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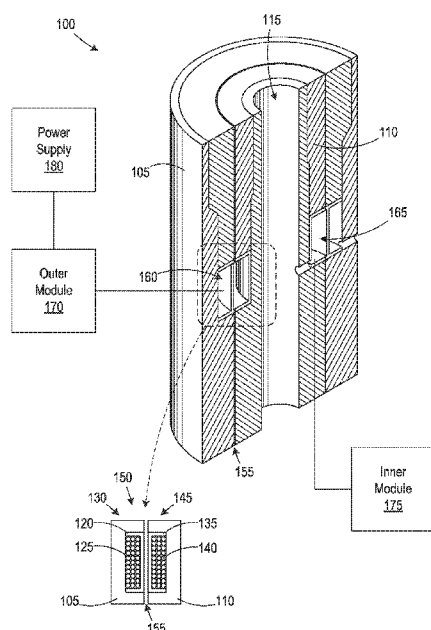


Figure 1

(57) Abstract: An apparatus includes a first housing 105 including a first magnetic core 120 extending about an inner perimeter of the first housing 105 and a first coil 125 disposed on the first magnetic core 125 to define a primary coil of a first perimetric transformer. A second housing 110 interfaces with the first housing 105 and includes a second magnetic core 135 disposed proximate the first magnetic core 120 and extending about an exterior perimeter of the second housing 110 and a second coil 140 disposed on the second magnetic core 135 to define a secondary coil of the first perimetric transformer.



INDUCTIVE WELLHEAD CONNECTOR

BACKGROUND

The disclosed subject matter relates generally to subsea hydrocarbon
5 production and, more particularly, to an inductive wellhead connector.

To monitor or control a subsea well, a connection is established between the well and a monitoring and control station. The monitoring and control station may be located on or near the wellhead, a platform or floating vessel near the subsea installation, or alternatively, in a more remote land station. The connection between
10 the control station and the subsea installation is usually established by installing an umbilical between the two points. The umbilical may include hydraulic lines for supplying hydraulic fluid to various hydraulic actuators located on or near the well. The umbilical may also include electrical and or fiber optic lines for supplying electric power and also for communicating control signals and/or well data between the
15 control station and the various monitoring and control devices located on or near the well. Alternatively, an underwater telemetry system may be employed to facilitate long-distance communications without umbilical or wire. Hybrid systems employing acoustics, radio-frequency, optical, or magnetic communications outside the well may also be used for this purpose.

Hydrocarbon production from the subsea well is controlled by a number of
20 valves that are assembled into a unitary structure generally referred to as a well tree or Christmas tree. Well tree and wellhead systems have the principle functions of providing an interface to the in-well environment, allowing flow regulation and measurement, and permitting intervention on the well or downhole systems during
25 the operational life of the well.

In addition to the flow control valves and actuators, a number of sensors and detectors are commonly employed in subsea systems to monitor the state of the system and the flow of hydrocarbons from the well. In some instances sensors, detectors, and/or actuators may be located within the wellhead or further downhole.
30 Such devices may be controlled and/or monitored by a dedicated control system, which is usually housed in the remote control module. Control signals and well data are also exchanged through the umbilical or telemetry system.

Providing downhole modules, such as sensors or controllers, is difficult. Downhole components are exposed to process fluid pressure environments. To facilitate power and data connections, penetrations need to be provided through the pressure boundary. Components must be perfectly aligned during installation to allow the appropriate connectors to align and mate. Such alignment and mating is difficult in subsea environments. In addition, the penetration provides an additional failure point that could give rise to a pressure boundary breach. Some industry regulations do not allow physical penetrations within the wellhead for this reason. These cost and physical limitations greatly restrict the use of directly connected modules on subsea hydrocarbon installations.

