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(54) Benævnelse: **FLEKSIBEL LEDNING, DER INDEHOLDER ET SYSTEM TIL DETEKTERING AF EN MILJØPARAMETERS UDVIKLING**

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Description

The invention relates to the remote detection systems for detecting a change in the state of a flexible conduit due to its environment or in the environment close to the conduit, particularly using resonant circuits. The invention relates in particular to the flexible offshore oil operation conduits intended to be immersed and/or to transport hydrocarbons or corrosive fluids.

For fluid-transporting flexible conduits, it is important to be able to detect a change in the state of the environment. Particularly for safety reasons, it can be important to detect the appearance of a pollutant in an industrial environment or even to detect the presence of liquid in a medium supposed to be leak-tight inside the wall of the conduit. In particular, for oil operation flexible conduits used at sea, it can prove critical to detect the appearance of water in zones that are assumed to be leak-tight. Indeed, the appearance of undesirable water in the wall of a flexible conduit can cause corrosion effects in the metal reinforcing layers of the conduit, subsequently accompanied by an accelerated degradation of the conduit.

The document US6025725 describes a detection system comprising a readout device and a detection module. The readout device includes an interrogation antenna winding. The detection device is a passive resonant circuit of LC type. The readout device is linked to the electrical state of the detection module by inductive coupling.

The resonant circuit of this document is sensitive to a physical parameter of the environment. Environmental parameters thus affect the electrical parameters of the resonant circuit of the detection device, for example by affecting its resonance frequency. In one example, the detection device comprises a substrate that is folded back to have two faces facing one another. Each face comprises several conductive windings, the windings of the two faces being interconnected to form a resonant circuit. The two faces of the substrate are separated by a dielectric layer. The dielectric layer chosen in one example is sensitive to humidity. The variation of the properties of this dielectric layer alters the resonance frequency of the resonant circuit.

One drawback with this device is that, in the case of a gradual modification of a resonant circuit of LC type that is a function of the environmental physical parameter to be monitored, it can be competing with stray modifications due to an uncontrolled difficult environment.

Another drawback with this device is that, in the case of a significant modification of the resonant circuit as a function of the environmental physical parameter to be monitored, the detection device can neither be tested nor identified for this state.

Finally, if the resonator is affected by several environmental physical parameters, the effect is globalized on one and the same resonator which does not make it possible to discriminate the different parameters. While it can be possible to envisage two electrical parameters of the resonator being affected, like the resonance frequency and the quality factor for example, that remains limited and non-discriminatory.

The document GB2549611 describes a tubular conduit that has a steel reinforcing layer included inside a tubular layer made of polymer. Measurement windings are included in the tubular layer. An alternating magnetic field can be applied to detect strains in the reinforcements by means of an excitation winding. A strain gauge is notably used and connected by wire to an antenna.

The document US2013/273343 describes an inductive antenna comprising a first planar conductive winding on a substrate surface, subdivided by intervals to form pairs of first conductors. A second planar conductive winding is disposed on another surface of the substrate opposite the first winding, and subdivided by intervals to form pairs of second conductors. Each pair of the first conductors defines a resonant subset with the opposite pair of second conductors.

The document FR3062211 describes a non-destructive method for inspecting a submarine flexible conduit for detecting a flooding of an annular space in which there are armourings. The method comprises steps of arrangement of a pair of electrodes in the vicinity of an outer sheath, and of measurement of the impedance at the terminals of the pair of electrodes, at a frequency lying between 10 Hz and 10 MHz. The measured impedance is compared with reference values to determine the nature of the fluid contained in the annular space.

The invention aims to resolve one or more of these drawbacks. The invention thus relates to a fluid-transporting flexible conduit, as defined in the attached claims.

The invention relates also to the variants of the dependent claims. The person skilled in the art will understand that each of the features of the description or of the dependent claims can be combined independently with the above features, without in any way constituting an intermediate generalization.

