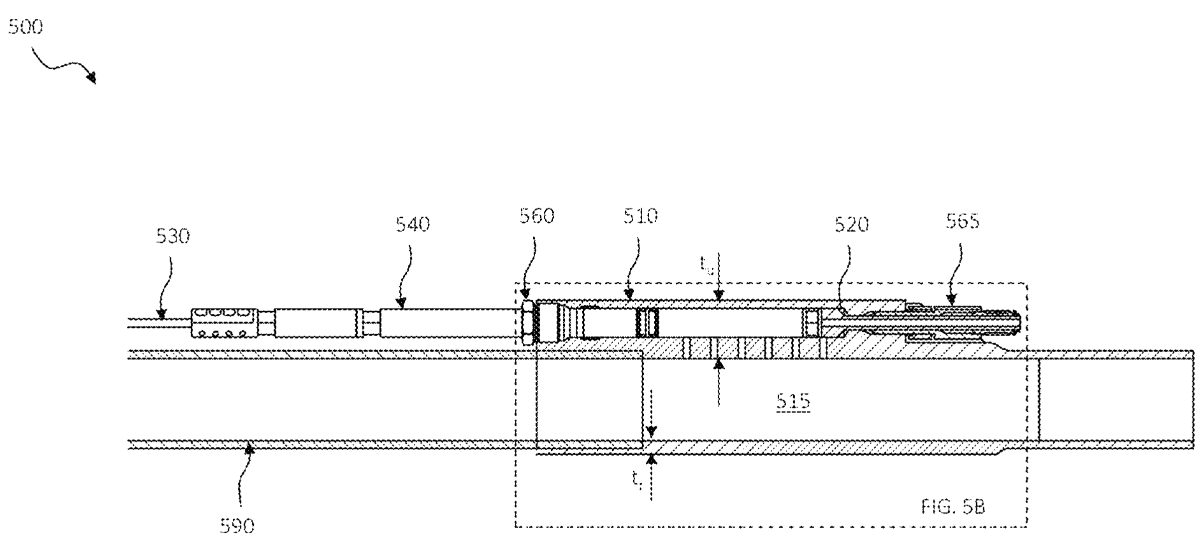
(57) **ABSTRACT**

Provided is a gauge sensor, a sensing system, and a well system. The gauge sensor, in one aspect, includes a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination, and a seal region coupled to the TEC region, the seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of a gauge cavity that the gauge sensor is configured to insert within. The gauge sensor, in this one aspect, further includes a sensor region coupled to the seal region, the sensor region including one or more temperature sensors, and a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p).

20 Claims, 19 Drawing Sheets



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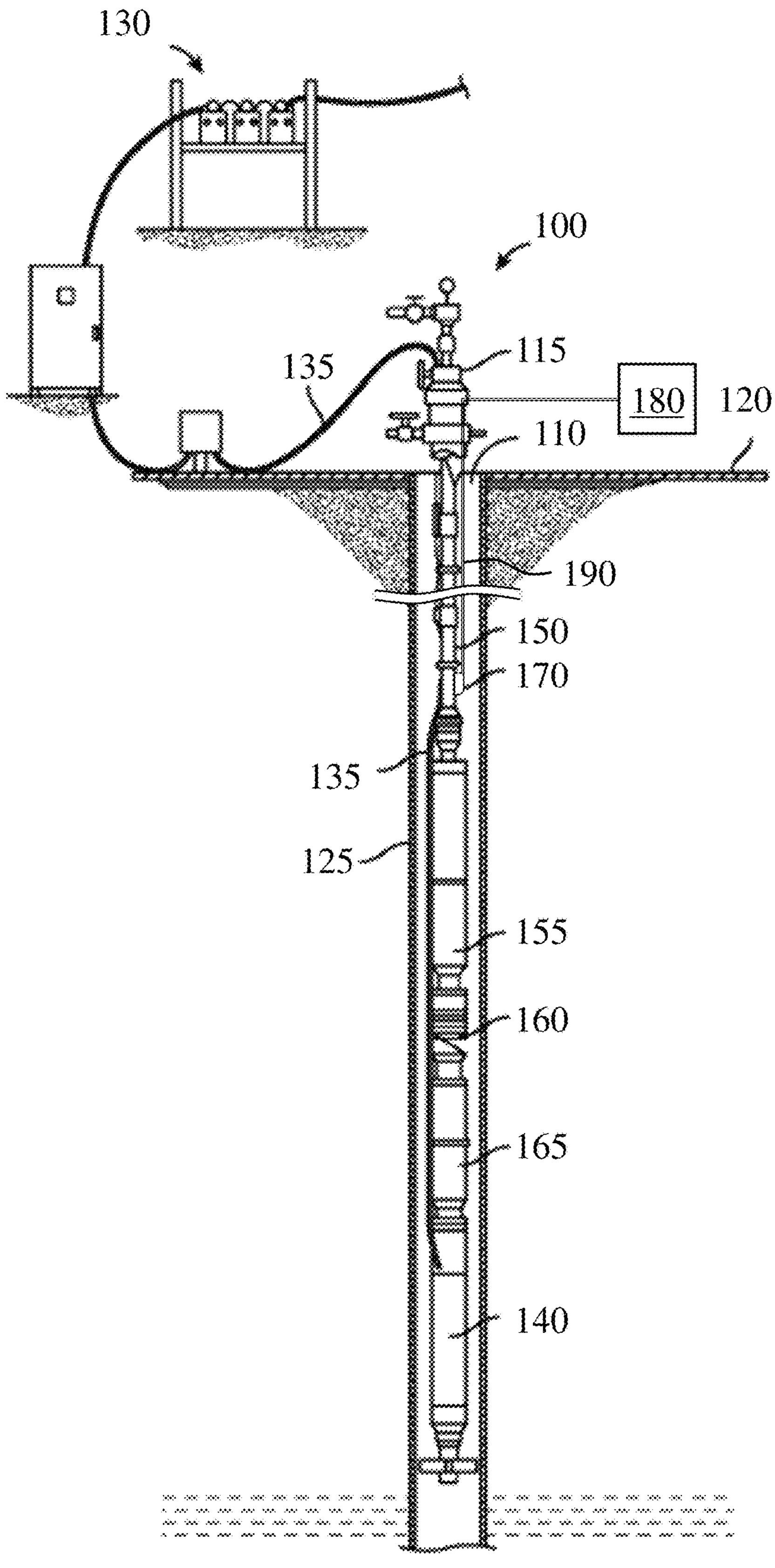