This section of this document is intended to introduce various aspects of art that may be related to various aspects of the disclosed subject matter described and/or claimed below. This section provides background information to facilitate a better understanding of the various aspects of the disclosed subject matter. It should be understood that the statements in this section of this document are to be read in this light, and not as admissions of prior art. The disclosed subject matter is directed to overcoming, or at least reducing the effects of, one or more of the problems set forth above.

SUMMARY

The following presents a simplified summary of the disclosed subject matter in order to provide a basic understanding of some aspects of the disclosed subject matter. This summary is not an exhaustive overview of the disclosed subject matter. It is not intended to identify key or critical elements of the disclosed subject matter or to delineate the scope of the disclosed subject matter. Its sole purpose is to present some concepts in a simplified form as a prelude to the more detailed description that is discussed later.

One aspect of the disclosed subject matter is seen in an apparatus including a first housing including a first magnetic core extending about an inner perimeter of the first housing and a first coil disposed on the first magnetic core to define a primary coil of a first perimetric transformer. A second housing interfaces with the first housing and includes a second magnetic core disposed proximate the first magnetic core and extending about an exterior perimeter of the second housing and a second

coil disposed on the second magnetic coil to define a secondary coil of the first perimetric transformer.

Another aspect of the disclosed subject matter is seen in a method including providing a first housing including a first magnetic core extending about an inner perimeter of the first housing and a first coil disposed on the first magnetic core to define a primary coil of a first perimetric transformer. A second housing is interfaced with the first housing. The second housing includes a second magnetic core disposed proximate the first magnetic core and extending about an exterior perimeter of the second housing and a second coil disposed on the second magnetic coil to define a secondary coil of the first perimetric transformer. A first signal is provided on one of the primary and secondary coils. The first signal is received on the other of the primary and secondary coils.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed subject matter will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements, and:

Figure 1 is a simplified diagram of an apparatus including a perimetric transformer, according to some embodiments disclosed herein;

Figure 2 is a top view of a magnetic core illustrating an alternative winding arrangement, according to some embodiments disclosed herein;

Figure 3 is a diagram of an alternative embodiment of a perimetric transformer including a second coil defining an additional secondary winding, according to some embodiments disclosed herein; and

Figure 4 is a cross-section diagram of an illustrative wellhead assembly that may be provided with one or more perimetric transformers, according to some embodiments disclosed herein.

While the disclosed subject matter is susceptible to various modifications and alternative forms, specific embodiments thereof have been shown by way of example in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific embodiments is not intended to limit the disclosed subject matter to the particular forms disclosed, but on the contrary, the intention is to cover all modifications, equivalents, and alternatives falling within

the spirit and scope of the disclosed subject matter as defined by the appended claims.

DESCRIPTION OF EMBODIMENTS

One or more specific embodiments of the disclosed subject matter will be described below. It is specifically intended that the disclosed subject matter not be limited to the embodiments and illustrations contained herein, but include modified forms of those embodiments including portions of the embodiments and combinations of elements of different embodiments as come within the scope of the following claims. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure. Nothing in this application is considered critical or essential to the disclosed subject matter unless explicitly indicated as being "critical" or "essential."

The disclosed subject matter will now be described with reference to the attached figures. Various structures, systems and devices are schematically depicted in the drawings for purposes of explanation only and so as to not obscure the disclosed subject matter with details that are well known to those skilled in the art. Nevertheless, the attached drawings are included to describe and explain illustrative examples of the disclosed subject matter. The words and phrases used herein should be understood and interpreted to have a meaning consistent with the understanding of those words and phrases by those skilled in the relevant art. No special definition of a term or phrase, *i.e.*, a definition that is different from the ordinary and customary meaning as understood by those skilled in the art, is intended to be implied by consistent usage of the term or phrase herein. To the extent that a term or phrase is intended to have a special meaning, *i.e.*, a meaning other than that understood by skilled artisans, such a special definition will be

expressly set forth in the specification in a definitional manner that directly and unequivocally provides the special definition for the term or phrase.