Other features and advantages of the invention will emerge clearly from the description which is given of it hereinbelow, as an indication and in a nonlimiting manner, with reference to the attached drawings, in which:
[Fig. 1] is a schematic view of a system for detecting an evolution of an environmental parameter for a flexible conduit according to an embodiment of the invention;
[Fig. 2] is a schematic representation of a variant of a detection block of a detection system for a flexible conduit according to an embodiment of the invention;
[Fig. 3] is a schematic representation of a declaration module according to an exemplary implementation;

[Fig. 4] is a schematic representation of a declaration module according to another exemplary implementation;

[Fig. 5] is a schematic representation of a declaration module according to another exemplary implementation;

[Fig. 6] is a schematic representation of a detection module according to an exemplary implementation;

[Fig. 7] is a schematic representation of a detection module according to another exemplary implementation;

[Fig. 8] and

[Fig. 9] illustrate conductive tracks that can be produced on two faces of a substrate to form detection modules according to the examples of Figures 6 and 7;

[Fig. 10] illustrates the structure of an example of fluid-transporting flexible conduit according to the invention with which the detection module is implemented;

[Fig. 11] is a schematic cross-sectional view of an example of flexible conduit termination for oil operation;

[Fig. 12] is a transverse cross-sectional view of a flexible conduit according to Figure 10, implementing a detection system;

[Fig. 13] and

[Fig. 14] are diagrams illustrating the frequency responses of a detection module according to its mode;

[Fig. 15] and

[Fig. 16] are diagrams illustrating the frequency responses of a detection block according to its mode;

[Fig. 17] is a schematic representation of another variant of a detection block of a detection system for a flexible conduit according to an embodiment of the invention.

Figure 1 is a schematic view of a detection system 1 for detecting an evolution of an environmental parameter for a flexible conduit according to an embodiment of the invention. The detection system 1 here comprises a detection block 18 fixed to an object 9, and a near-field contactless readout device 10. The detection block 18 of the detection system 1 here comprises a declaration module 11, a detection module 12 and a detection module 13. The detection modules 12 and 13 and the declaration module 11 are distinct, with no electrical connection between them. The detection modules 12 and 13 and the declaration module 11 are fixed to an object 9, for which it is desired to evaluate the evolution of one or more environmental parameters. The detection modules 12 and 13 are disposed in proximity to the declaration module 11.

The invention proposes a detection system 1 in which the declaration module 11 is configured to be detectable by the readout device 10 in proximity to it, while being little or not at all affected by the variation of the environmental parameter to be studied. The declaration module 11 can, by its presence detection, be configured to declare the presence of the detection modules 12 and 13 in proximity to it. The declaration module 11 is thus configured to communicate contactlessly in near-field mode with the readout device 10 independently of said environmental parameter.

The invention proposes a detection system 1 in which one or more detection modules 12 or 13 each include an LC resonant circuit, sensitive to an evolution of an environmental parameter to be studied. Such an LC resonant circuit thus has first and second modes of operation, according to the value of the environmental parameter to be studied:

- a first mode of operation in which this resonant circuit exhibits a resonance frequency lying within a predefined range. In this nominal mode of operation, the resonance frequency is not sufficiently altered by a variation of the environmental parameter;
- a second mode of operation in which this resonant circuit exhibits a resonance frequency outside of said range or an absence of resonance frequency. This second mode making it possible to indicate the variation of an environmental parameter.

A logic that is the reverse of the first and second modes of operation can also be envisaged: the absence of resonance frequency or the resonance frequency out of range can be assigned to the second mode of operation.

The predefined range of the resonance frequency of the LC resonant circuit can range from 0.9*f0 to 1.1*f0 for example, or even from 0.8*f0 to 1.2*f0, with f0 the nominal resonance frequency (corresponding to the resonance frequency of the LC resonant circuit in normal conditions of use) of the LC resonant circuit.

The detection system 1 is advantageously based on a detection of all or nothing type of the detection modules 12 and 13. The all-or-nothing detection principle is based on a significant variation of a passive electrical element, for example a conductive track, a resistive track or a capacitance, following a change of the environment close to this electrical element. The variation of the passive electrical element can be reversible or irreversible. The detection modules 12 and 13 can thus function in all-or-nothing mode, according to their mode of operation.