FIG. 1

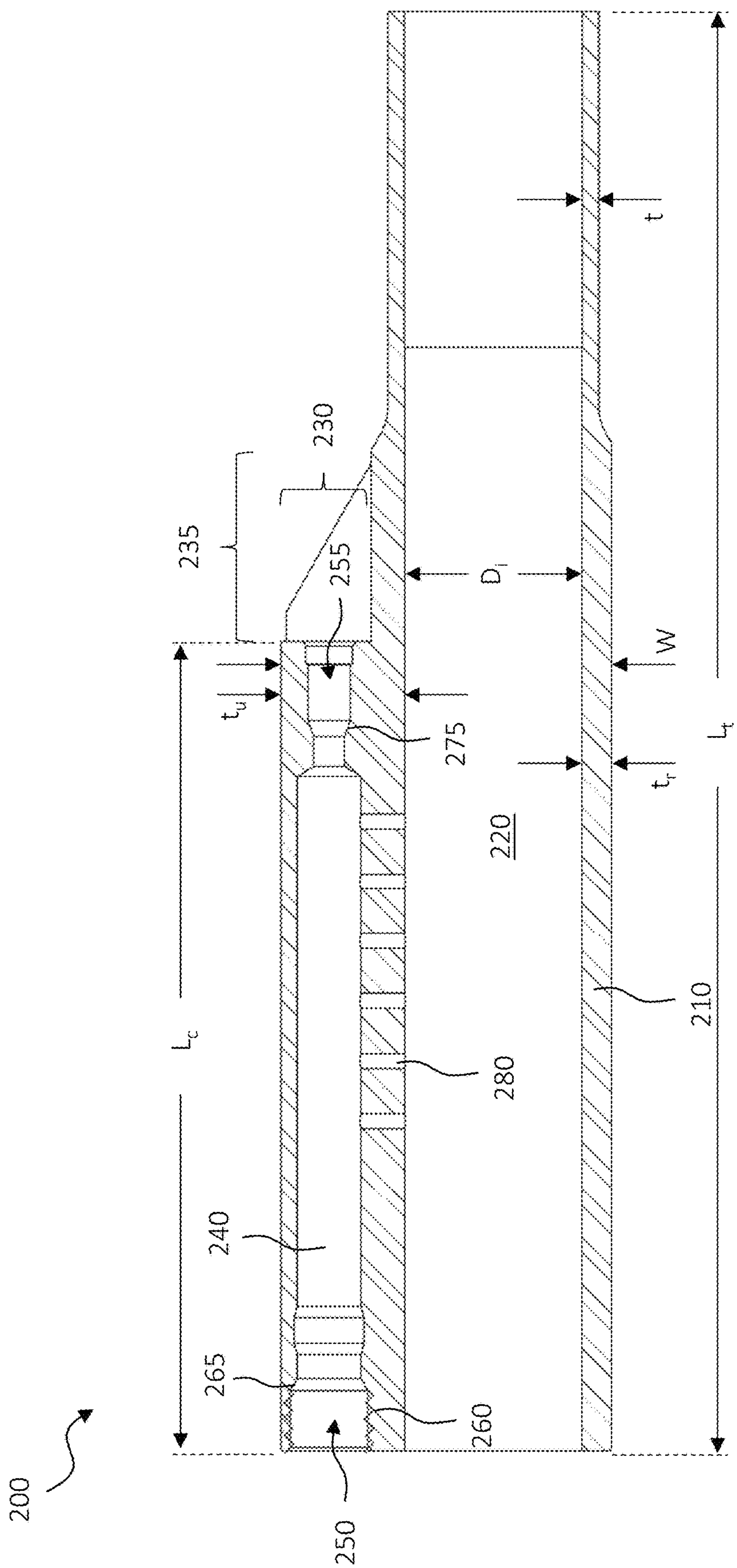

FIG. 2A

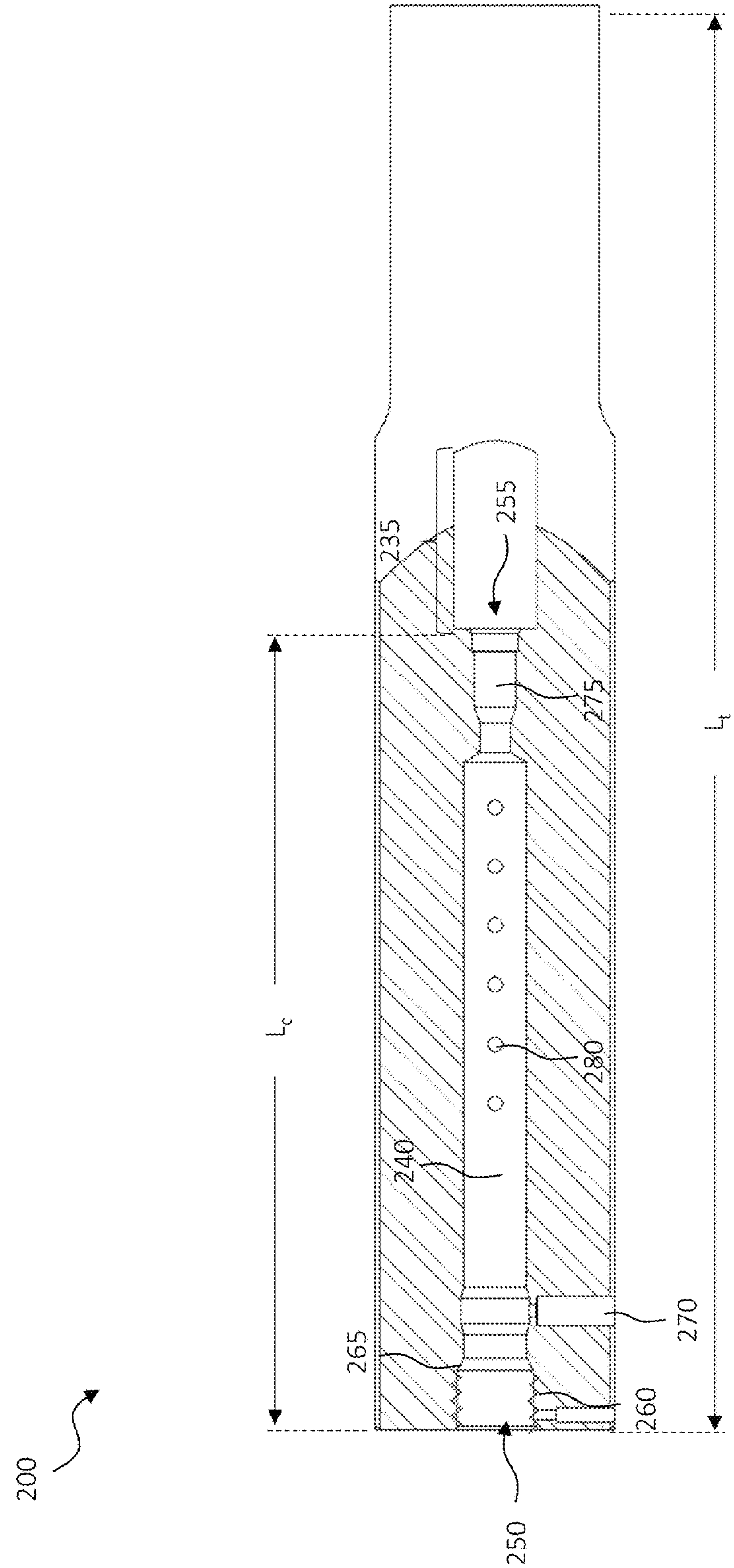

FIG. 2B

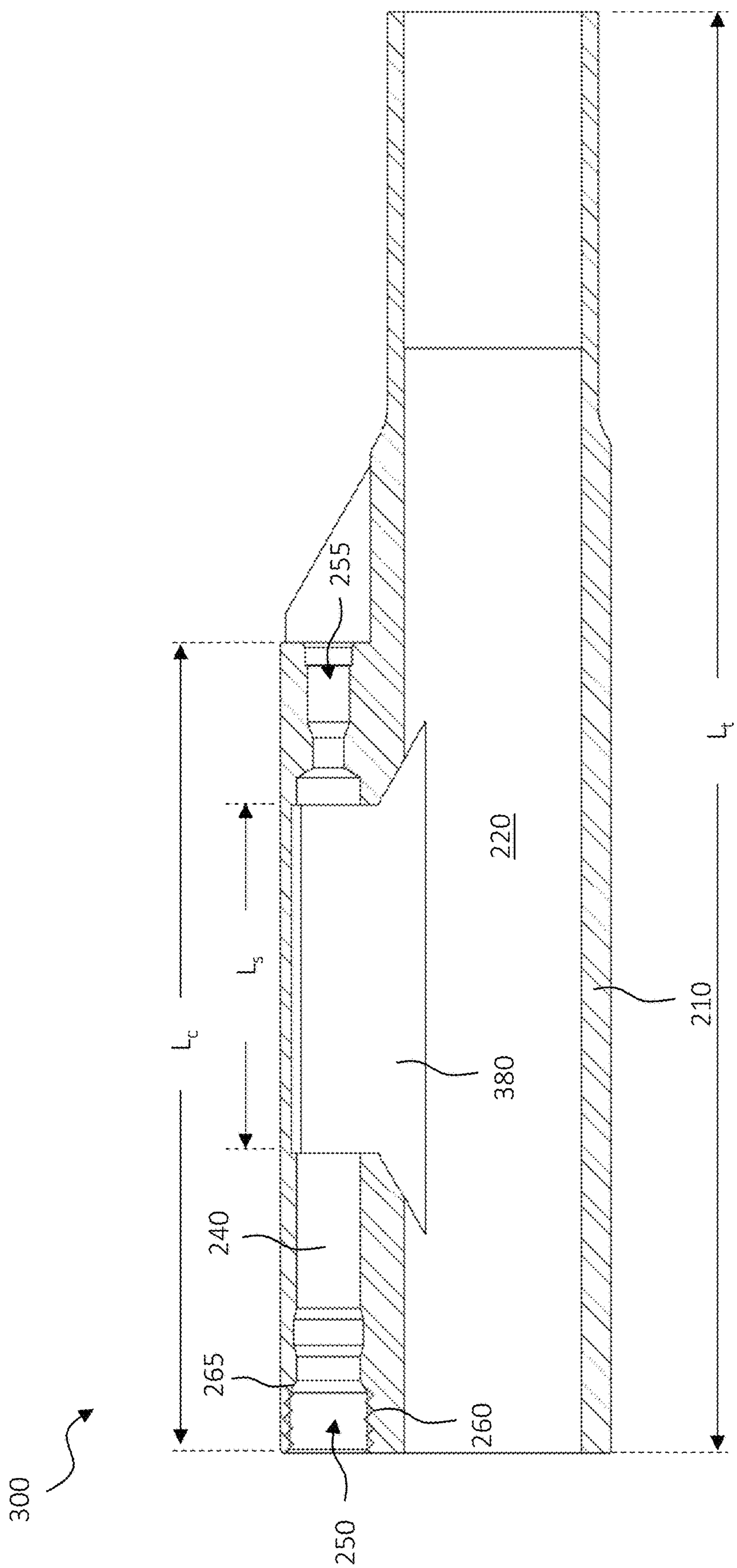

FIG. 3A

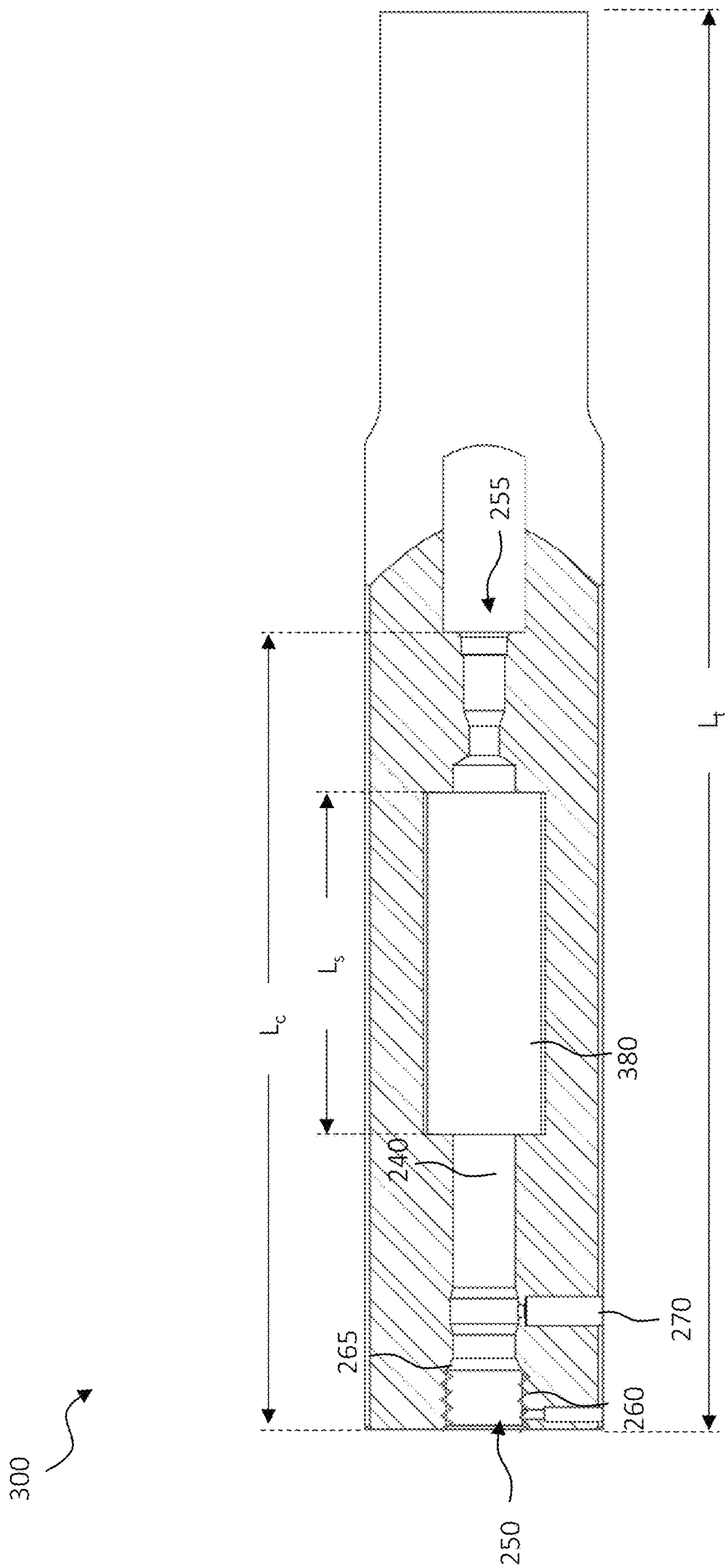

FIG. 3B

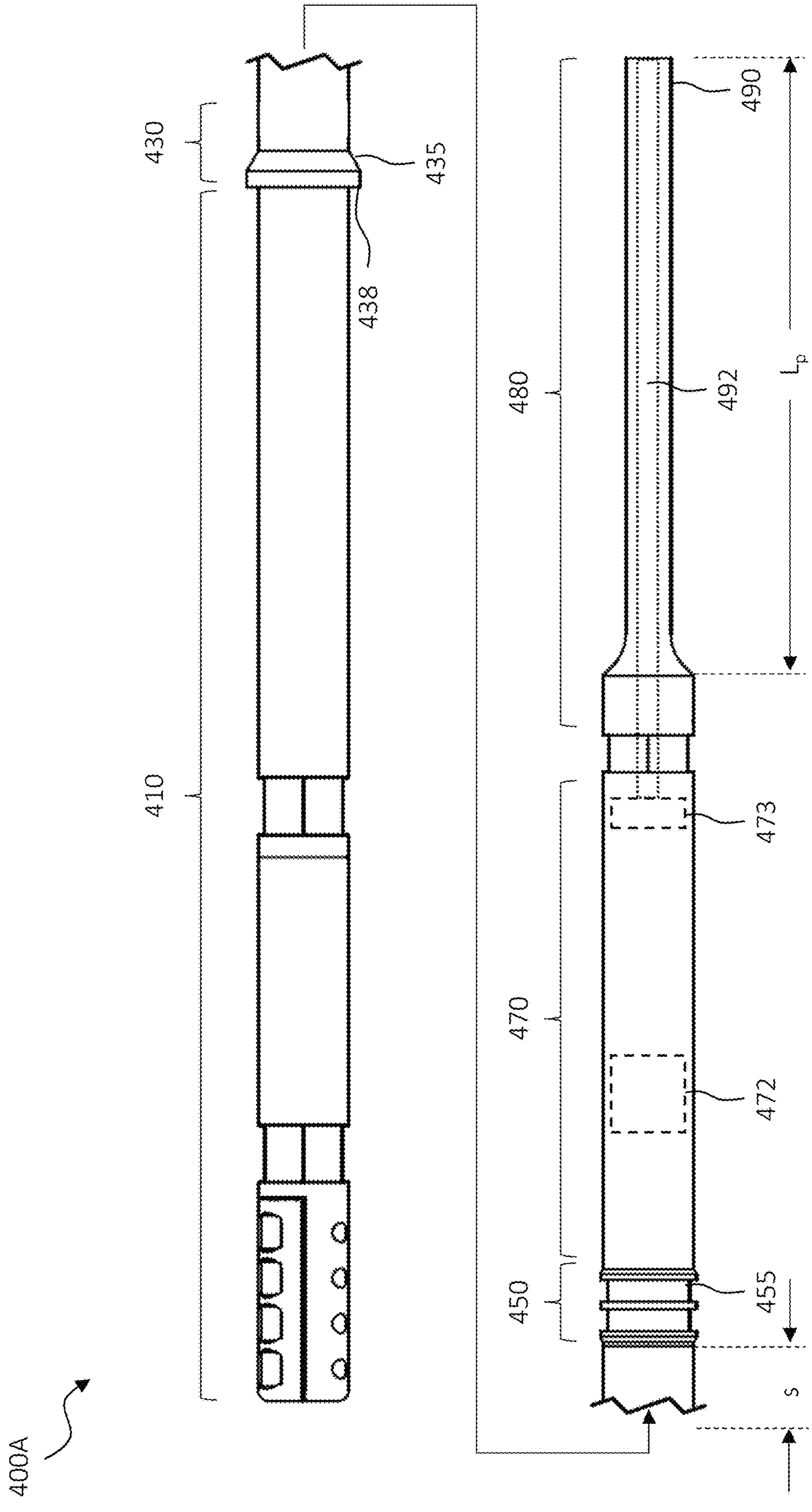