Referring now to the drawings wherein like reference numbers correspond to similar components throughout the several views and, specifically, referring to Figure 1, the disclosed subject matter shall be described in the context of an assembly 100. Figure 1 illustrates a partial cross-section view of the assembly 100. The assembly 100 includes an outer housing 105 and an inner housing 110 that is received in an interior space defined by the outer housing 105. The inner housing 110 also defines an interior space 115 and provides a pressure boundary between the interior space 115 and the outer housing 105. Although the housings 105, 110 are illustrated as having generally circular cross-sections (e.g., pipes or tubing), in some embodiments, they may not be circular.

The outer housing 105 supports a perimetric magnetic core 120 and a coil 125, defining a primary coil 130. The inner housing 110 supports a perimetric magnetic core 135 and a coil 140, defining a secondary coil 145. In general, the magnetic core 120 extends around an interior perimeter of the housing 105, and the magnetic core 135 extends around an exterior perimeter of the housing 110. When the inner housing 110 engages the outer housing 105, the magnetic cores 120, 135 overlap regardless of the radial orientation of the inner housing 110 due to the perimetric nature of the cores 120, 135.

The primary and secondary coils 130, 145 define a perimetric transformer 150. The term "coil" is not intended to specify any particular type of construction. The coil may be wound wire, a laminated structure, *etc.* For ease of illustration, the coils 125, 140 are only shown in the exploded view in Figure 1. The coils 125, 140 may be encapsulated in a protective material, such as a resin material. In some embodiments an air gap 155 may be present between the outer housing 105 and the inner housing 110, and thus between the primary coil 130 and the secondary coil 145.

In some embodiments, the coils 125, 140 are also perimetric in that they are wound around the entire perimeter the respective magnetic cores 120, 135. The coils 125, 140 may be disposed in cavities 160, 165 defined in the respective housings 105, 110.

Figure 2 is a top view of a magnetic core 200 illustrating an alternative winding arrangement. For ease of illustration, the housings 105, 110 are omitted. In

the embodiment of Figure 2, a coil 205 may be wound in a direction parallel to the longitudinal axis of the respective core 200. The magnetic core 200 and coil 250 may represent either the primary or secondary coil. In such an embodiment, the primary and secondary coils need not be positioned directly opposite one another on
5 their respective magnetic cores.

Returning to Figure 1, the primary coil 130 is coupled to an outer module 170, and the secondary coil 145 is coupled to an inner module 175. The perimetric transformer 150 allows the outer module 170 to provide power and/or data signals to the inner module 175 without requiring any penetrations through the pressure
10 boundary defined between the outer and inner housings 105, 110. In some embodiments, the outer module 170 may be a controller, and the inner module 175 may be a sensor. The outer module 170 (controller) may apply a voltage on the primary coil 130, and the inner module 175 (sensor) may modulate a data signal indicating its output data on the secondary coil 145. For example, the inner module
15 175 (sensor) may measure a parameter associated with the interior space 115, such as a process fluid pressure, temperature, etc.

In another embodiment, both the outer module 170 and the inner module 175 may be controllers, where the outer module 170 provides power to the inner module 174 and they both communicate control signals.

A power supply 180 may be coupled to or integrated with the outer module 170. In some embodiments, the power supply 180 may be a battery located near the assembly 100. Because, the power supply 180 is external to the assembly, 100, it may be readily exchanged when the charge is depleted. Alternatively, the power supply 180 may be located remotely with respect to the assembly 100 and cabling
20 may connect the power supply 180 to the outer module 170. A similar wireless power interface using inner module 175 and outer module 170 may be used to provide wireless power outside of the pressure boundary.

Figure 3 is a diagram of an alternative embodiment of the perimetric transformer 150 including a second coil 200 defining an additional secondary winding 205. Of course, any number of secondary windings 145, 205 may be provided to allow the outer module 170 to provide power to or communicate with any
25 number of inner modules 175 (e.g., multiple sensors and/or controllers).