Such all-or-nothing operation can prove particularly useful, in particular if the electromagnetic environment is variable or disturbed and thus prevents a detection of a limited variation of the resonance frequency of the detection modules 12 or 13. Through an all-or-nothing mode detection, it is possible to robustly detect if the detection modules 12 or 13 are in a first or a second mode of operation. The detection modules 12 and 13 can be sensitive to different environmental parameters.

Depending on the environmental parameter to be studied, an electrical component can exhibit a break (for example a fuse) or a strong variation of an electrical characteristic to alter the resonance frequency of the resonant circuit at least by a factor of 2, preferably a factor of 5.

The changes of state of the environment close to the detection modules 12 or 13 are for example those which can lead to the corrosion of metal elements involved in the structure of the flexible conduit with which the detection system 1 can be associated. It can be in particular the ingress of water (freshwater or saltwater) or of corrosive gases (H_2S) or of undesirable gases for certain applications (CO_2).

The detection system 1 can use the technical principles of passive RFID tags for the data exchange mode and for the remote power feed electrical power supply mode.

The communication of data and the remote power supply can thus involve the technical solutions of RFID tags, in particular of the LF or HF RFID tags that use a radiofrequency link of inductive type. This technology is used by standardized identification systems, for example the systems conforming to the standards ISO14443, ISO15693 and ISO18000-3 at the frequency of 13.56 MHz, and ISO18000-2 at a frequency lower than 150 kHz.

The frequency range can extend from the low-frequency range (LF: 30 kHz - 300 kHz) to the high-frequency range (HF: 3 MHz - 30 MHz). The antennas then typically form an LC resonant circuit, the inductance L being formed by a winding whose geometry conditions the coupling with the electromagnetic field (hereinafter in the text called antenna circuit), the capacitance C being able to be incorporated (even partially) in an integrated circuit.

Figure 2 is a schematic representation of a detection block 18 of a system 1 including a declaration detection module 11 and detection modules 12 and 13 according to an embodiment of the invention. The modules 11 to 13 are, here, formed on a same substrate 190, for example a flexible plastic film. The formation of the modules 11 to 13 on one and the same substrate makes it possible to precisely arrange these modules with respect to one another and makes it possible to reduce the manufacturing costs of the system 1. In order to ensure its protection and its immunity with respect to one or more environmental parameters to be studied, the declaration module 11 is protected in a zone 191 (illustrated by a broken line). The module 11 can thus be sealed between a protection film and the substrate 190. It is for example possible to use a thin protection film on the zone 191, for example with a thickness of 0.1 mm, in order to favour the compactness of the detection block 18 of the system 1 which has to be associated with a flexible conduit (the system is, here, illustrated in association with an object 9 in the interests of simplification). The module 11 houses the modules 12 and 13 in the median part of its antenna circuit. The zone 191 forms an opening in which the modules 12 and 13 are disposed, therefore not covered by the zone 191, while being in proximity to the module 11. The modules 12 and 13 are thus exposed to the environmental parameter, by being for example exposed to a fluid that may or may not include a pollutant to be detected. The modules 12 and 13 or at least one of their electrical components are not covered by a protection film. It is also possible to envisage the devices 12 and 13 being disposed at the periphery of the zone 191.

In this example, the module 11 has an antenna circuit via which this module 11 is configured to communicate with the reader 10. The antenna circuit of the module 11 can be coupled magnetically with antenna circuits of the modules 12 and 13. The antenna circuit of the module 11 can serve as relay antenna for the detection modules 12 and 13, which can be provided with resonant antenna circuits of much smaller sizes. It is thus possible to improve the range of the antennas of the modules 12 and 13, even with reduced sizes.

The declaration module 11 can have an antenna circuit associated with an RFID chip that is always operational. This antenna circuit is of the LC resonator type. This RFID chip is a main RFID chip whose operation is not degraded by the changes of state of the environment to be detected.

The antenna circuits of the detection modules 12 and 13 each form an LC resonator. This LC resonator is greatly modified by one of the changes of state of the environment to be detected (strong variation of its resonance frequency or strong reduction of its quality factor). This resonator can be a simple passive LC circuit, and the detection of the change of state can then be performed on the analysis of the form of its frequency response. This change of state of the environment to be detected can also induce a switching of the resonator from a second mode of operation to the first mode of operation.