FIG. 4A

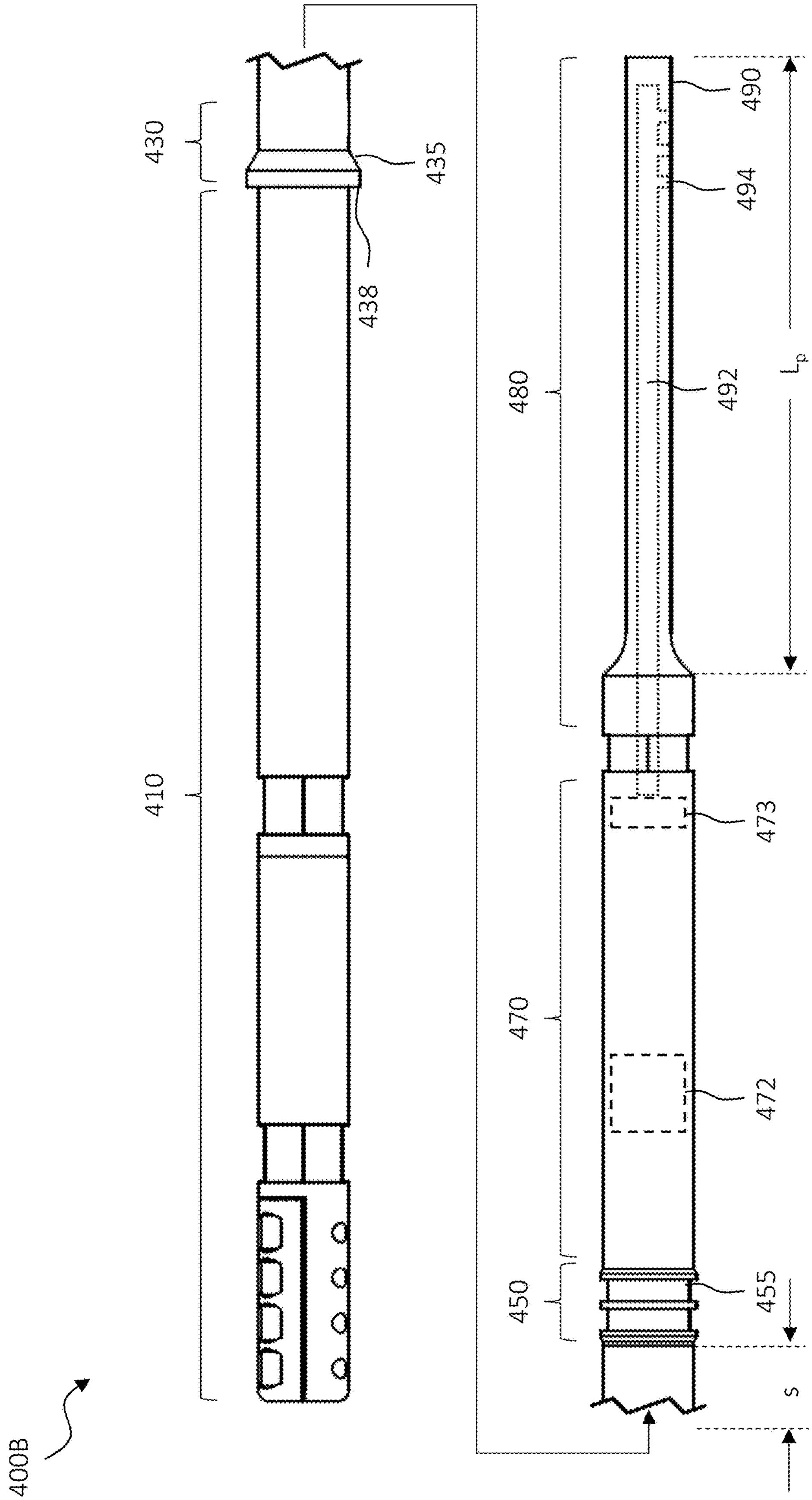

FIG. 4B

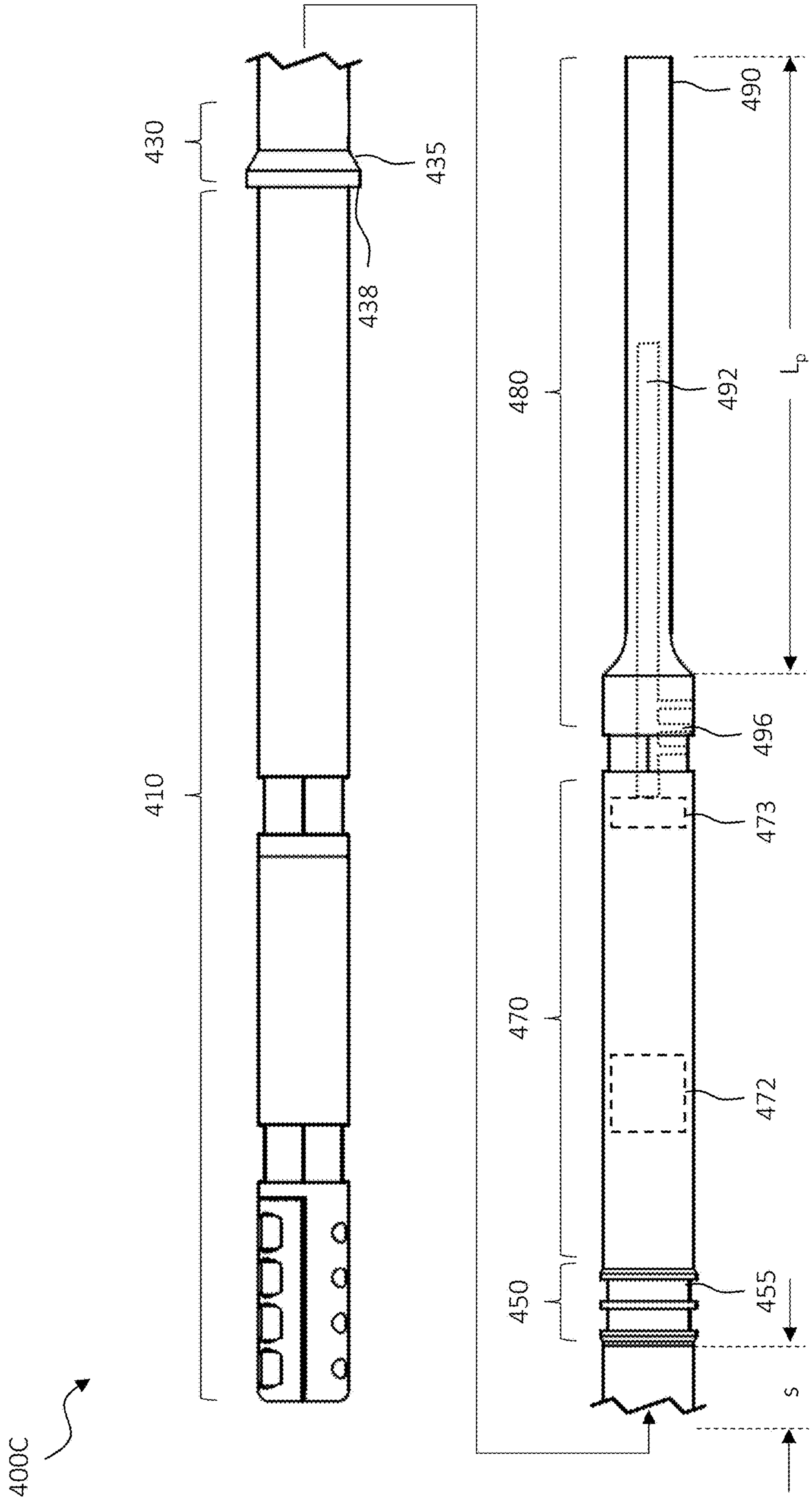

FIG. 4C

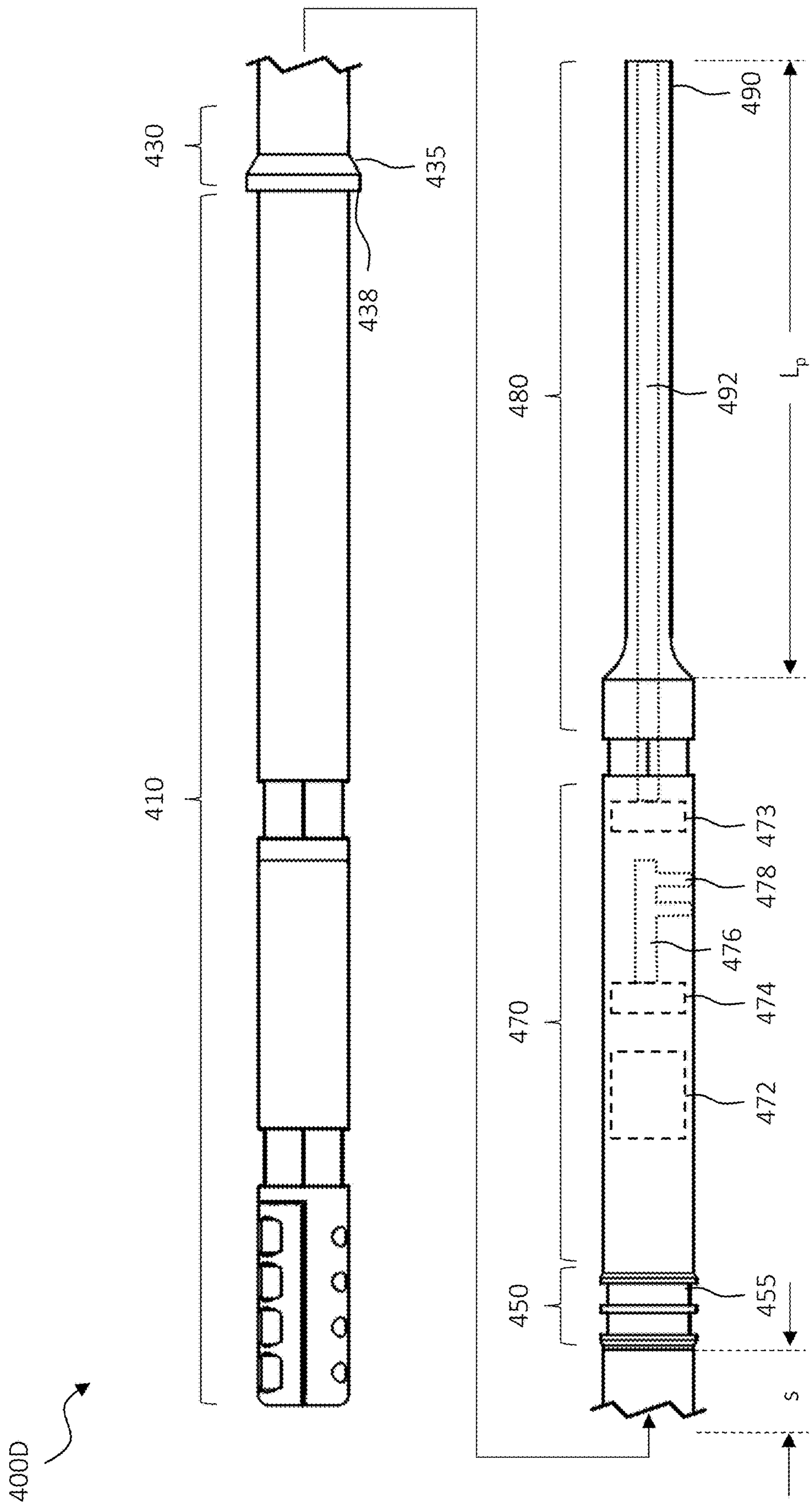
400D
410
430
435
438
450
455
470
472
473
474
476
478
480
490
492
L_p
s