Figure 4 is a cross-section diagram of an illustrative wellhead assembly 400 (e.g., subsea) that may be provided with one or more perimetric transformers 150.

The construct and operation of the components in the wellhead assembly 400 are well known to those of ordinary skill in the art, so they are not described in detail herein. The wellhead assembly 400 includes a low pressure conductor housing 405 that interfaces with a high pressure wellhead housing 410 that defines a production path 415 into the well structure. A first position casing hanger 420, a second position casing hanger 425, and seal assemblies 430, 435 are provided in the production path 115. Perimetric transformers 450A-450I may be provided at various interfaces between the components of the wellhead assembly 400.

The transformer locations illustrated in Figure 4 are intended to be example locations. Not all of the transformers 450A-450I may be present and the particular locations may vary from those illustrated.

A perimetric transformer 450A may be located on a landing shoulder 440 defined in the low pressure conductor housing 405 that engages the high pressure wellhead housing 410.

A perimetric transformer 450B may be located on a centralizing region 445 defined in the low pressure conductor housing 405 that engages the high pressure wellhead housing 410.

A perimetric transformer 450C may be located between the high pressure wellhead housing 410 and the first position casing hanger 420. A perimetric transformer 450D may be located between the high pressure wellhead housing 410 and the second position casing hanger 425.

A perimetric transformer 450E may be located on a load shoulder region 455 between the first position casing hanger 420 and the second position casing hanger 425.

A perimetric transformer 450F may be located on an inner diameter of the second position casing hanger 425 between the high pressure wellhead housing 410 and the first position casing hanger 420. Only the primary coil of the perimetric transformer 450F is illustrated in Figure 4. The secondary coil is illustrated in phantom, as it would be located on a subsea running device that may be inserted into the production path 415 and supported by the second position casing hanger 425 for purposes of installing, operating, or intervening with the wellhead 400 (or tree, etc.). In this manner, power and communication signals can link with anything upstream or downstream of the well with complete connectivity. Running devices

may include temporary well caps, test tools, fishing tools, abandonment tools, feedthrough to downhole completion equipment, etc.

A perimetric transformer 450G may be located between the high pressure wellhead housing 410 and the seal assembly 435.

5 A perimetric transformer 450H may be located between the seal assembly 435 and the second position casing hanger 425.

A perimetric transformer 450I may be located on an inner diameter of the high pressure wellhead housing 410. Only the primary coil of the perimetric transformer 450I is illustrated in Figure 4. The secondary coil is illustrated in phantom, as it
10 would be located on a wellhead running tool (not shown) that may be inserted into the production path 415.

In some embodiments a production string may be inserted into the production path 415. A secondary coil of a perimetric transformer 150 may be provided on the final length of production tubing to interface with one of the primary coils of the
15 perimetric transformer 450I or the perimetric transformer 450F to allow monitoring of well parameters.

In some embodiments, the perimetric transformers 450A-450I may be interconnected through wired or wireless connections to bridge multiple pressure boundaries. For example, the secondary coil of the perimetric transformer 450A may
20 be coupled to the primary coil of the perimetric transformer 450D (as indicated by phantom lines). The secondary coil of the perimetric transformer 450B may be coupled to primary coil of the perimetric transformer 450C, and the secondary coil of the perimetric transformer 450C may be coupled to the primary coil of the perimetric transformer 450E (as indicated by phantom lines).