The detection module 12 (or 13) can also include an RFID chip connected to the LC resonator. The detection of the change of state of the environment can be performed on whether or not it is possible to read the identifier of the RFID chip connected to the resonator of the detection module 12.

The reading of the identifier of the RFID chip of the declaration module 11 by the reader 10 makes it possible to confirm being in the presence of this module 11 (and therefore of the detection block 18 of the detection system 1) in the absence of response from the detection modules 12 and 13, in order to avoid a false diagnosis corresponding to a search which would be performed by the reader 10 at the wrong place, remotely from the declaration module 11.

The absence of response from the declaration module 11 corresponds either to the absence thereof in proximity to the reader 10, or to the malfunctioning thereof.

Figure 17 illustrates a variant embodiment in which the modules 12 and 13 are disposed at the periphery of the zone 191. In this variant, the antenna circuit of the module 11 follows a cross-shaped form, and the detection modules 12 and 13 are placed in proximity to this antenna circuit, outside of the zone 191.

It will be noted that the form of the zone 191 can also be designed for one of the detection modules 12-13 to be placed in an aperture at the centre of this zone, and for another of the detection modules 12-13 to be placed at the periphery.

Figure 3 is a schematic representation of a declaration module 11 according to an exemplary implementation. In this example, the module 11 includes an LC resonator. The module 11 is, here, provided with an RFID chip 111. The chip 111 is configured to supply an identifier of the module 11, and possibly an identifier of the associated detection modules 12 and 13, in response to a request from the reader 10. The LC resonator here includes a winding 110 of several turns, forming an antenna circuit and an inductance for the LC resonator. The winding 110 can have an area of 100 cm^2, in order to favour a communication with the reader 10. The winding 110 is, here, connected to the terminals of the RFID chip 111. The RFID chip 111 can include a capacitance incorporated for the LC resonator (for example of 23.5 pF, or even of 97 pF). The capacitance will for example be defined to be as robust as possible to the environment for the declaration module 11, by for example having a relatively high value of 97 pF. The capacitance will for example be of a lower value for the detection modules 12 and 13, for example 23.5 pF. The LC resonator of the module 11 is insensitive or almost insensitive to the variations of the environmental parameter to be studied.

Figure 4 is a schematic representation of a declaration module 11 according to another exemplary implementation. In this example, the module 11 also includes an LC resonator. The module 11 is, here, also provided with an RFID chip 111. The chip 111 is configured to supply an identifier of the module 11, and possibly an identifier of the associated detection modules 12 and 13, in response to a request from the reader 10. The LC resonator here includes a winding 110 of several turns, forming an antenna circuit and an inductance for the LC resonator. The winding 110 is connected to a capacitor 114.

The winding 110 is, here, connected to a matching circuit 112. The chip 111 is also connected to the terminals of the matching circuit 112. The winding 110 and the capacitor 114 can form a main LC resonator. A self-resonant inductive antenna as described in the document FR2961353 can notably be used. Such an antenna is particularly suited to use in a wet environment, with a resonance frequency largely unaffected by variations of humidity in proximity to it. The matching circuit 112 can include a winding of smaller dimension to form a resonant circuit with the RFID chip 111, and possibly to allow the matching of the chip 111 to the main LC resonator. The LC resonators of the module 11 are insensitive or largely insensitive to the variations of the environmental parameter to be studied.

Figure 5 is a schematic representation of a declaration module 11 according to another exemplary implementation. In this example, the module 11 also includes an LC resonator. The module 11 is, here, also provided with an RFID chip 111. The chip 111 is configured to supply an identifier of the module 11, and possibly an identifier of the associated detection modules 12 and 13, in response to a request from the reader 10. The LC resonator here includes a winding 110 of several turns, forming an antenna circuit and an inductance for the LC resonator. The winding 110 is connected to a capacitor 114.