FIG. 4D

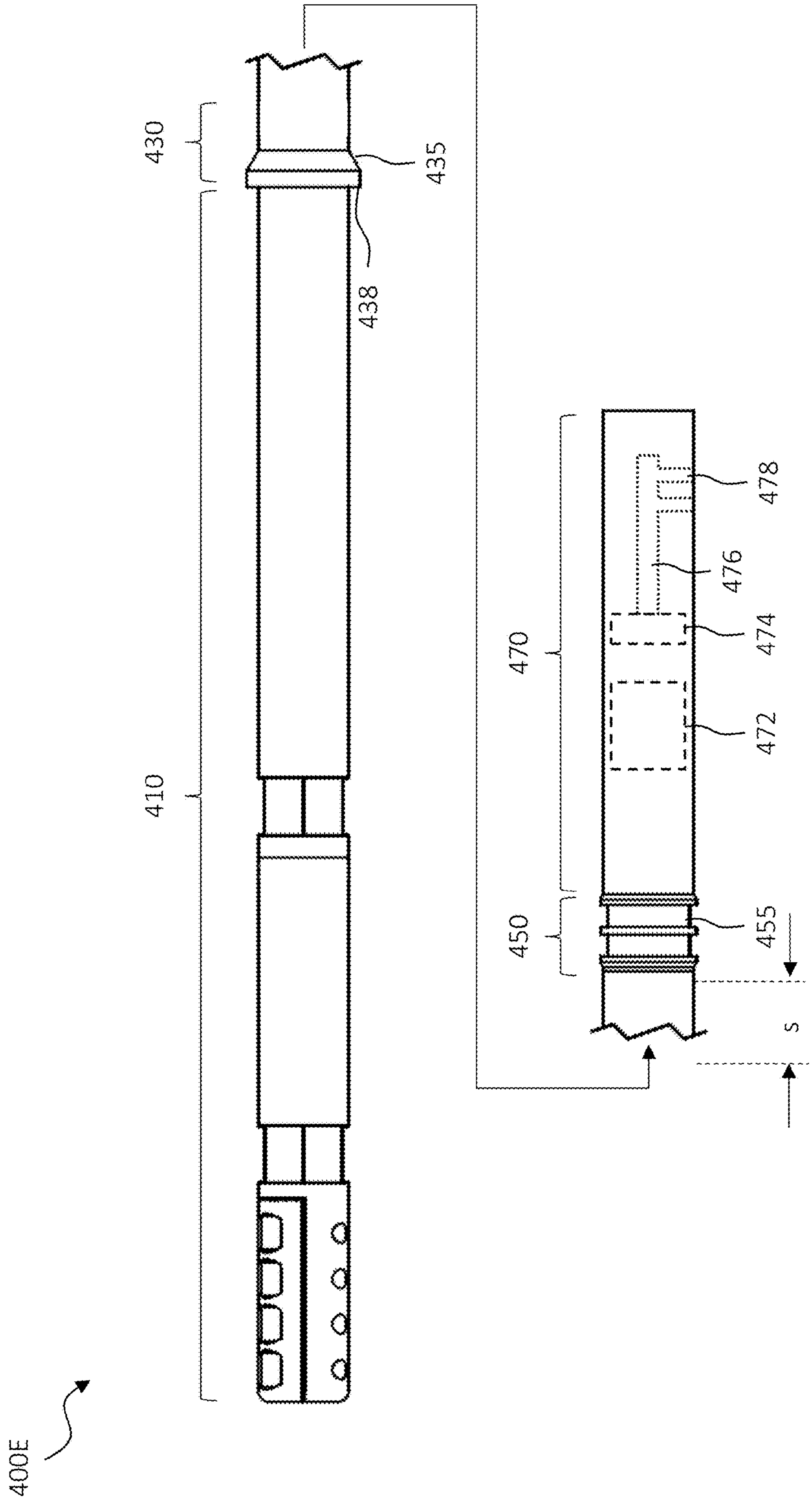

FIG. 4E

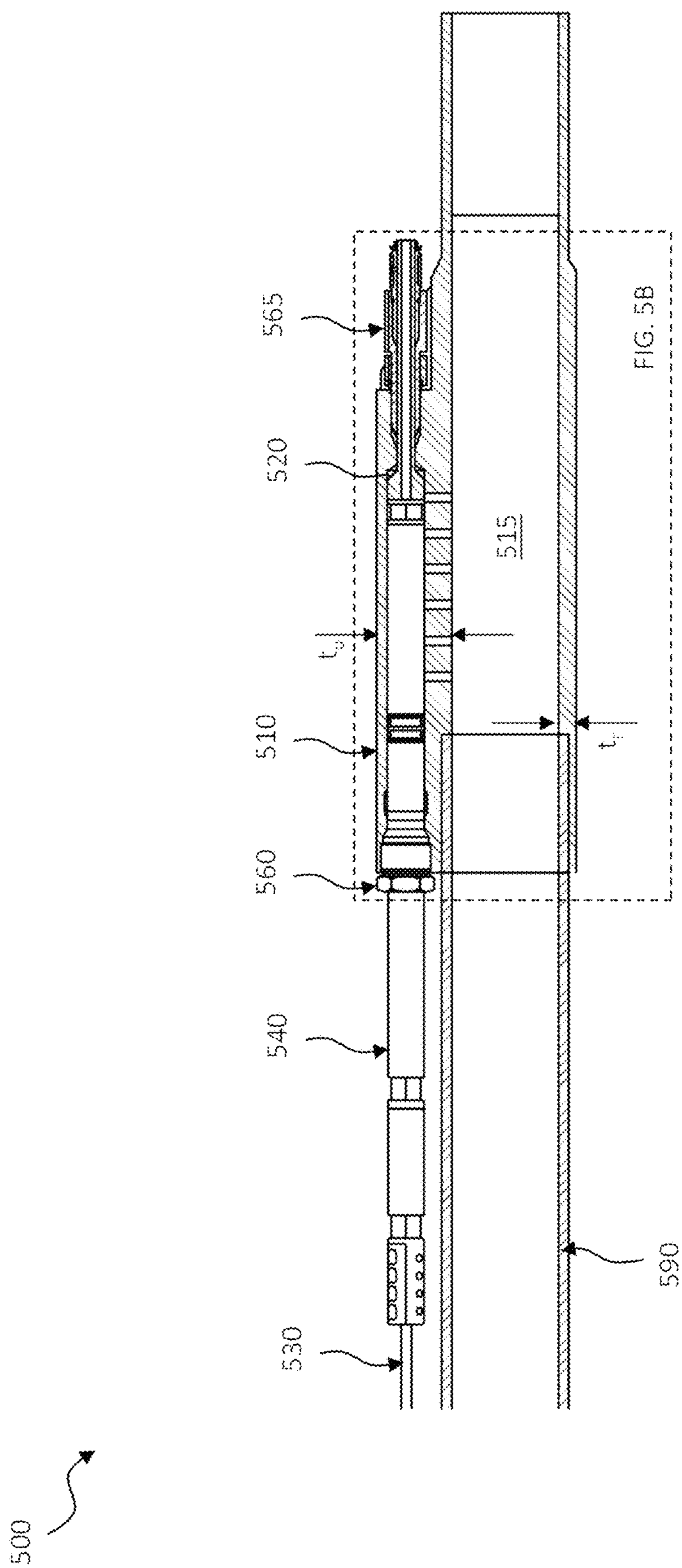

FIG. 5A

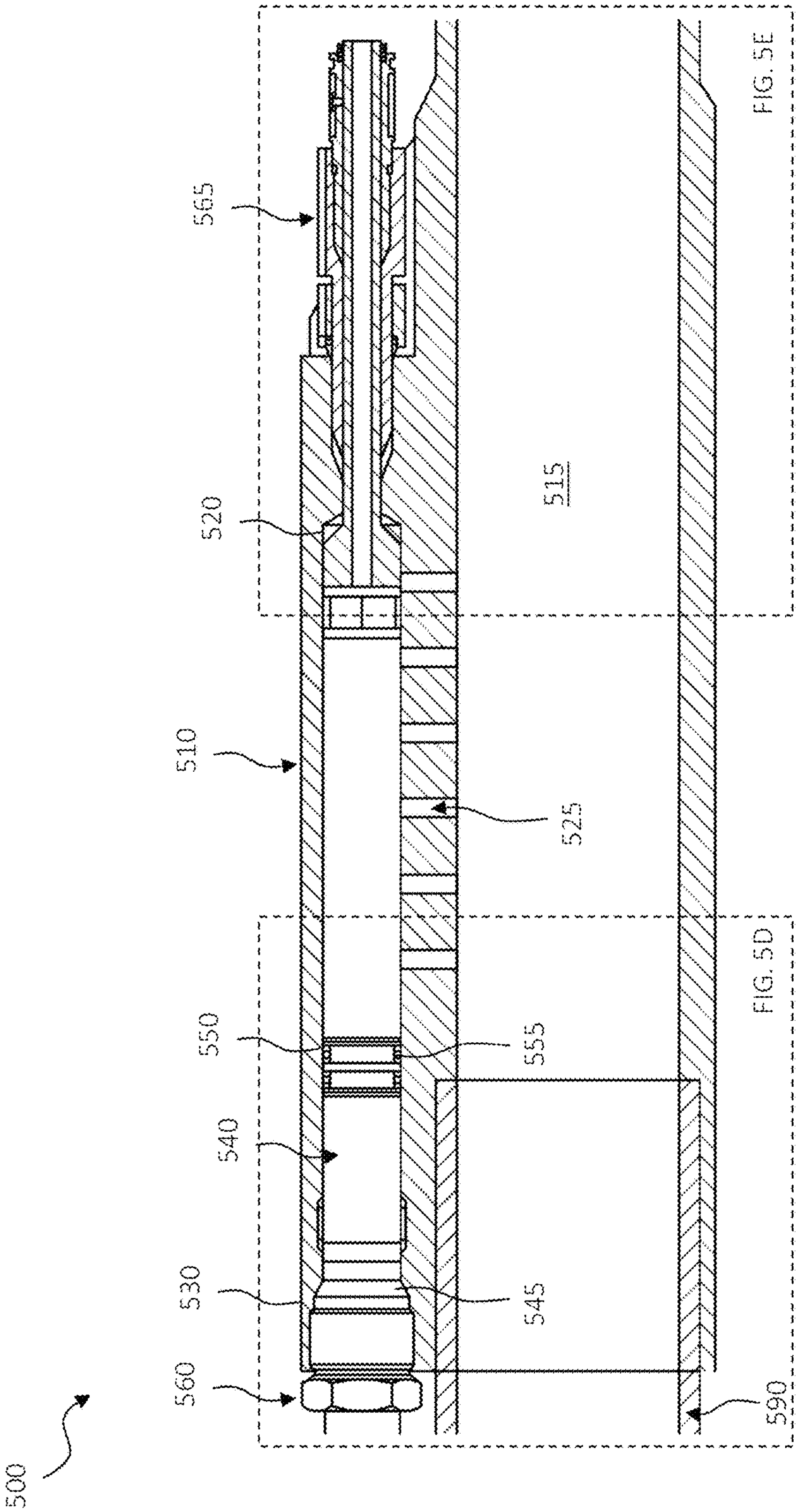

FIG. 5B

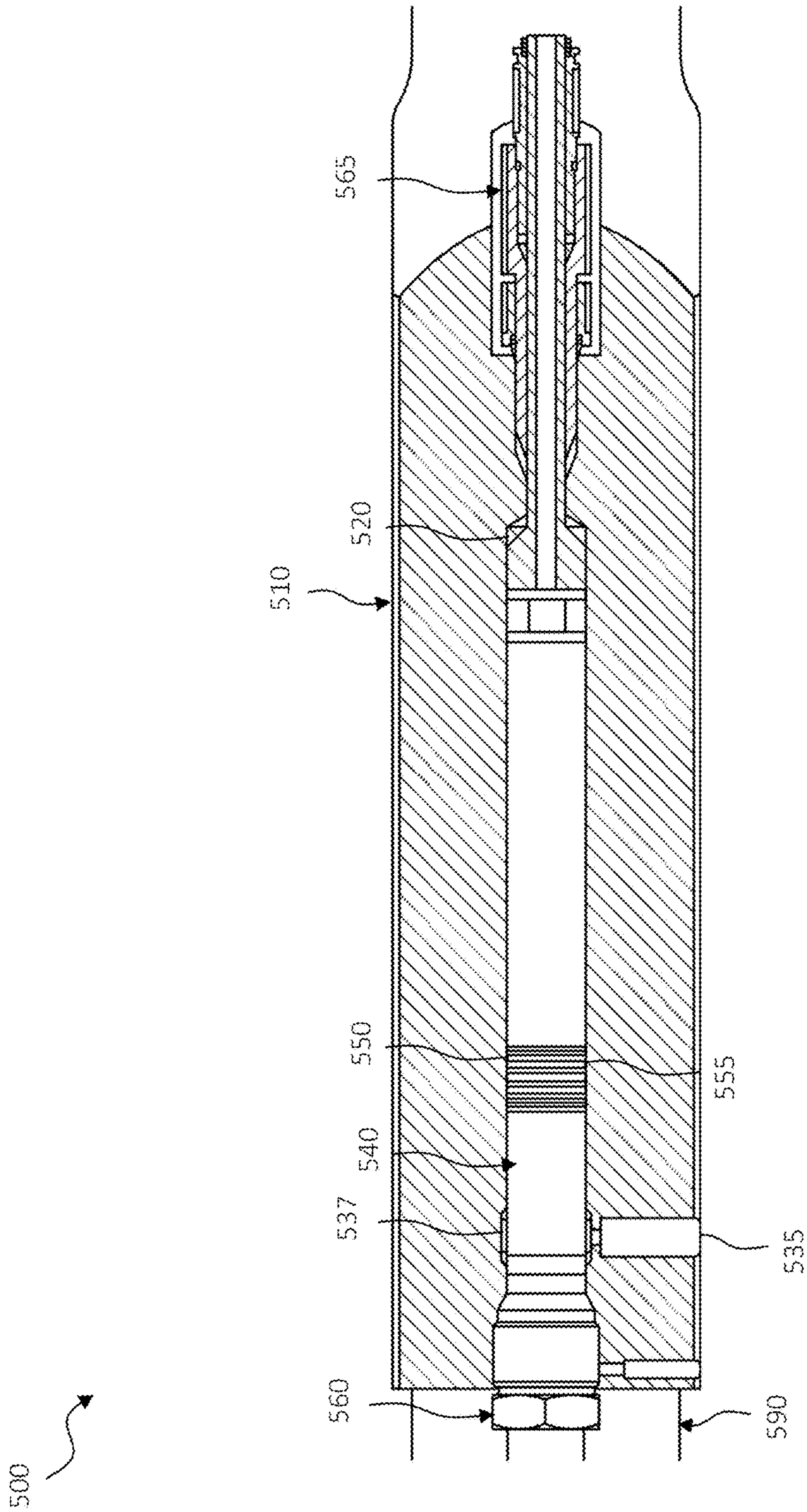

FIG. 5C

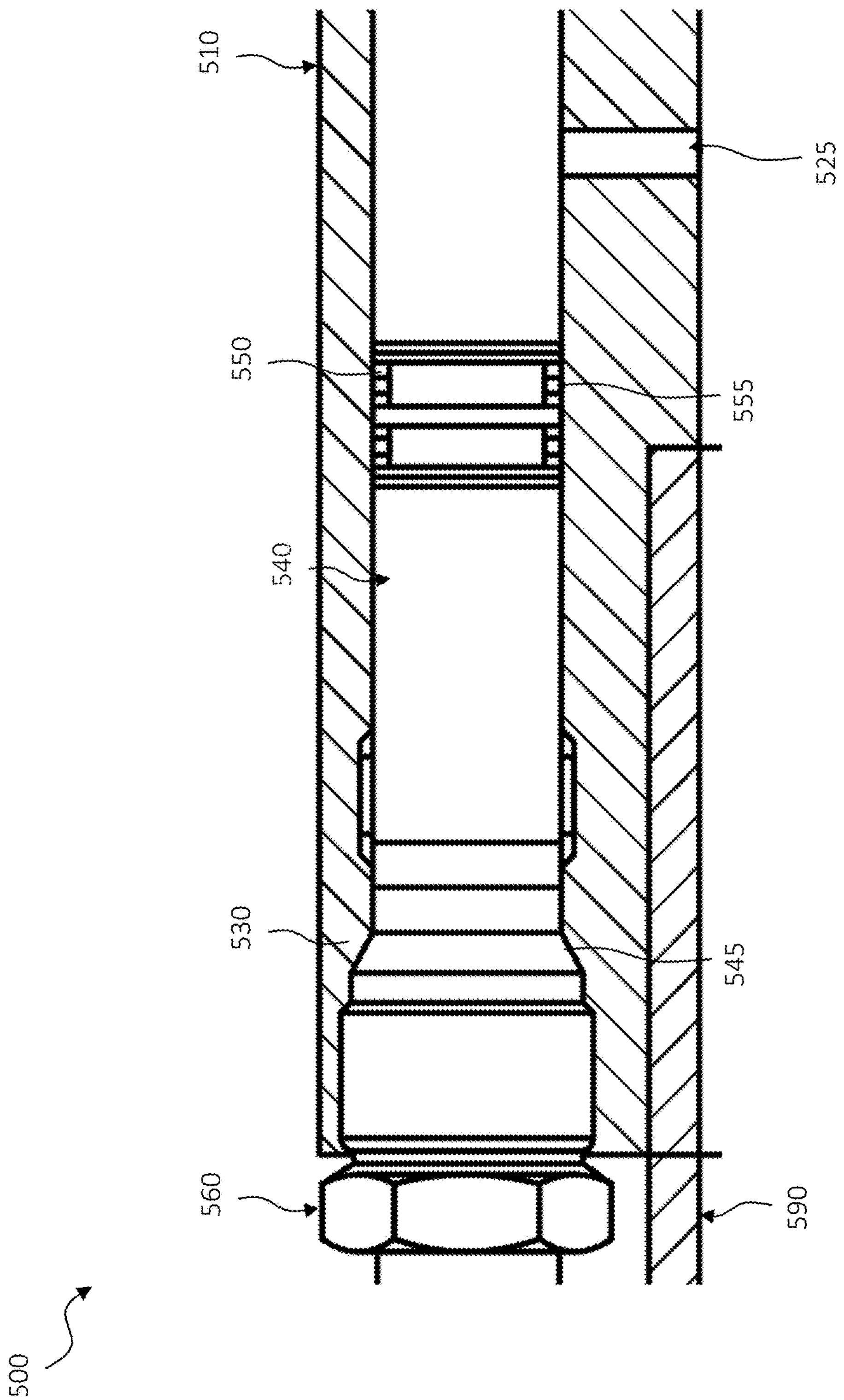

FIG. 5D

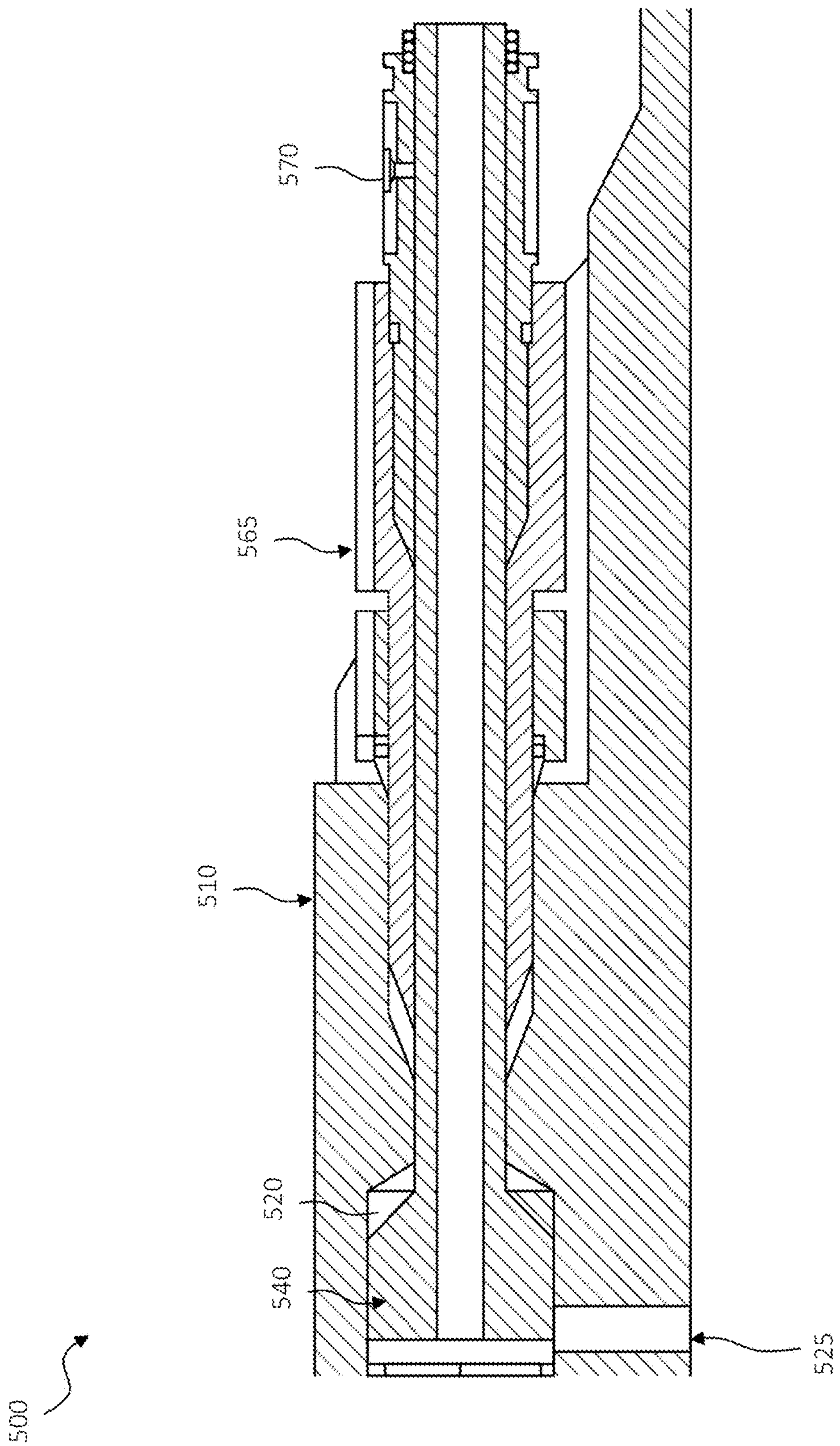

FIG. 5E

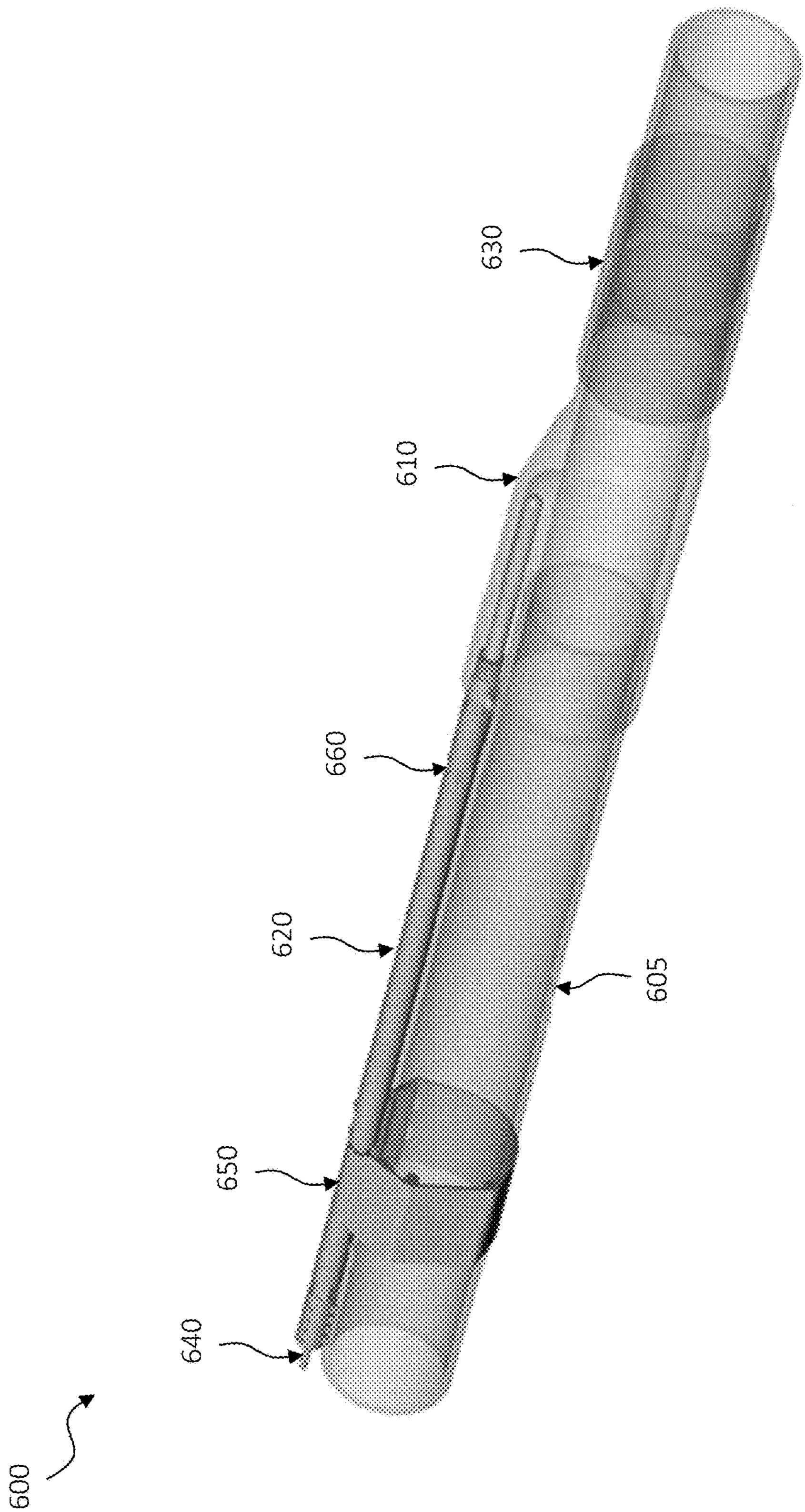

FIG. 6A

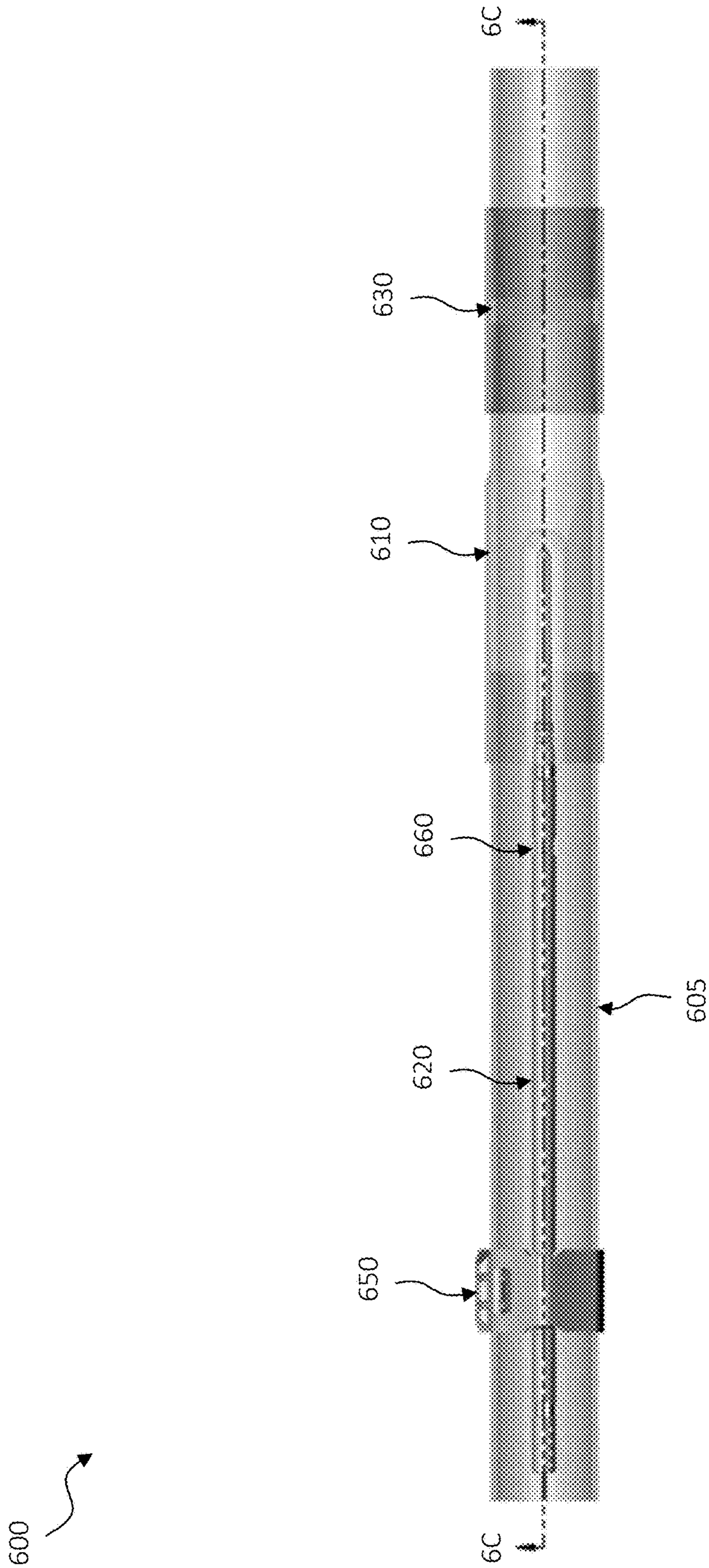

FIG. 6B

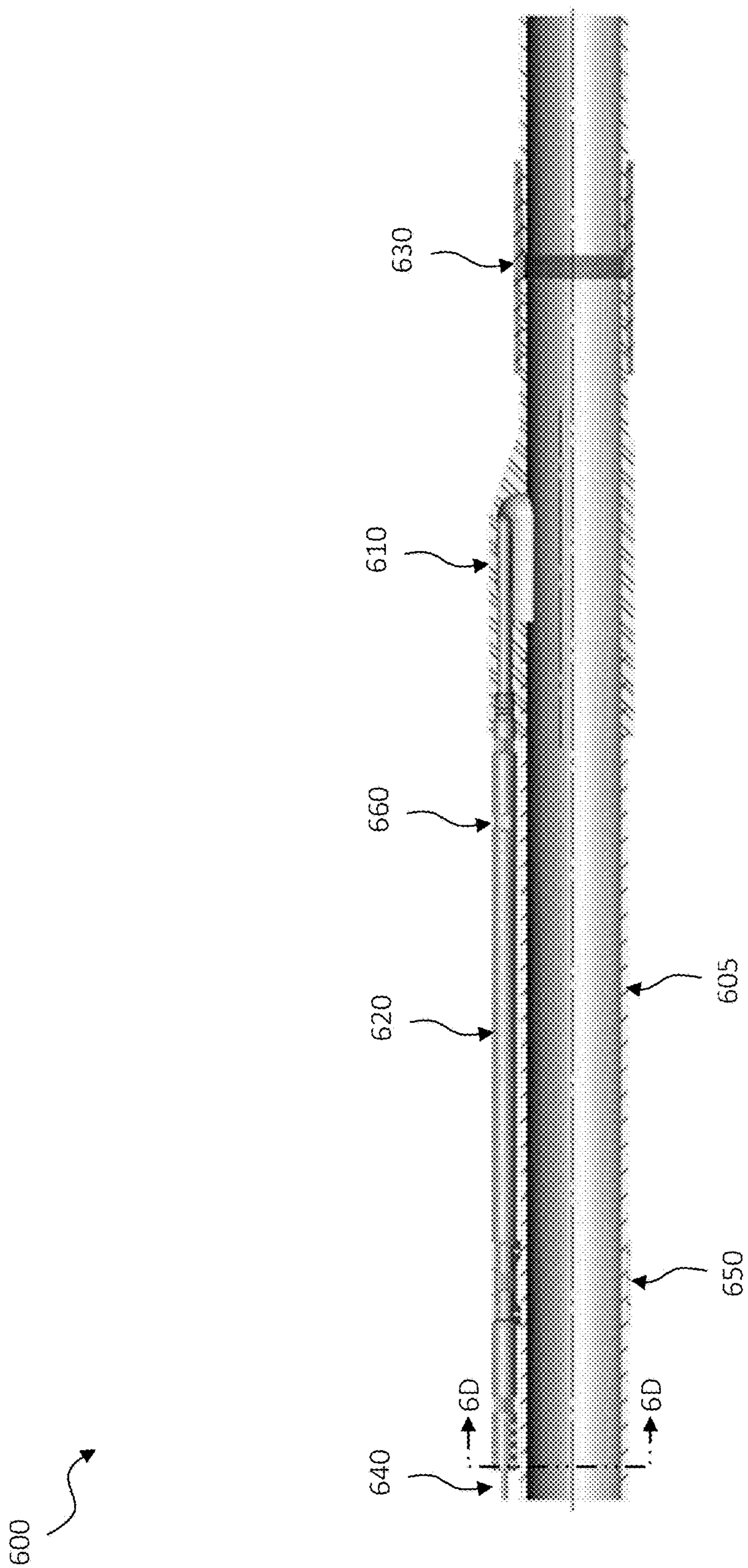

FIG. 6C

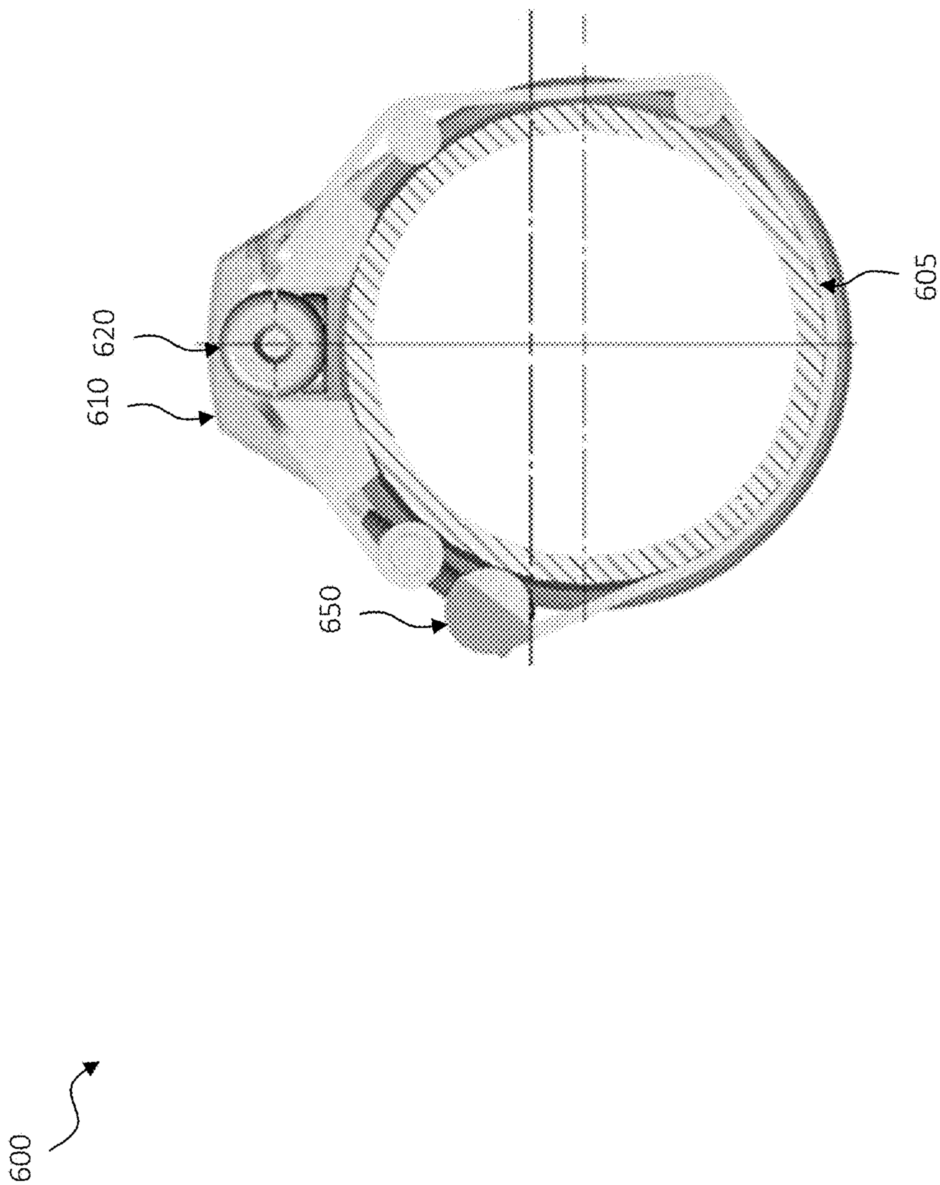

FIG. 6D

GAUGE SENSOR FOR DOWNHOLE PRESSURE/TEMPERATURE MONITORING OF ESP INTAKE PRESSURE AND DISCHARGE TEMPERATURE

CROSS-REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application Ser. No. 63/137,595, filed on Jan. 14, 2021, entitled "PERMANENT DOWNHOLE PRESSURE/TEMPERATURE MONITORING OF ESP INTAKE PRESSURE AND DISCHARGE TEMPERATURE," commonly assigned with this application and incorporated herein by reference in its entirety.

BACKGROUND

Electric submersible pumps (ESPs) may be deployed for any of a variety of pumping purposes. For example, where a substance (e.g., hydrocarbons in a subterranean formation) does not readily flow responsive to existing natural forces, an ESP may be implemented to artificially lift the substance. If an ESP fails during operation, the ESP must be removed from the pumping environment and replaced or repaired, either of which results in a significant cost to an operator.

The ability to predict an ESP failure, for example by monitoring the operating conditions and parameters of the ESP, provides the operator with the ability to change the operation of the ESP, perform preventative maintenance on the ESP or replace the ESP in an efficient manner, reducing the cost to the operator. However, when the ESP is in a wellbore, it is difficult to monitor the operating conditions and parameters with sufficient accuracy to accurately predict ESP failures.

BRIEF DESCRIPTION

Reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

FIG. **1** illustrates a perspective view of a well system including an exemplary operating environment that the apparatuses, systems and methods disclosed herein may be employed;

FIGS. **2**A and **2**B illustrate a cross-sectional view and top view, respectively, of one embodiment of a gauge mandrel designed, manufactured and/or operated according to one or more embodiments of the disclosure;

FIGS. **3**A and **3**B illustrate a cross-sectional view and top view, respectively, of one embodiment of a gauge mandrel designed, manufactured and/or operated according to one or more alternative embodiments of the disclosure;

FIGS. **4**A through **4**E illustrate various different embodiments of a gauge sensor designed, manufactured and/or operated according to one or more embodiments of the disclosure;

FIGS. **5**A to **5**E illustrate various different views of sensing system (e.g., installed sensing system) according to any of the embodiments, aspects, applications, variations, designs, etc. disclosed herein; and

FIGS. **6**A to **6**D illustrate yet another design of a sensing system designed, manufactured and operated according to one or more embodiments of the disclosure.

DETAILED DESCRIPTION

In the drawings and descriptions that follow, like parts are typically marked throughout the specification and drawings with the same reference numerals, respectively. The drawn figures are not necessarily, but may be, to scale. Certain features of the disclosure may be shown exaggerated in scale or in somewhat schematic form and some details of certain elements may not be shown in the interest of clarity and conciseness.