25 Within the context of Figure 1, the outer module 170 may interface with one or more of the perimetric transformers 450A-450I and the inner module 175 may sense or control various parameters associated with the wellhead assembly 400. For example stress/strain gauges may be installed on the high pressure wellhead housing 410, stress/strain gauges may be installed on the casing hangers 420, 425,
30 position indicators may be installed on the casing hangers 420, 425; position indicators may be installed on the seal assemblies 435; pressure/temperature and/or fluid composition sensors may be installed gauge in an annulus between the high pressure wellhead housing 410 and the first position casing hanger 420; pressure/temperature or fluid composition sensors may be installed in an annulus

between the low pressure conductor housing 405 and the high pressure wellhead housing 410; a cement detection sensor may be installed between the low pressure conductor housing 406 and the high pressure wellhead housing 410; or a position indicator may be installed for wellhead system tools (not shown) inserted into the production path 415 along the inner diameter of the high pressure wellhead housing 410. Other sensors or controllers may be provide in addition to or in place of the examples provided herein.

In general, the perimetric transformers 150, 450A-450I allow interfaces to be made across and within pressure boundaries without requiring penetrations of the pressure boundaries. Because the perimetric transformers 150, 450A-450I employ interfacing perimetric magnetic cores 120, 135, the associated components may be seated without requiring a particular radial alignment to allow mating of connector interfaces.

The particular embodiments disclosed above are illustrative only, as the disclosed subject matter may be modified and practiced in different but equivalent manners apparent to those skilled in the art having the benefit of the teachings herein. Furthermore, no limitations are intended to the details of construction or design herein shown, other than as described in the claims below. It is therefore evident that the particular embodiments disclosed above may be altered or modified and all such variations are considered within the scope and spirit of the disclosed subject matter. Accordingly, the protection sought herein is as set forth in the claims below.

CLAIMS

WE CLAIM:

1. An apparatus, comprising:

a first housing including a first magnetic core extending about an inner
perimeter of the first housing and a first coil disposed on the first
magnetic core to define a primary coil of a first perimetric transformer;
and

a second housing interfacing with the first housing and including a second
magnetic core disposed proximate the first magnetic core and
extending about an exterior perimeter of the second housing and a
second coil disposed on the second magnetic coil to define a
secondary coil of the first perimetric transformer.

2. The apparatus of claim 1, further comprising a first module coupled to
the first coil and a second module coupled to the second coil, wherein the first
module is to provide a power signal to the second module via the perimetric
transformer.

3. The apparatus of claim 1, wherein the second module is to provide a
data signal to the first module via the perimetric transformer.

4. The apparatus of claim 1, wherein the first coil extends perimetrically
around the first magnetic core, and the second coil extends perimetrically around the
second magnetic core.

5. The apparatus of claim 1, wherein the first and second housings have
circular cross-sections.

6. The apparatus of claim 2, wherein the inner housing defines an interior
space, and the inner module comprises a sensor to measure a parameter associated
with the interior space.

7. The apparatus of claim 6, wherein a process fluid flows through the
interior space.

8. The apparatus of claim 1, wherein the second housing includes a third magnetic core disposed proximate the first magnetic core and extending about an exterior perimeter of the second housing and a third coil disposed on the third magnetic core to define an additional secondary coil of the first perimetric transformer.

5

9. The apparatus of claim 1, wherein the inner housing defines an interior space, the second housing includes a third magnetic core extending about an interior perimeter of the second housing and a third coil disposed on the third magnetic core to define a primary coil of a second perimetric transformer, and the apparatus further comprises a third housing disposed in the interior space and including a fourth magnetic core extending about an exterior perimeter of the third housing proximate the third magnetic core and a fourth coil disposed on the fourth magnetic core to define a secondary coil of the second perimetric transformer.

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10. The apparatus of claim 9, wherein the secondary coil of the first perimetric transformer is coupled to the primary coil of the second perimetric transformer.

20

11. The apparatus of claim 9, wherein the first housing comprises a low pressure conductor housing of a wellhead assembly, the second housing comprises a high pressure wellhead housing of the wellhead assembly defining a production path, and the third housing comprise a casing hanger disposed in the production path.

25

12. The apparatus of claim 1, wherein the first housing comprises a low pressure conductor housing of a wellhead assembly, and the second housing comprises a high pressure wellhead housing of the wellhead assembly defining a production path.