The winding 110 is, here, coupled magnetically to a matching circuit 113. The chip 111 is connected to the terminals of the matching circuit 113. The winding 110 and the capacitor 114 can form a main LC resonator. The matching circuit 113 can include a winding of smaller dimension to form a resonant circuit with the RFID chip 111, and possibly to allow the matching of the chip 111 to the main LC resonator. The LC resonators of the module 11 are insensitive or largely insensitive to the variations of the environmental parameter to be studied.

Figure 6 is a schematic representation of a detection module 12 according to an exemplary implementation. In this example, the module 12 takes the form of an LC resonator. The module 12 here has no RFID chip. The module 12 here comprises a winding 120 of several conductive turns, intended to form the inductance of the LC circuit. The winding 120 is, here, connected to the terminals of a capacitor 124. The capacitor 124 is insensitive or largely insensitive to the variations of the environmental parameter to be studied. The structure of the capacitor 124 can for example be protected from the environmental parameter by one or more appropriate protection layers. The capacitor 124 here forms a fixed part of the capacitance of the LC circuit. An additional capacitor 125 is connected to the terminals of the capacitor 124 described previously. This additional capacitor 125 is sensitive to the variations of the environmental parameter. The additional capacitor 125 can for example be placed in contact with a fluid, in which it is desired to detect the variation of the environmental parameter. The additional capacitor 125 can for example have a part that is not covered by a protection layer. The additional capacitor 125 here comprises a comb geometry, with interdigital metal lines, such that its capacitance is greatly dependent on the electrical characteristics of the close environment or of a fluid in contact with it. The capacitor 125 can for example be placed in electrical contact with a fluid in which it is desired to detect the variation of the environmental parameter, or else be placed in close presence to the fluid and electrically insulated therefrom by an insulating layer of small thickness ensuring a galvanic insulation.

It is for example possible to describe an application to the detection of water. The water (fresh or salt) is characterized by a strong dielectric constant ($\varepsilon r = \varepsilon r/\varepsilon o \sim 80$). The water, containing salts in solution, is characterized by an electrical conductivity that increases with the salt concentration.

A capacitor with comb geometry exhibits a capacitance dependent on the dielectric constant of the materials in proximity to it, and the losses of the capacitance (parallel resistance) are dependent on the conductivity of the materials in proximity to it (more significantly if there is electrical contact with the material). The comb geometry of the capacitor 125 allows the equivalent of a capacitor formed by two parallel lines of greater length, practically the equivalent of the deployed length of the meander formed in the comb geometry, approximately 25 cm for an example such as that of Figure 8 described hereinbelow.

The capacitance between two parallel metal lines is proportional to the dielectric constant of the material in which these two lines are bathed. The thickness of material around the metal lines contributing to the capacitance value is practically of the order of the separation between the two lines. The capacitance value in a “vacuum” is of the order of a few 10 pF to 30 pF per metre of line according to the ratio between the width of the lines and the separation between them. This capacitance value is multiplied by a factor of several tens when the material around the metal lines is impregnated with water (dielectric constant ($\varepsilon r = \varepsilon r/\varepsilon o \sim 80$)).

The conductivity of the water induces losses which are reflected by a parallel resistance according to the quantity of ions dissolved, of the order of a kilo ohm per metre of line with seawater and in the case where the metal lines are electrically insulated. The parallel resistance is much lower in the case where an electrolytic conduction can be established between the two metal lines.

Figure 7 is a schematic representation of a detection module 12 according to another exemplary implementation. In this example, the module 12 also takes the form of an LC resonator. The module 12 is, here, provided with an RFID chip 121. The module 12 here comprises a winding 120 of several conductive turns, intended to form the inductance of the LC circuit. The winding 120 is, here, connected to the terminals of the RFID chip 121. The RFID chip 121 here includes a capacitance (for example of 23.5 pF). The capacitance of the chip 121 is insensitive or largely insensitive to the variations of the environmental parameter to be studied. The internal capacitance of the chip 121 can intrinsically be protected from the environmental parameter by one or more protection layers of this chip 121. The capacitance of the chip 121 here forms a fixed part of the capacitance of the LC circuit. An additional capacitor 125 is connected to the terminals of the chip 121. The additional capacitor 125 is sensitive to the variations of the environmental parameter. The additional capacitor 125 can, for example, be placed in contact with a fluid, in which it is desired to detect the variation of the environmental parameter, or else be placed in close presence to the fluid and electrically insulated therefrom by an insulating layer of small thickness. The additional capacitor 125 can, for example, have a part that is not covered with a protection layer. The additional capacitor 125 here comprises a comb geometry, such that its capacitance is greatly dependent on the electrical characteristics of the close environment or of a fluid in contact with it.