The present disclosure may be implemented in embodiments of different forms. Specific embodiments are described in detail and are shown in the drawings, with the understanding that the present disclosure is to be considered an exemplification of the principles of the disclosure, and is not intended to limit the disclosure to that illustrated and described herein. It is to be fully recognized that the different teachings of the embodiments discussed herein may be employed separately or in any suitable combination to produce desired results. Moreover, all statements herein reciting principles and aspects of the disclosure, as well as specific examples thereof, are intended to encompass equivalents thereof. Additionally, the term, "or," as used herein, refers to a non-exclusive or, unless otherwise indicated.

Unless otherwise specified, use of the terms "connect," "engage," "couple," "attach," or any other like term describing an interaction between elements is not meant to limit the interaction to direct interaction between the elements and may also include indirect interaction between the elements described.

Unless otherwise specified, use of the terms "up," "upper," "upward," "uphole," "upstream," or other like terms shall be construed as generally away from the bottom, terminal end of a well, regardless of the wellbore orientation; likewise, use of the terms "down," "lower," "downward," "downhole," or other like terms shall be construed as generally toward the bottom, terminal end of a well, regardless of the wellbore orientation. Use of any one or more of the foregoing terms shall not be construed as denoting positions along a perfectly vertical or horizontal axis. Unless otherwise specified, use of the term "subterranean formation" shall be construed as encompassing both areas below exposed earth and areas below earth covered by water, such as seawater or fresh water.

Typical downhole pressure/temperature gauges (e.g., permanent downhole pressure/temperature gauges) have the pressure and temperature sensors in close proximity. The downhole pressure/temperature gauges are typically mounted on the exterior of the tubing string and can be ported to measure the pressure of either the tubing or the annulus. This presents a challenge when monitoring the temperature inside the tubing while also monitoring the pressure in the annulus, which at a very minimum would require two separate sensors.

Accordingly, the present disclosure provides a novel sensing system, which is a combination of a downhole pressure/temperature gauge sensor and gauge mandrel (e.g., permanent downhole pressure/temperature gauge and gauge mandrel in one embodiment). In at least one embodiment, the gauge sensor is installed inside the gauge mandrel and employs one or more seals (e.g., metal to metal seals) to secure the gauge sensor and maintain wellbore integrity. In at least one embodiment, a downhole end of the gauge sensor is configured with a pressure nipple which extends out of the downhole end of the upset of the gauge cavity in the gauge mandrel to enable monitoring of the annulus, which may also be the ESP intake pressure. This design can also be configured such that the gauge sensor monitors the pressure and temperature inside the tubing string.

A novel sensing system according to the disclosure may have many different unique features. In at least one embodiment, the gauge sensor may be installed in a gauge cavity (e.g., as opposed to a slot) inside the gauge mandrel. In at least one other embodiment, the gauge cavity may be bored inside a sidewall thickness (t) of the gauge mandrel (e.g., the upset of the gauge mandrel) for the gauge sensor to insert within. In yet another embodiment, the gauge sensor (e.g., gauge sensor housing) may have an angled surface on the gauge insertion end that is configured to engage with an opposing angled surface in the gauge cavity of the gauge mandrel to create a metal to metal seal.