30

13. The apparatus of claim 1, wherein the first housing comprises a high pressure wellhead housing of a wellhead assembly defining a production path, and the second housing comprises a tool disposed within the production path.

14. The apparatus of claim 1, wherein the first housing defines a shoulder for engaging the second housing, wherein the first magnetic core is disposed on the shoulder.

5 15. The apparatus of claim 1, further comprising a power supply external to the first housing and coupled to the primary winding.

16. The apparatus of claim 15, wherein the power supply comprises a battery.

10

17. A method, comprising:

providing a first housing including a first magnetic core extending about an inner perimeter of the first housing and a first coil disposed on the first magnetic core to define a primary coil of a first perimetric transformer;

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interfacing a second housing with the first housing, the second housing including a second magnetic core disposed proximate the first magnetic core and extending about an exterior perimeter of the second housing and a second coil disposed on the second magnetic coil to define a secondary coil of the first perimetric transformer;

20

providing a first signal on one of the primary and secondary coils; and receiving the first signal on the other of the primary and secondary coils.

18. The method of claim 17, wherein the first signal comprises a power signal applied to the primary coil.

25

19. The method of claim 17, wherein the first signal comprises a data signal applied to the secondary coil.

20. The method of claim 17, wherein the first coil extends perimetrically around the first magnetic core, and the second coil extends perimetrically around the second magnetic core.

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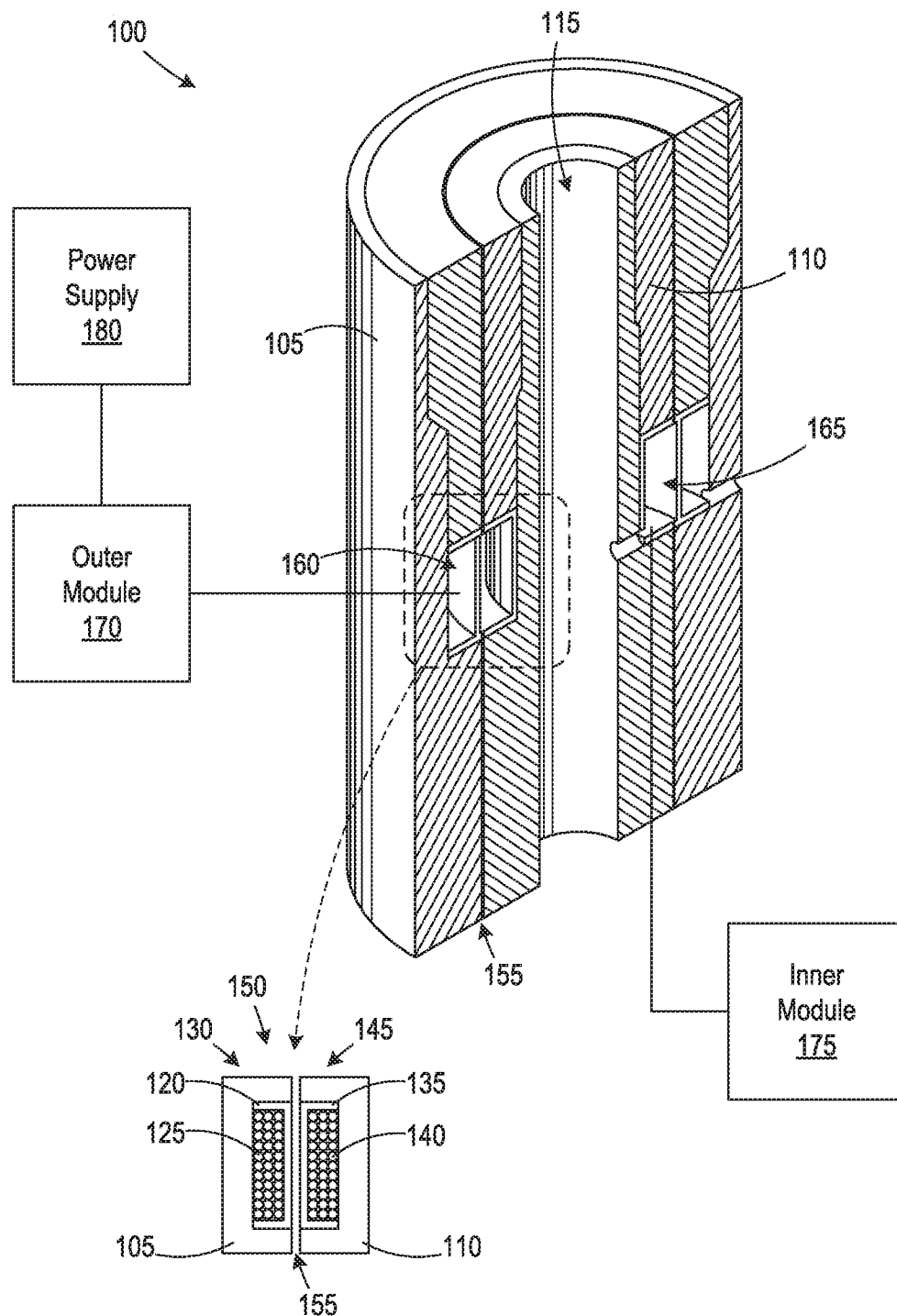