It is for example possible to provide for the winding 120 to occupy a square of 14 mm side, including 19 turns formed on two faces of a substrate, the pitch of the turns being 0.4 mm and the width of the turns being 0.2 mm.

The capacitors 124 and 125 (or the capacitor of the chip 121 and the additional capacitor 125) are, here, illustrated in parallel. It is however also possible to envisage a series connection of these capacitors to, for example, reverse the direction of transition between the two modes of operation: the influence of the presence of water (in particular the presence of saltwater) causes the impedance of the capacitor 125 to drop, establishing in this way a nominal mode of operation with a direct resonance between the inductance 123 and the capacitor 124.

The resonance frequency of the LC circuit of the module 12 in its first mode of operation is advantageously close to the resonance frequency of the LC circuit of the module 11.

When the declaration module 11 is associated with several different detection modules and when an analysis of the frequency response of the detection block 18 is envisaged, the different detection modules will advantageously have distinct resonance frequencies.

Figures 8 and 9 illustrate conductive tracks that can be formed on two opposite faces of a substrate, in order to selectively form a module 12 corresponding either to the configuration of Figure 6 or to the configuration of Figure 7.

Figure 8 illustrates the configuration on one face of the substrate. Pads 128 are formed between turns 122 and interdigital tracks of an additional capacitor 125. The turns 122 belong to the winding 120. One end of the turns 122 is connected to a pad 123. Another end of the turns 122 is connected to one of the pads 128.

Figure 9 illustrates the configuration on another face of the substrate, seen by transparency from the same point of view as Figure 8. Pads 129 are formed alongside turns 126. The pads 129 face the pads 128. The pad 127 faces the pad 123. The pads 123 and 127 are electrically connected.

The facing pads 128 and 129 are electrically connected. Bonding pads intended to selectively connect either an RFID chip 121, or a capacitor 124, are connected to the pads 128 and 129.

To differentiate the RFID chip 121 from the RFID chip 111 of the module 11, the latter advantageously have different identifiers. The modules can also be differentiated by memories storing different information, read by the reader 10.

The diagrams of Figures 13 and 14 illustrate the respective frequency responses, recorded by a reader 10:

- of a declaration module 11 and of a coupled detection module 12, this detection module having a resonance frequency in its second mode, for example following a degradation because of a variation of an environmental parameter;
- of a declaration module 11 and of a coupled detection module 12, this detection module having a resonance frequency in its first mode, for example in the absence of sufficient variation of an environmental parameter.

In the present particular case, the detection module 12 has a resonance frequency in its first mode which is centred on the resonance frequency of the declaration module 11. It is found that the frequency response for the first particular case exhibits a simple profile corresponding to the characteristics of the LC circuit of the declaration module 11. It can be seen that the frequency response in the second particular case exhibits a complex profile with two peaks separated by a dip, linked to the integrity of the LC circuit of the detection module 12, coupled to the LC circuit of the declaration module 11.

Figures 15 and 16 illustrate the respective frequency responses, recorded by a reader 10:

- of a declaration module 11 and of coupled detection modules 12, these detection modules having been degraded because of a variation of an environmental parameter;
- of a declaration module 11 and of coupled detection modules 12, these detection modules having been kept intact in the absence of sufficient variation of an environmental parameter.

In the present particular case, the detection modules 12 have resonance frequencies in their first mode which are distributed on either side of the resonance frequency of the declaration module 11, for example at 13.3 MHz and 13.9 MHz for a resonance frequency of 13.6 MHz of the declaration module 11.