In at least one embodiment, the gauge cavity has an insertion end entering the sidewall thickness (t) and an exit end exiting the sidewall thickness (t). In at least one embodiment, the insertion end of the gauge cavity has threads to enable the use of a gland to drive the gauge sensor into the gauge cavity and energize the metal to metal seal. Similarly, in at least one embodiment the exit end of the gauge cavity incorporates threads and a seal surface, for example to secure a pressure nipple of the gauge sensor. In at least one embodiment, the pressure nipple extends through the exit end of the gauge cavity and into an annulus, and a pressure nipple fitting engages with the threads in the exit end of the gauge cavity to secure the pressure nipple. In at least one embodiment, a compression fitting may be installed to create a metal to metal seal between the gauge sensor and the gauge mandrel at the exit end. The pressure nipple can either be bored through to enable monitoring the annulus pressure, or ESP intake pressure, or the pressure nipple can have a closed end with perforations along its length to measure tubing pressure. In this embodiment, the gauge sensor might have a single temperature sensor and a single pressure sensor. In yet another embodiment, the gauge sensor might have a single temperature sensor and a pair of pressure sensors (e.g., one to measure the annulus pressure and another to measure the tubing pressure). In yet another embodiment, the gauge sensor might have a pair of temperature sensors (e.g., one to measure the tubing temperature and another to measure the annulus temperature) and a pair of pressure sensors (e.g., one to measure the annulus pressure and another to measure the tubing pressure).

In at least one embodiment, the gauge mandrel may also have one or more fluid passageways (e.g., one or more machined fluid passageways) in the sidewall thickness (t) coupling the tubular and the gauge cavity. This allows fluid flowing through the tubular to enter the gauge cavity via the one or more fluid passageways and surround the gauge sensor so the gauge sensor can obtain the most accurate measurement, whether it be temperature and/or pressure.

In at least one embodiment, the method used to mount the gauge sensor to the gauge mandrel and create the metal to metal seals does not induce mechanical strain on the sensors of the gauge sensor, which could induce errors in the measurements. In at least one other embodiment, one or more of the metal to metal seals (e.g., at opposing ends of the gauge cavity) are pressure testable, and thus in certain embodiments there is no need to pressure test the gauge mandrel to confirm that the metal to metal seals are assembled correctly.

The term insertion end and exit end, as used herein, are in reference to the end of the gauge cavity that the gauge sensor inserts into, as well as the end of the gauge cavity that the gauge sensor could exit from. In many embodiments, the insertion end is an uphole end, and the exit end is downhole of the insertion end. Nevertheless, the opposite may be true.

One or more additional advantages of the novel sensing system, include: requires minor modifications to the mechanical packaging of existing downhole pressure/temperature gauges; enables monitoring of ESP intake pressure (e.g., annulus pressure) and discharge temperature (e.g., tubing temperature) in a single gauge package; does not require multiple gauge sensors or "splitting" of a TEC downhole; no welds on the gauge mandrel; gauge mandrel can be manufactured with conventional methods and tooling; standard/common gauge mandrel design can be used for monitoring either the tubing pressure or the annulus pressure; metal to metal seals can be pressure tested in the field without requiring a pressure test of the gauge mandrel or tubing string; single component of the gauge sensor may be changed to monitor tubing pressure or annulus pressure; can be used with any ESP as it is installed in the production tubing; suitable for SAGD or Geothermal applications, as it can accommodate the high temperatures (e.g., 260° C. and 315° C.) used with Datasphere® ERD™ HT or Datasphere® ERD™ XHT gauges.

Referring to FIG. **1**, depicted is a perspective view of a well system **100** including an exemplary operating environment that the apparatuses, systems and methods disclosed herein may be employed. For example, the well system **100** could use a gauge mandrel and/or gauge sensor according to any of the embodiments, aspects, applications, variations, designs, etc. disclosed in the following paragraphs. The well system **100**, in the illustrated embodiment, includes a wellbore **110** having a wellhead **115** at a surface **120** thereof. The wellbore **110** extends and penetrates various earth strata, including in certain embodiments hydrocarbon containing subterranean formations.

A casing **125** can be cemented along a length of the wellbore **110**. Nevertheless, in certain other embodiments the wellbore **110**, or at least a portion thereof, is an open hole wellbore. A power source **130** can have an electrical cable **135**, or multiple electrical cables, extending into the wellbore **100** and coupled with a motor **140**. It should be noted that while FIG. **1** generally depicts a land-based operation, those skilled in the art will readily recognize that the principles described herein are equally applicable to subsea operations that employ floating or sea-based platforms and rigs, without departing from the scope of the disclosure. Also, even though FIG. **1** depicts a vertical wellbore, the present disclosure is equally well-suited for use in wellbores having other orientations, including horizontal wellbores, slanted wellbores, multilateral wellbores or the like.

Disposed within the wellbore **110** can be a tubing string **150** having an ESP **155** forming an electric submersible pump string. The ESP **155** may be driven by the motor **140**. The tubing string **150** can also include a pump intake **160** for withdrawing fluid from the wellbore **110**. The pump intake **160**, or pump admission, can separate the fluid and gas from the withdrawn hydrocarbons and direct the fluid into the ESP **155**. A protector **165** can be provided between the motor **140** and the pump intake **160** to prevent entrance of fluids into the motor **140** from the wellbore **110**. The motor **140** can be electrically coupled with the power source **130** by the electrical cable **135**. The motor **140** can be disposed below the ESP **155** within the wellbore **110**, among other locations. The ESP **155** can provide artificial pressure, or lift, within the wellbore **110** to increase the withdrawal of hydrocarbons, and/or other wellbore fluids. The ESP **155** can provide energy to the fluid flow from the well thereby increasing the flow rate within the wellbore **110** toward the wellhead **115**.

The tubing string **150** can be a series of tubing sections, coiled tubing, or other conveyance for providing a passageway for fluids. In at least one embodiment, a gauge mandrel **170** is interposed within the tubing string **150**, the gauge mandrel **170** having a gauge sensor (not shown, but including a temperature and/or pressure sensor) disposed therein. The gauge sensor, in the disclosed embodiment, is configured to determine the temperature and/or pressure within the tubing string **150**, and/or as well as within the annulus between the wellbore **110** and the gauge mandrel **170**, or any combination of the foregoing. Accordingly, the gauge sensor may be coupled with sensor technology **180** via a wire **190** (e.g., TEC conductor). The gauge mandrel **170** may include one or more of the novel features as disclosed within the present disclosure, including a gauge cavity extending along at least a portion of a length (L_t) of its tubular and located entirely within a sidewall thickness of the tubular.

Turning to FIGS. **2**A and **2**B, illustrated are a cross-sectional view and top view, respectively, of one embodiment of a gauge mandrel **200** designed, manufactured and/or operated according to one or more embodiments of the disclosure. The gauge mandrel **200**, in the illustrated embodiment, includes a tubular **210** having a primary fluid passageway **220** extending longitudinally therethrough. In at least one embodiment, the tubular **210** has a length (L_t), an internal diameter (D_i) and a width (W). The length (L_t) may vary greatly and remain within the scope of the disclosure. Nevertheless, in at least one embodiment the length (L_t) ranges from 45 cm to 125 cm, and in yet another embodiment the length (L_t) ranges from 60 cm to 90 cm. In one or more embodiments, the width (W) is an external diameter (D_e), as opposed to a flat or shaved surface, such as shown in FIGS. **2**A and **2**B. Further to the embodiment of FIGS. **2**A and **2**B, the internal diameter (D_i) and the width (W) define a sidewall thickness (t).

As shown, the sidewall thickness (t) does not need to be consistent all the way around the tubular **210**. For example, the tubular **210** may include an upset section **230**, thereby providing an inconsistent sidewall thickness (t) around the tubular **210**. In at least one embodiment, the upset section **230** creates a clearance **235** for a gauge sensor pressure fitting. For example, in the illustrated embodiment, the gauge mandrel **200** has the upset section **230**, such that the primary fluid passageway **220** within the gauge mandrel **200** is not concentric with an exterior of the gauge mandrel **220** in the upset section **230**. In accordance with this embodiment, a sidewall thickness (t_u) of the upset section **230** is greater than a sidewall thickness (t_r) of the remainder of the gauge mandrel **200**. In yet another embodiment, the primary fluid passageway **220** and an exterior of the gauge mandrel **200** are concentric with one another, and thus the gauge cavity **240** may be located anywhere in the sidewall thickness (t).

The gauge mandrel **200**, in accordance with one or more embodiments, may additionally include a gauge cavity **240** extending along at least a portion of the length (L_t) of the tubular **210**. The gauge cavity **240** in the illustrated embodiment is located entirely within the sidewall thickness (t) of the tubular **210** and has a gauge cavity length (L_c). This is as opposed to a slot, that would be exposed to an outside of the gauge mandrel along at least a portion of the length (L_t) of the tubular **210**. In at least one embodiment, such as shown, the gauge cavity **240** is located within the greater sidewall thickness (t_u) of the upset section **230**. The length (L_c) may vary greatly and remain within the scope of the disclosure. Nevertheless, in at least one embodiment the length (L_c) ranges from 35 cm to 95 cm, and in yet another embodiment the length (L_c) ranges from 55 cm to 75 cm.

In one or more embodiments, the gauge cavity **240** includes an insertion end **250** entering the sidewall thickness (t) and configured to accept a gauge sensor. Further to the embodiment of FIGS. **2**A and **2**B, the gauge cavity **240** may include an exit end **255** exiting the sidewall thickness (t) opposite the insertion end **250**. In at least one embodiment, the exit end **255** is operable to allow a pressure nipple of the gauge sensor to extend through the insertion end **250** and exit the gauge cavity **240**. In the illustrated embodiment, the length (L_c) of the gauge cavity **240** is less than the length (L_t) of the tubular **210**. For example, in at least one embodiment the length (L_c) of the gauge cavity **240** is at least 10 percent less than the length (L_t) of the tubular **210**. In yet another embodiment, the length (L_c) of the gauge cavity **240** is at least 20 percent less, if not at least 30 percent less, than the length (L_t) of the tubular **210**.

In at least one embodiment, the insertion end **250** includes one or more threads **260** for accepting a gland (not shown) therein. For example, the gland could have associated threads that mate with the one or more threads **260** of the insertion end **250** to hold a related gauge sensor within the gauge cavity **240**. While the one or more threads **260** are illustrated in FIG. **2**A as the coupling feature, those skilled in the art understand that other coupling features (e.g., a press fit feature, a set screw, etc.) could be used to hold the related gauge sensor within the gauge cavity **240**.

The gauge cavity **240**, in at least the embodiment shown, includes a gauge mandrel angled surface **265** proximate the insertion end **250**. In at least another embodiment, the gauge mandrel angled surface **265** is substantially proximate the insertion end **250**. The term proximate, as used with regard to the placement of the gauge mandrel angled surface **265**, means within the first 20 percent of the gauge cavity **240**. The term substantially proximate, as used with regard to the placement of the gauge mandrel angled surface **265**, means within the first 10 percent of the gauge cavity **240**. As discussed above, the gauge mandrel angled surface **265** may couple with a gauge sensor angled surface of the gauge sensor that it accepts. Accordingly, the coupling of the gauge mandrel angled surface **265** and the gauge sensor angled surface transfers any stresses from the gauge sensor to the gauge mandrel **200** away from a sensor region of the gauge sensor. Thus, the coupling of the gauge sensor with the gauge mandrel **200** would not impact the accuracy of the gauge sensor. In at least one embodiment, an angle of the gauge mandrel angled surface **265** is slightly mismatched with an angle of the gauge angled surface. For example, in at least one embodiment, the two angles are mismatched by 2 degrees or more, if not 5 degrees or more. As discussed above, the coupling of the gauge sensor with the gauge mandrel **200** may provide a metal to metal seal.

In certain other embodiments, the gauge cavity **240** may have a pressure test port **270** coupling an exterior of the gauge mandrel **200** to the gauge cavity **240**, as shown in FIG. **2**B. This pressure test port **270**, when employed, may be used to pressure test the gauge cavity **240** and all of the associated connections and fittings thereof when the gauge sensor is positioned therein. The gauge cavity **240** may additionally include a second seal profile **275**. The second seal profile **275**, in at least one embodiment, may be configured to engage with a pressure fitting used to create a seal with the pressure nipple region of a gauge sensor.

In accordance with one embodiment of the disclosure, the gauge mandrel **200** may additionally include one or more fluid passageways **280** coupling the tubular **210** and the gauge cavity **240**. In the illustrated embodiment of FIGS. **2**A and **2**B, the gauge mandrel **200** employs a plurality of fluid ports. For example, the gauge mandrel **200** may include at least three fluid ports, if not at least six fluid ports as shown in FIGS. **2**A and **2**B. In yet other embodiments, the gauge mandrel **200** may include only a single fluid slot coupling the tubular **210** and the gauge cavity **240**. The one or more fluid passageways **280** are shown as multiple drilled ports, however this can be changed from several small diameter ports to fewer large diameter ports or to a long slot to ensure the fluid surrounding the gauge sensor is the same temperature as the fluid in the primary fluid passageway **220**. In the illustrated embodiment, the one or more fluid passageways **280** couple the primary fluid passageway **220** of the tubular **210** and the gauge cavity **240** through the sidewall thickness (t).

Turning to FIGS. **3**A and **3**B, illustrated are a cross-sectional view and top view, respectively, of one embodiment of a gauge mandrel **300** designed, manufactured and/or operated according to one or more alternative embodiments of the disclosure. The gauge mandrel **300** is similar in many respects to the gauge mandrel **200** of FIGS. **2**A and **2**B. Accordingly, like reference numbers have been used to illustrate similar, if not identical, features. The gauge mandrel **300** differs, for the most part, from the gauge mandrel **200** in that the gauge mandrel **300** employs a larger (e.g., single) fluid slot **380** to couple the tubular **210** with the gauge cavity **240**. The larger fluid slot **380** allows the fluid from the primary fluid passageways **220** of the tubular **210** to enter and exit the gauge cavity **240** with greater regularity than might be possible with one or more smaller fluid ports, such as shown in FIGS. **2**A and **2**B. In at least one embodiment, the larger fluid slot **380** has a length (L_s) of at least 14 cm. In at least one other embodiment, the larger fluid slot **380** has a greater length (L_s) of at least 65 cm.

Turning to FIG. **4**A, illustrated is one embodiment of a gauge sensor **400**A designed, manufactured and/or operated according to one or more embodiments of the disclosure. The gauge sensor **400**A, in at least one embodiment, might be used with one or more of the gauge mandrels discussed above, among other uses. In the illustrated embodiment, the gauge sensor **400**A may be divided into a plurality of different regions, for example including a tubing encapsulated conductor (TEC) termination region **410**, a first seal region **430** (e.g., primary seal region), a second seal region **450** (e.g., secondary seal region), a sensor region **470**, and pressure nipple region **480**. The TEC termination region **410**, as those skilled in the art would expect, is configured to provide a termination point with an incoming TEC and the gauge sensor **400**A, and thus may include a TEC termination. Nevertheless, any termination may be used and remain within the scope of the disclosure.

The first seal region **430**, in at least one embodiment, includes a gauge sensor angled surface **435**. As discussed above, the gauge sensor angled surface **435** is configured to couple with a gauge mandrel angled surface (e.g., gauge mandrel angled surface **265**) of the gauge mandrel that the gauge sensor is configured to insert within. In at least one embodiment, the gauge sensor angled surface **435** couples with the gauge mandrel angled surface to form a metal to metal seal. The gauge sensor angled surface **435** additionally provides a face **438** that a gland (not shown) may be torqued against to energize the metal to metal seal.

The second seal region **450**, in at least one embodiment, includes one or more seal grooves **455**. The one or more seal grooves **455**, which in the embodiment shown in FIG. **4**A are a pair of seal grooves **455**, are configured to engage with and position one or more seals (e.g., one or more O-ring seals). Accordingly, the one or more seal grooves **455** may hold the one or more seals in place as the gauge sensor **400**A is being positioned within a gauge cavity of an associated gauge mandrel. In this embodiment, the one or more seals would engage with the gauge cavity in the gauge mandrel to provide another seal (e.g., secondary seal). The second seal region **450** enables pressure testing of the assembled tool in the field. In this illustration the seal grooves are O-ring seal grooves, however this can be updated as required for higher temperature rated seals if a secondary seal is required. In at least one embodiment, a spacing (s) between the first seal region **430** and the second seal region **450** ranges from 6 cm to 20 cm. In yet another embodiment, the spacing (s) between the first seal region **430** and the second seal region **450** ranges from 8 cm to 10 cm.