Figure 1

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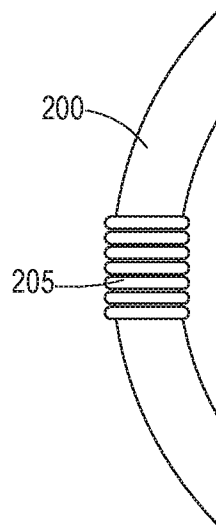


Figure 2

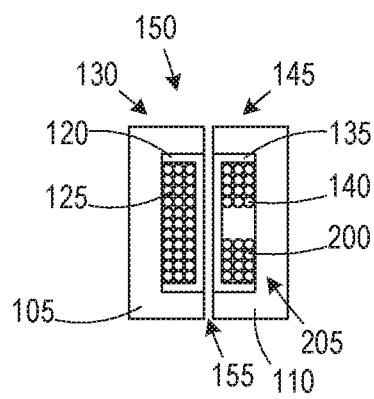


Figure 3

3 / 3

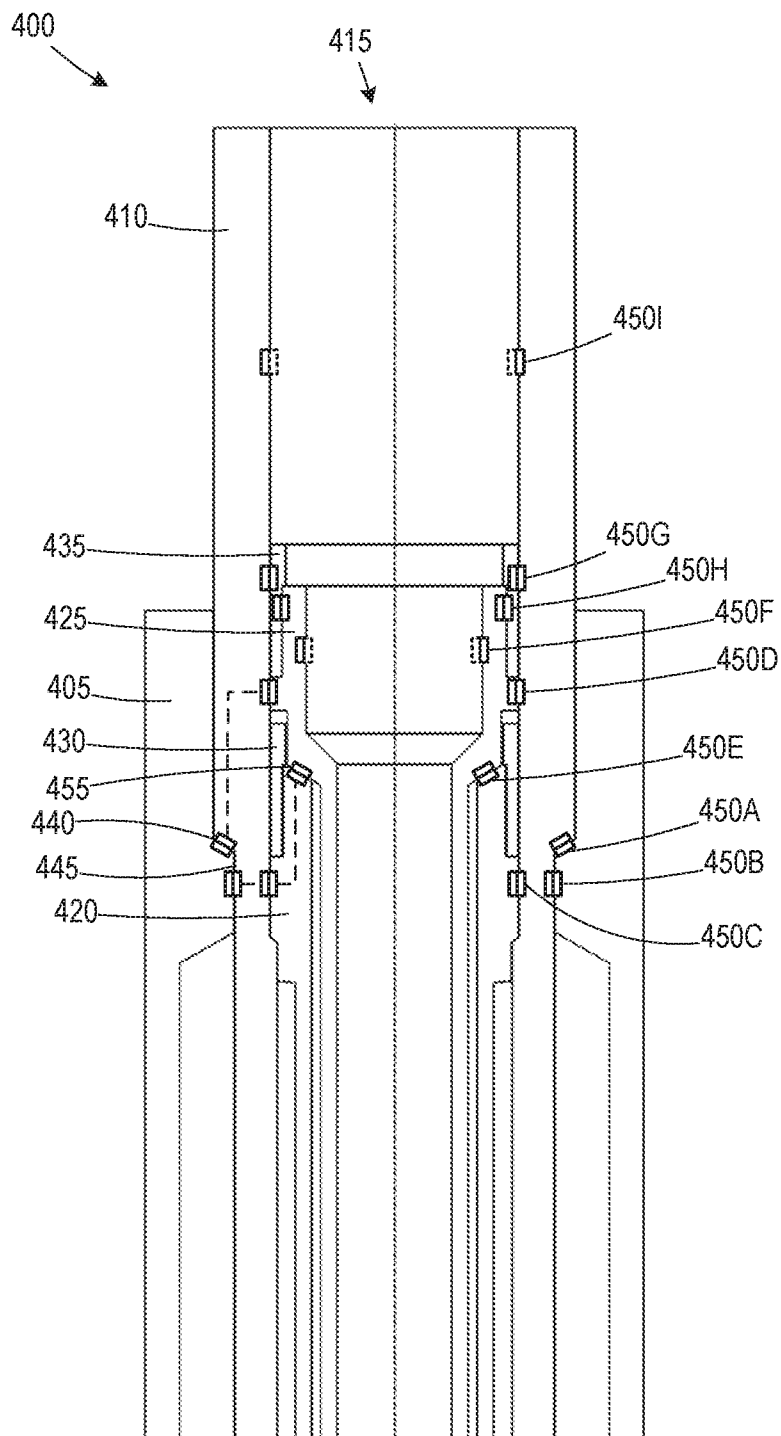


Figure 4

INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. E21B33/035 E21B33/038 E21B47/12
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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

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X	US 6 866 306 B2 (BOYLE BRUCE W [US] ET AL) 15 March 2005 (2005-03-15)	1-20
Y	column 4, line 23 - line 59; figures 1-3 -----	11-13
X	WO 2012/003999 A2 (SCHLUMBERGER SERVICES PETROL [FR]; SCHLUMBERGER TECHNOLOGY BV STBV [NL] 12 January 2012 (2012-01-12) paragraphs [0016], [0020]; figure 1 -----	1-20
X	US 2003/159823 A1 (PICHERY THIERRY [FR] ET AL) 28 August 2003 (2003-08-28) paragraphs [0041], [0049] - [0052]; figure 2 -----	1-20
Y	US 2016/069178 A1 (MULHOLLAND JOHN J [NO] ET AL) 10 March 2016 (2016-03-10) paragraphs [0050], [0053], [0054]; figure 5 -----	11-13
	-/--	



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search

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22/05/2017

Name and mailing address of the ISA/

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Schneiderbauer, K

INTERNATIONAL SEARCH REPORT

International application No

PCT/US2016/046966

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 455 573 A (DELATORRE LEROY C [US]) 3 October 1995 (1995-10-03) column 5, line 30 - column 6, line 8; figure 6 -----	1-20
A	US 5 971 072 A (HUBER KLAUS B [US] ET AL) 26 October 1999 (1999-10-26) column 4, line 40 - column 5, line 13; figure 2 -----	1-20

INTERNATIONAL SEARCH REPORT

Information on patent family members

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