It can be seen that the frequency response for the first particular case exhibits a simple profile corresponding to the characteristics of the LC circuit of the declaration module 11. It can be seen that the frequency response in the second particular case exhibits a complex profile with peaks separated by several dips, linked to the integrity of the LC circuits of the detection modules 12, coupled to the LC circuit of the declaration module 11.

In the preceding examples, the detection modules are coupled to the antenna circuit of the declaration module 11. A detection module 12 comprising an RFID chip can thus communicate with the reader 10, the antenna circuit of the declaration module serving as relay antenna. It is also possible to provide for a detection module 12 comprising an RFID chip to be able to communicate independently with the reader 10.

Figure 10 is an illustration of an example of structure of a flexible conduit 90 for transporting a fluid, in particular for transporting oil in a marine environment.

The flexible conduit 90 here comprises, starting from the inside to the outside, an inner carcass 99, an inner sealing sheath 98, a pressure vault 97, a first anti-wear layer 96, a first ply of tensile armourings 95, a second anti-wear layer 94, a second ply of tensile armourings 93, one or more layers of holding strips 92 and an outer sheath 91.

The inner carcass 99 is a tubular and flexible metal layer which is not leak-tight. Its main function is to absorb the radial forces oriented from the outside to the inside of the conduit, notably those linked to the hydrostatic pressure when the conduit is immersed at great depth. It contributes to preventing the crushing of the conduit under the effect of the external pressure. The inner carcass 99 is produced from a metal leaf made of stainless steel which is provided with an S-shaped profile then helically wound to form joined turns. The helical winding of the profiled metal leaf forming the inner carcass 99 has a short pitch, that is to say that it has a helix angle with an absolute value close to 90°, typically lying between 75° and 90°. The thickness of the inner carcass 99 is typically between 5 mm and 20 mm.

The inner sealing sheath 98, also called pressure sheath, is a leak-tight layer made of polymer which surrounds the inner carcass 99. The inner sealing sheath 98 is intended to tightly contain the fluid transported in the flexible conduit 90. It is formed from a polymer material, for example based on a polyolefin such as polyethylene, based on a polyamide such as PA11 or PA12, or based on a fluorinated polymer such as polyvinylidene fluoride (PVDF). The thickness of the inner sealing sheath 98 is for example between 5 mm and 20 mm.

The pressure vault 97 is a tubular and flexible metal layer which is not leak-tight and whose main function is to absorb the radial forces linked to the pressure prevailing inside the inner sealing sheath 98. The pressure vault 97 thus makes it possible to prevent the bursting of the inner sealing sheath 98 under the effect of the pressure exerted by the fluid transported in the flexible conduit 90. The pressure vault 97 is for example formed by a metal profiled wire helically wound and forming joined turns. This profiled wire is helically wound with a short pitch, that is to say with a helix angle with an absolute value close to 90°, typically between 75° and 90°. This profiled wire generally has a complex geometry, notably Z, T, U, K, X or I shaped. The thickness of the pressure vault 97 is typically between 5 mm and 20 mm.

The main function of the two plies of tensile armourings 93, 95 is to absorb the axial tensile forces exerted on the flexible conduit 90, for example those linked to the weight of the conduit when the latter extends vertically from the seabed to a production unit situated on the surface. Each ply of tensile armourings 93, 95 is composed of a plurality of tensile armouring wires helically wound with a long pitch, that is to say with a helix angle with an absolute value of less than 60°, and typically between 25° and 55°. The tensile armouring wires are generally metal and of substantially rectangular section. The two plies of tensile armourings 93, 95 are generally crossed, that is to say wound according to opposing helix angles, which makes it possible to balance the conduit with respect to torsion and thus minimize its tendency to turn about its longitudinal axis under the effect of tension. The thickness of each ply of tensile armourings 93, 95 is typically between 2 mm and 10 mm.

The function of the first anti-wear layer 96 is to prevent the wear by friction between, on the one hand, the pressure vault 97 and, on the other hand, the first ply of tensile armourings 95. The function of the second anti-wear layer 94 is to prevent the wear by friction between, on the one hand, the first ply of tensile armourings 95 and, on the other hand, the second ply of tensile armourings 93. Each anti-wear layer 94, 96 is composed of a polymeric strip helically wound with a short pitch, typically a strip 3 mm thick, which is disposed at the interface between the two metal layers likely to rub against one another, such that the direct metal-on-metal contacts are avoided.