The sensor region **470**, in at least one embodiment, is a temperature sensor region including one or more temperature sensors **472**. For example, the sensor region **470** could align with the one or more fluid passageways in the gauge mandrel between the tubular and the gauge cavity to measure the temperature of the fluid travelling through the primary fluid passageway of the tubular. Again, in at least one embodiment, the sensor region **470** is spaced apart from the first seal region **430**, such that the coupling of the gauge sensor **400** within the gauge mandrel does not impact the accuracy of the gauge sensor **400**A. The sensor region **470**, in at least one embodiment, may additionally include a first pressure sensor **473**. For example, the first pressure sensor **473**, depending on the configuration, could be used to measure a pressure of the fluid in the annulus surrounding the gauge mandrel or alternatively used to measure a pressure of the fluid within the gauge mandrel.

The pressure nipple region **480**, in at least one embodiment, may be used to help measure the pressure within the annulus surrounding the gauge mandrel or alternatively the pressure of the fluid within the tubular of the gauge mandrel, or in certain embodiments a combination of the two. In the illustrated embodiment of FIG. **4**A, the pressure nipple region **480** further includes a pressure nipple **490** having a length (L_p), as well as a hollow section **492**. In at least one embodiment, the length (L_p) is at least 7 cm. In at least one other embodiment, the length (L_p) is at least 40 cm. Further, the length (L_p) may range from 17 cm to 25 cm. In the illustrated embodiment of FIG. **4**A, the hollow section **492** is open at its end (e.g., not capped). Accordingly, in the embodiment of FIG. **4**A the first pressure sensor **473** and the hollow section **492** may be used to measure a pressure in the annulus surrounding the gauge mandrel (not shown). As shown in FIG. **4**, the coupling of the seal region (e.g., first seal region **430** or second seal region **450**) to the tubing encapsulated conductor (TEC) termination region **410**, the sensor region **470** to the seal region (e.g., first seal region **430** or second seal region **450**), and the pressure nipple region **480** to the sensor region **470** forms a single coupled together gauge sensor unit, the single coupled together gauge sensor unit configured to be insert within a gauge mandrel from a single direction.

Turning to FIG. **4**B, illustrated is one embodiment of a gauge sensor **400**B designed, manufactured and/or operated according to one or more alternative embodiments of the disclosure. The gauge sensor **400**B of FIG. **4**B is similar in many respects to the gauge sensor **400**A of FIG. **4**A. Accordingly, like reference numbers have been used to indicate similar, if not identical, features. The gauge sensor **400**B differs, for the most part, from the gauge sensor **400**A, in that the gauge sensor **400**B is not open at its end (e.g., it is capped), but further includes one or more sidewall perforations **494** extending into the hollow section **492** proximate the tip of the pressure nipple **490**. So long as the one or more sidewall perforations **494** are exposed to the annulus, the pressure sensor **473**, the hollow section **492** and the one or more sidewall perforations **494** may be used to measure a pressure in the annulus surrounding the gauge mandrel (not shown). The use of the one or more sidewall perforations **494**, as opposed to the use of the open end as shown in FIG. **4**A, may be beneficial in preventing unwanted debris from entering the gauge sensor **400**B, while still allowing the annulus pressure to be measured.

Turning to FIG. **4**C, illustrated is one embodiment of a gauge sensor **400**C designed, manufactured and/or operated according to one or more alternative embodiments of the disclosure. The gauge sensor **400**C of FIG. **4**C is similar in many respects to the gauge sensor **400**A of FIG. **4**A. Accordingly, like reference numbers have been used to indicate similar, if not identical, features. The gauge sensor **400**C differs, for the most part, from the gauge sensor **400**A, in that the gauge sensor **400**C is configured to measure a pressure of the fluid within the tubular of the gauge mandrel. For example, in FIG. **4**C, the hollow section **492** is capped at its end, but further includes one or more sidewall perforations **496** extending into the hollow section **492** proximate where the pressure nipple region **480** couples to the sensor region **470**. In yet another embodiment, the one or more sidewall perforations **496** extend into the hollow section **492** substantially proximate where the pressure nipple region **480** couples to the sensor region **470**. The term proximate, as used with regard to the placement of the one or more sidewall perforations **496**, means within the first 20 percent of the pressure nipple **490**. The term substantially proximate, as used with regard to the placement of the one or more sidewall perforations **496**, means within the first 10 percent of the pressure nipple **490**. Thus, in the embodiment of FIG. **4**C, the same first pressure sensor **473** may be used to measure the pressure of the fluid within the tubular of the gauge mandrel.

Turning to FIG. **4**D, illustrated is one embodiment of a gauge sensor **400**D designed, manufactured and/or operated according to one or more alternative embodiments of the disclosure. The gauge sensor **400**D of FIG. **4**D is similar in many respects to the gauge sensor **400**A of FIG. **4**A. Accordingly, like reference numbers have been used to indicate similar, if not identical, features. The gauge sensor **400**D differs, for the most part, from the gauge sensor **400**A, in that the gauge sensor **400**D is also configured to measure a pressure of the fluid within the tubular of the gauge mandrel. Thus, in the embodiment of FIG. **4**D, the gauge sensor **400**D includes a second pressure sensor **474** within the sensor region **470**, a second hollow section **476** within the sensor region **470**, as well as one or more sidewall perforations **478** extending into the second hollow section **476**. Accordingly, in the embodiment of FIG. **4**D the second pressure sensor **474**, the hollow section **476**, and the one or more sidewall perforations **478** may also be used to measure a pressure in the gauge mandrel (not shown). While not shown, the second pressure sensor **474**, the hollow section **476**, and the one or more sidewall perforations **478** could be also be used with the embodiment of FIG. **4**B. Similarly, a gauge sensor could be designed that included the second pressure sensor **474**, the hollow section **476**, and the one or more sidewall perforations **478** of FIG. **4**D, but did not include the pressure nipple region **480**. In such an embodiment, the gauge sensor would only measure the fluid temperature and pressure within the gauge mandrel, and would not measure either of the temperature or pressure in the fluid in the annulus. Such an embodiment is illustrated in FIG. **4**E.

Turning to FIG. **5**A, illustrated is a cross-sectional view of a sensing system **500** (e.g., installed sensing system) according to any of the embodiments, aspects, applications, variations, designs, etc. disclosed herein. In at least one embodiment, the sensing system **500** is located in a wellbore and fluidly coupled to production tubing proximate a submersible pump. In yet another embodiment, the sensing system **500** is located in a wellbore and fluidly coupled to production tubing substantially proximate a submersible pump. The term proximate, as used with regard to the placement of the sensing system **500** relative to the submersible pump, means the sensing system **500** is positioned within 20 meters of the submersible pump. The term proximate, as used with regard to the placement of the sensing system **500** relative to the submersible pump, means the sensing system **500** is positioned within 4 meters of the submersible pump.

The sensing system **500** of the embodiment of FIG. **5**A includes a gauge mandrel **510** having a primary fluid passageway **515**, the gauge mandrel **510** being coupled to tubing **590** (e.g., production tubing). The sensing system **500** of the embodiment of FIG. **5**A additionally includes a gauge sensor **540** located within a gauge cavity **520** in a sidewall thickness (t) of the gauge mandrel **510**. In the illustrated embodiment, the gauge mandrel **510** has an upset section, such that the primary fluid passageway **515** within the gauge mandrel **510** is not concentric with an exterior of the gauge mandrel **510** in the upset section. In accordance with this embodiment, a sidewall thickness (t_u) of the upset section is greater than a sidewall thickness (t_r) of the remainder of the gauge mandrel **510**. In at least one embodiment, the gauge cavity **520** is located within the greater sidewall thickness (t_u) of the upset section. In yet another embodiment, the primary fluid passageway **515** and an exterior of the gauge mandrel **510** are concentric with one another, and thus the gauge cavity **520** may be located anywhere in the sidewall thickness (t).

The sensing system **500** of the embodiment of FIG. **5**A may additionally include a first pressure fitting **560** sealing one end of the gauge sensor **540** within the gauge cavity **520** (e.g., an uphole pressure fitting such as the illustrated seal gland) and a second pressure fitting **565** sealing an opposing end of the gauge sensor **540** within the gauge cavity **520** (e.g., a pressure nipple pressure fitting as illustrated in FIG. **5**A). A secondary purpose of the second pressure fitting **565** is to secure the gauge sensor **540** and minimize the potential for damage due to vibration. The seal arrangement (e.g., first pressure fitting **560** and second pressure fitting **565**) does not place the gauge sensor **540** under compressive or tensile loading to eliminate the potential for these loads to distort the internal features of the gauge sensor **540**, which could compromise the measurement accuracy. The sensing system **500** of the embodiment of FIG. **5**A may further include a conductor **530** coupled with the gauge sensor **540**. In at least one embodiment, the conductor **530** is a TEC.

Turning to FIG. **5**B, illustrated is a zoomed in cross-sectional view of the sensing system **500** (e.g., installed sensing system) of FIG. **5**A according to any of the embodiments, aspects, applications, variations, designs, etc. disclosed herein. As is evident in the embodiment of FIG. **5**B, the gauge mandrel **510** may include one or more fluid passageways **525** between the primary fluid passageway **515** and the gauge cavity **520**. As is evident in the embodiment of FIG. **5**B, the gauge mandrel **510** may additionally include a gauge mandrel angled surface **530**.

With continued reference to FIG. **5**B, the gauge sensor **540** may include a gauge angled surface **545** that couples with the gauge mandrel angled surface **530** of the gauge mandrel **510**, thereby forming a metal to metal seal. As is further evident in the embodiment of FIG. **5**B, the gauge sensor **540** may include one or more seal grooves **550** and one or more seals **555**, the one or more seal grooves **550** and one or more seals **555** providing a secondary seal for the metal to metal seal. The one or more seal grooves **550** and the one or more seals **555** may additionally create a chamber with the metal to metal seal created with the gauge angled surface **545** and the gauge mandrel angled surface **530** to test the metal to metal seal.

Turning briefly to FIG. **5**C, illustrated is a zoomed in top view of the sensing system **500** (e.g., installed sensing system) of FIG. **5**B according to any of the embodiments, aspects, applications, variations, designs, etc. disclosed herein. As is illustrated in FIG. **5**C, the gauge mandrel **510** may additionally include a pressure test port **535**. The pressure test port **535** enables pressure testing in the field without the requirement to pressurize the ID of the gauge mandrel **510**. In the embodiment of FIG. **5**C, there is an undercut **537** where the pressure test port **535** enters into the gauge cavity **520** to prevent any secondary seals from getting damaged as they are pushed past the pressure test port **535** during installation. Also, a second pressure test port could be located in the downhole seal profile, if it were desirable to test this seal or set of seals as well.

Turning to FIG. **5**D, illustrated is a further zoomed in cross-sectional view of the sensing system **500** (e.g., installed sensing system) of FIG. **5**B according to any of the embodiments, aspects, applications, variations, designs, etc. disclosed herein. FIG. **5**D illustrates an insertion end of the sensing system **500** (e.g., installed sensing system). In the illustrated embodiment, the insertion end includes a primary seal (e.g., metal to metal seal created by the gauge mandrel angled surface **530** and the gauge sensor angled surface **545**) and a secondary seal (e.g., created with the seal groove **550** and the one or more seals **555** sealing against the gauge cavity **520**). In at least one embodiment, the pressure test port **535** (not shown in this view) may be placed between the primary seal and the secondary seal for testing the sensing system **500**. Thus, FIG. **5**D illustrates details of the insertion end seals between the Datasphere® ERD™ Gauge and the Datasphere® ERD™ Gauge Mandrel. The gauge mandrel **510** and gauge sensor **540** include at least two novel features. The first feature is the increased OD for the primary seal (e.g., metal to metal seal) which also serves as the face the gland is torqued against to energize the primary seal (e.g., metal to metal seal). The second feature is the one or more seal grooves **550** for the installation of the secondary seals (e.g., seals **555**). This enables the primary seal (e.g., metal to metal seal) to be pressure tested through the pressure test port **535** in the gauge mandrel **510**. The secondary seals (e.g., O-rings), and one or more seal grooves **550**, can be replaced with high temperature seals to function as a secondary seal between the tubing ID and the annulus.

Turning to FIG. **5**E, illustrated is a further zoomed in cross-sectional view of the sensing system **500** (e.g., installed sensing system) of FIG. **5**B according to any of the embodiments, aspects, applications, variations, designs, etc. disclosed herein. FIG. **5**E illustrates an exit end of the sensing system **500** (e.g., installed sensing system). In the illustrated embodiment, the exit end also includes a primary seal (e.g., metal to metal seal between the gauge mandrel **510** and the second pressure fitting **565**) and a secondary seal (e.g., O-ring seals). In at least one embodiment, a second pressure test port **570** may be placed between the primary seal and the secondary seal for testing the sensing system. In the embodiment of FIG. **5**E, a ½" pressure testable fitting assembly is installed, and the ½" FMJ fitting has redundant metal to metal seals and is pressure testable in the field. FIG. **5**E illustrates that the pressure nipple region of the gauge sensor **540** is hollow, thereby enabling the pressure measurement of the annulus surrounding the gauge mandrel **510**. In an alternative embodiment, as discussed above, the pressure nipple region may be capped, thus allowing the gauge sensor **540** to measure the pressure in the primary fluid passageway.

FIGS. **6**A to **6**D illustrates yet another design of a sensing system **600** designed, manufactured and operated according to one or more embodiments of the disclosure. The sensing system **600** may include casing joint **605**, a gauge mandrel **610**, a gauge sensor **620**, and a coupling **630**. The sensing system **600** may additionally include a TEC **640**, a TEC cable head clamp **650**, and in certain embodiments an external pressure port **660**. In the embodiment of FIGS. **6**A to **6**D, a pocket may be machined in the gauge mandrel **610**, as shown. Further to the embodiment of FIGS. **6**A to **6**D, both the temperature and the pressure sensors are within the pocket. Nevertheless, the pressure may be ported to read external pressure. In at least one embodiment, the temperature sensor measures the temperature of the fluid within the casing joint, and thus one or more fluid passageways are formed in the gauge mandrel **610**. In at least one embodiment, a seal is created, which is preferably a metal to metal seal, on the housing of the gauge sensor **620** below the TEC cable head clamp **650**. Further to the embodiment of FIGS. **6**A to **6**D, the sensing system **600** may be run decentralized, as it may be one full joint above the ESP.

Alternative embodiments, certain of which are not illustrated, are within the scope of the present disclosure. For example, the following alternative embodiments may be used: Datasphere® Opsis™ Gauge and Gauge Mandrel instead of Datasphere® ERD™ Gauge and Gauge Mandrel; Pressure nipple can have a capped end with perforations to monitor tubing pressure if required; exit end of the mandrel, including the upset, can be lengthened to better protect the fitting assembly; Gauge cavity can be deeper to allow more of the gauge to be installed inside the mandrel. This could better protect the cable termination however it might require additional design modification; Further modifications could enable the use of multi-drop gauges on the same TEC. In this case the TEC to downhole gauges would exit the mandrel instead of the gauge pressure nipple. The easiest application would be for a gauge to monitor tubing pressure. With some additional design work the TEC could exit the gauge from inside the pressure nipple to enable monitoring annulus pressure.

In certain instances, there may be a concern that the temperature sensor will not read the actual fluid temp. For example, there may be a concern that the mass of the gauge mandrel may dampen the fluid temperature response. To address this concern, in at least one or more embodiments, the following changes may be made: 1) Replace the (e.g., vertical) fluid ports spanning between the tubing ID and the gauge cavity with one or more longer slots. 2) Replace the (e.g., vertical) fluid ports spanning between the tubing ID and the gauge cavity with one or more angled fluid ports. 3) Increase the OD, or the ID of the gauge cavity, such that the fluid flows around an entirety of the gauge sensor. 4) Apply insulating coating or "VIT sleeve" around gauge mandrel to minimize the cooling effect of annulus fluid. 5) Place the gauge cavity off center of the tubing sidewall thickness, with the thicker portion closest to the gauge mandrel ID and the thinner portion closest to the tubing ID, thereby providing greater insulation. 6) Trapezoidal gauge cavity for gauge sensor to orient gauge sensor properly. 7) Offset nose to properly align the gauge sensor. Offset nose can also enable the gauge sensor to be installed closer to the tubing ID. 8) Gauge cavity is installed at an angle (e.g., angled toward the tubing ID from the insertion end) to get the gauge sensor closer to the tubing ID. For example, it could be completely across the gauge mandrel. 9) Install gauge sensor in the tubing, for example similar to a pitot tube. 10) Redesign the gauge mandrel with a Bernoulli Tube feature that helps "pump" the fluid around the gauge sensor.

In yet other embodiments, the metal to metal seal design on the top may be changed to use a Ferrule. Also, the pressure testable fitting assembly may be replaced with a seal that can be removed as needed. For example, graphoil packing and annealed copper, compressed with a gland nut, could be used. In another embodiment, the design may allow movement of the gauge sensor relative to the gauge mandrel to accommodate thermal expansion differences. Also, an O-ring or seal stack could be used. Also, the pressure testable fitting assembly could be eliminated downhole, and then the bottom of the gauge sensor could be converted to a 37 degree flare, and thus the gland drives the gauge sensor into the gauge mandrel for sealing. In another embodiment, one could remove the pressure testable fitting assembly from the end, thread nipple, and the nut pulls gauge into the seal. Also, one could redesign the bottom end of the gauge to have a metal to metal seal design.

In another embodiment, the gauge could be installed from inside of the tubing. In yet another embodiment, a longer gauge cavity could be used, and thus the gauge sensor could be installed from the downhole side, pushed out uphole to connect the wire (e.g., TEC), pulled back in and then the fittings made up.

Aspects disclosed herein include:

A. A gauge mandrel for use with a gauge sensor, the gauge mandrel including: 1) a tubular having a length (L_t), an internal diameter (D_i) and a width (W), the internal diameter (D_i) and the width (W) defining a sidewall thickness (t), the tubular defining a primary fluid passageway; and 2) a gauge cavity extending along at least a portion of the length (L_t) of the tubular and located entirely within the sidewall thickness (t), the gauge cavity having an insertion end configured to accept a gauge sensor.

B. A sensing system, the sensing system including: 1) tubing; 2) a gauge mandrel coupled to the tubing, the gauge mandrel including: a) a tubular having a length (L_t), an internal diameter (D_i) and a width (W), the internal diameter (D_i) and the width (W) defining a sidewall thickness (t), the tubular defining a primary fluid passageway; and b) a gauge cavity extending along at least a portion of the length (L_t) of the tubular and located entirely within the sidewall thickness (t), the gauge cavity having an insertion end; and 3) a gauge sensor positioned at least partially within the gauge cavity, the gauge sensor configured to measure temperatures or pressures within the gauge mandrel or outside of the gauge mandrel.

C. A well system, the well system including: 1) a wellbore located in a subterranean formation; 2) production tubing located in the wellbore; 3) a submersible pump located in the wellbore and fluidly coupled to the production tubing; and 4) a sensing system located in the wellbore and fluidly coupled to the production tubing proximate the submersible pump, the sensing system including: a) a gauge mandrel, the gauge mandrel including: i) a tubular having a length (L_t), an internal diameter (D_i) and a width (W), the internal diameter (D_i) and the width (W) defining a sidewall thickness (t), the tubular defining a primary fluid passageway; and ii) a gauge cavity extending along at least a portion of the length (L_t) of the tubular and located entirely within the sidewall thickness (t), the gauge cavity having an insertion end; and b) a gauge sensor positioned at least partially within the gauge cavity, the gauge sensor configured to measure temperatures or pressures within the gauge mandrel or outside of the gauge mandrel.

D. A gauge sensor for use with a gauge mandrel, the gauge sensor including: 1) a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination; 2) a seal region coupled to the TEC region, the seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of a gauge cavity that the gauge sensor is configured to insert within; 3) a sensor region coupled to the seal region, the sensor region including one or more temperature sensors; and 4) a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p).

E. A sensing system, the sensing system including: 1) tubing; 2) a gauge mandrel coupled to the tubing, the gauge mandrel having a gauge cavity with an insertion end; and 3) a gauge sensor positioned within the gauge cavity of the gauge mandrel, the gauge sensor including: a) a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination; b) a seal region coupled to the TEC region, the seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of the gauge cavity; c) a sensor region coupled to the seal region, the sensor region including one or more temperature sensors; and d) a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p).

F. A well system, the well system including: 1) a wellbore located in a subterranean formation; 2) production tubing located in the wellbore; 3) a submersible pump located in the wellbore and fluidly coupled to the production tubing; and 4) a sensing system located in the wellbore and fluidly coupled to the production tubing proximate the submersible pump, the sensing system including: a) a gauge mandrel, the gauge mandrel having a gauge cavity with an insertion end; and b) a gauge sensor positioned within the gauge cavity of the gauge mandrel, the gauge sensor including: i) a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination; ii) a seal region coupled to the TEC region, the seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of the gauge cavity; iii) a sensor region coupled to the seal region, the sensor region including one or more temperature sensors; and iv) a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p).

Aspects A, B, C, D, E and F may have one or more of the following additional elements in combination: Element 1: wherein the gauge cavity has an exit end exiting the sidewall thickness (t) opposite the insertion end, the exit end operable to allow a pressure nipple of the gauge sensor to extend through the insertion end and exit the gauge cavity. Element 2: further including one or more fluid passageways coupling the tubular and the gauge cavity. Element 3: wherein the one or more fluid passageways are a plurality of fluid ports coupling the tubular and the gauge cavity. Element 4: wherein the one or more fluid passageways are a single fluid slot coupling the tubular and the gauge cavity. Element 5: wherein the one or more fluid passageways couple the tubular and the gauge cavity through the sidewall thickness (t). Element 6: further including a gauge mandrel angled surface proximate the insertion end, the gauge mandrel angled surface configured to engage with a gauge sensor angled surface to form a metal to metal seal as the gauge sensor extends through the insertion end of the gauge cavity. Element 7: further including a pressure test port coupling an exterior of the gauge mandrel with the gauge cavity. Element 8: wherein the tubular includes an upset section such that the primary fluid passageway is not concentric with an exterior of the gauge mandrel. Element 9: wherein the gauge cavity is located within the upset section. Element 10: wherein the upset section forms a clearance for a gauge sensor pressure fitting. Element 11: wherein the gauge cavity has an exit end exiting the sidewall thickness (t) opposite the insertion end, and further wherein a pressure nipple of the gauge sensor extends through the insertion end and exits the exit end of the gauge cavity. Element 12: further including a pressure fitting at least partially entering the exit end of the gauge cavity and at least partially surrounding the pressure nipple of the gauge sensor. Element 13: further including a gauge mandrel angled surface proximate the insertion end, the gauge mandrel angled surface configured to engage with a gauge sensor angled surface of the gauge sensor forming a metal to metal seal. Element 14: wherein the seal region is a first seal region, and further including a second seal region positioned between the first seal region and the sensor region. Element 15: wherein the second seal region includes a one or more seal grooves. Element 16: wherein a spacing (s) between the first seal region and the second seal region ranges from 6 cm to 20 cm. Element 17: wherein a spacing (s) between the first seal region and the second seal region ranges from 8 cm to 10 cm. Element 18: wherein the pressure nipple has a hollow section that is open at its end. Element 19: wherein the pressure nipple has a hollow section that is capped at its end, and further includes one or more sidewall perforations extending into the hollow section proximate where the pressure nipple region couples to the sensor region. Element 20: wherein the length (L_p) is at least 7 cm. Element 21: wherein the length (L_p) is at least 40 cm. Element 22: wherein the length (L_p) ranges from 17 cm to 25 cm. Element 23: wherein the gauge cavity has an exit end opposite the insertion end, and further wherein the pressure nipple of the gauge sensor extends through the insertion end and exits the exit end of the gauge cavity. Element 24: further including a pressure fitting at least partially entering the exit end of the gauge cavity and at least partially surrounding the pressure nipple of the gauge sensor. Element 25: wherein the seal region is a first seal region, and further including a second seal region including one or more seal grooves positioned between the first seal region and the sensor region. Element 26: wherein the gauge mandrel includes a pressure test port coupling an exterior of the gauge mandrel with the gauge cavity, the gauge sensor positioned such that the pressure test port is located between the first seal region and the second seal region. Element 27: wherein a spacing (s) between the first seal region and the second seal region ranges from 6 cm to 20 cm. Element 28: wherein the pressure nipple has a hollow section that is open at its end for testing a pressure outside of the gauge mandrel. Element 29: wherein the pressure nipple has a hollow section that is capped at its end, and further includes one or more sidewall perforations extending into the hollow section and in fluid communication with the gauge cavity for testing a pressure of fluid within the gauge cavity.

Those skilled in the art to which this application relates will appreciate that other and further additions, deletions, substitutions and modifications may be made to the described embodiments.

What is claimed is:

1. A gauge sensor for use with a gauge mandrel, comprising:

- a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination;
- a first seal region coupled to the TEC region, the first seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of a gauge cavity that the gauge sensor is configured to insert within;
- a sensor region coupled to the first seal region, the sensor region including one or more temperature sensors;
- a second seal region positioned between the first seal region and the sensor region, the second seal region including a one or more seal grooves; and
- a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p), the coupling of the first seal region to the tubing encapsulated conductor (TEC) termination region, the sensor region to the first seal region, and the pressure nipple region to the sensor region forming a single coupled together gauge sensor unit.

2. The gauge sensor as recited in claim **1**, wherein a spacing(s) between the first seal region and the second seal region ranges from 6 cm to 20 cm.

3. The gauge sensor as recited in claim **1**, wherein a spacing(s) between the first seal region and the second seal region ranges from 8 cm to 10 cm.

4. The gauge sensor as recited in claim **1**, wherein the pressure nipple has a hollow section that is open at its end.

5. The gauge sensor as recited in claim **1**, wherein the pressure nipple has a hollow section that is capped at its end, and further includes one or more sidewall perforations extending into the hollow section proximate where the pressure nipple region couples to the sensor region.

6. The gauge sensor as recited in claim **1**, wherein the length (L_p) is at least 7 cm.

7. The gauge sensor as recited in claim **1**, wherein the length (L_p) is at least 40 cm.

8. The gauge sensor as recited in claim **1**, wherein the length (L_p) ranges from 17 cm to 25 cm.

9. A sensing system, comprising:

- tubing;
- a gauge mandrel coupled to the tubing, the gauge mandrel having a gauge cavity with an insertion end; and
- a gauge sensor positioned within the gauge cavity of the gauge mandrel, the gauge sensor including:
  - a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination;
  - a first seal region coupled to the TEC region, the first seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of the gauge cavity;
  - a sensor region coupled to the first seal region, the sensor region including one or more temperature sensors;
  - a second seal region positioned between the first seal region and the sensor region, the second seal region including a one or more seal grooves; and
  - a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p), the coupling of the first seal region to the tubing encapsulated conductor (TEC) termination region, the sensor region to the

first seal region, and the pressure nipple region to the sensor region forming a single coupled together gauge sensor unit.

10. The sensing system as recited in claim **9**, wherein the gauge cavity has an exit end opposite the insertion end, and further wherein the pressure nipple of the gauge sensor extends through the insertion end and exits the exit end of the gauge cavity.

11. The sensing system as recited in claim **10**, further including a pressure fitting at least partially entering the exit end of the gauge cavity and at least partially surrounding the pressure nipple of the gauge sensor.

12. The sensing system as recited in claim **9**, wherein the gauge mandrel includes a pressure test port coupling an exterior of the gauge mandrel with the gauge cavity, the gauge sensor positioned such that the pressure test port is located between the first seal region and the second seal region.

13. The sensing system as recited in claim **9**, wherein a spacing(s) between the first seal region and the second seal region ranges from 6 cm to 20 cm.

14. The sensing system as recited in claim **9**, wherein the pressure nipple has a hollow section that is open at its end for testing a pressure outside of the gauge mandrel.

15. The sensing system as recited in claim **9**, wherein the pressure nipple has a hollow section that is capped at its end, and further includes one or more sidewall perforations extending into the hollow section and in fluid communication with the gauge cavity for testing a pressure of fluid within the gauge cavity.

16. The sensing system as recited in claim **9**, wherein the length (L_p) is at least 7 cm.

17. A well system, comprising:

a wellbore located in a subterranean formation;

production tubing located in the wellbore;

a submersible pump located in the wellbore and fluidly coupled to the production tubing; and

a sensing system located in the wellbore and fluidly coupled to the production tubing proximate the submersible pump, the sensing system including:

a gauge mandrel, the gauge mandrel having a gauge cavity with an insertion end; and

a gauge sensor positioned within the gauge cavity of the gauge mandrel, the gauge sensor including:

a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination;

a first seal region coupled to the TEC region, the first seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of the gauge cavity;

a sensor region coupled to the first seal region, the sensor region including one or more temperature sensors;

a second seal region positioned between the first seal region and the sensor region, the second seal region including a one or more seal grooves; and

a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p), the coupling of the first seal region to the tubing encapsulated conductor (TEC) termination region, the sensor region to the first seal region, and the pressure nipple region to the sensor region forming a single coupled together gauge sensor unit.

18. A gauge sensor for use with a gauge mandrel, comprising:

a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination;

a seal region coupled to the TEC region, the seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of a gauge cavity that the gauge sensor is configured to insert within;

a sensor region coupled to the seal region, the sensor region including one or more temperature sensors; and

a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p), the coupling of the seal region to the tubing encapsulated conductor (TEC) termination region, the sensor region to the seal region, and the pressure nipple region to the sensor region forming a single coupled together gauge sensor unit, wherein the pressure nipple has a hollow section that is open at its end.

19. A gauge sensor for use with a gauge mandrel, comprising:

a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination;

a seal region coupled to the TEC region, the seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of a gauge cavity that the gauge sensor is configured to insert within;

a sensor region coupled to the seal region, the sensor region including one or more temperature sensors; and

a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p), the coupling of the seal region to the tubing encapsulated conductor (TEC) termination region, the sensor region to the seal region, and the pressure nipple region to the sensor region forming a single coupled together gauge sensor unit, wherein the pressure nipple has a hollow section that is capped at its end, and further includes one or more sidewall perforations extending into the hollow section proximate where the pressure nipple region couples to the sensor region.

20. A sensing system, comprising:

tubing;

a gauge mandrel coupled to the tubing, the gauge mandrel having a gauge cavity with an insertion end; and

a gauge sensor positioned within the gauge cavity of the gauge mandrel, the gauge sensor including:

a tubing encapsulated conductor (TEC) termination region, the TEC region including a TEC termination;

a seal region coupled to the TEC region, the seal region including a gauge sensor angled surface configured to couple with a gauge mandrel angled surface of the gauge cavity;

a sensor region coupled to the seal region, the sensor region including one or more temperature sensors; and

a pressure nipple region coupled to the sensor region, the pressure nipple region including a pressure nipple having a length (L_p), the coupling of the seal region to the tubing encapsulated conductor (TEC) termination region, the sensor region to the seal region, and the pressure nipple region to the sensor region forming a single coupled together gauge sensor unit, wherein the gauge cavity has an exit end opposite the insertion end, and further wherein the pressure nipple of the gauge sensor extends through the insertion end and exits the exit end of the gauge cavity, and further including a pressure fitting at least partially entering the exit end of the gauge cavity and at least partially surrounding the pressure nipple of the gauge sensor.

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