The layers of holding strips 92 are helically wound with a short pitch around the second ply of tensile armourings 93. Some are intended to provisionally hold the armouring wires during the manufacturing of the flexible duct 90, by notably preventing the outer ply of tensile armourings 93 from being able to unravel before the final step of manufacturing of the outer sheath 91. Additionally, the flexible conduits 90 intended to be immersed at great depth advantageously comprise holding strips 92 of great mechanical strength, and whose function is to prevent the inflation of the plies of tensile armourings when the conduit is subjected to axial compression forces which are exerted when the pressure prevailing inside the conduit is lower than the pressure prevailing outside the conduit. These anti-inflation strips are generally woven or reinforced with light and highly resistant fibres, notably with aramid fibres.

The outer sheath 91 is a seal-tight protection sheath which is intended to prevent the permeation of fluid from the outside of the flexible conduit 90 to the inside. It is advantageously produced by extrusion of a thermoplastic polymer material, typically a polyamide or a polyethylene, around the layers of holding strips 92. The thickness of the outer sheath 91 is, for example, between 5 mm and 15 mm.

The flexible conduit 90 is of "unbonded" type in that the metal reinforcing layers, notably the pressure vault 97 and the two plies of tensile armourings 93, 95, are free to move longitudinally with respect to the adjacent layers when the conduit is flexed. An unbonded flexible conduit generally has no bonding materials connecting the concentric layers forming the conduit.

The flexible conduit 90 is, for example, produced according to the normative documents API 17J and API RP 17B drawn up by the American Petroleum Institute. The flexible conduit 90 is notably used for offshore oil or gas operation in very severe conditions. Thus, the transported hydrocarbons can have a pressure and a temperature that are very high, for example a pressure of between 500 bar and 1500 bar, and a temperature of between 110°C and 130°C. In addition, in the case where the flexible conduit is immersed at great depth, it must be capable of withstanding a very high external pressure, for example of the order of 250 bar if the conduit is immersed at a depth of 2500 metres. The flexible conduit 90 must also be able to withstand very strong tensions, commonly of several tens of tons, to which it is subjected in service and/or when being installed at sea. The internal diameter of the flexible conduit 90 is typically between 50 mm and 400 mm, primarily between 100 mm and 250 mm.

The inner sealing sheath 98 is tight to liquids but not to gases, so that the gases present in the hydrocarbon can slowly diffuse through the latter, notably when the temperature and the pressure are high. This phenomenon primarily relates to molecules of small size, notably the water in vapour phase, and the carbon dioxide (CO_2), hydrogen sulfide (H_2S) and methane (CH_4) gases. Thus, when the hydrocarbon contains one or more of these gases, it or they can slowly diffuse through the inner sealing sheath 98 and accumulate in the annular space situated between, on the one hand, the outer face of the inner sealing sheath 98 and, on the other hand, the inner face of the outer sheath 91. In the case where this annular space is accidentally filled with liquid water, the combination of the presence of liquid water with the presence of acid gases of CO_2 and/or H_2S and/or CH_4 type can generate an acid medium that is corrosive for the metal wires of the pressure vault 97 and of the two plies of tensile armourings 93, 95, notably when these metal wires are made of carbon steel.

Thus, when the flexible conduit 90 is immersed and in service, an accidental tearing of the outer sheath 91 can provoke a flooding of this annular space by the salt seawater, and this flooding can, ultimately, provoke corrosion of the pressure vault 97 and/or of the plies of tensile armourings 93, 95 in the case where the hydrocarbon being transported includes a high acid gas content.

In addition, even if the seal-tightness of the outer sheath 91 is preserved, it is possible for the water vapour located initially in the transported hydrocarbon to be able to slowly diffuse through the inner sealing sheath 98, and then condense in the form of freshwater in the annular space, with, once again here in certain particular cases, a potential risk of corrosion of the pressure vault 97 and/or of the plies of tensile armourings 93, 95. This risk is however significantly lower than that linked to an accidental tearing of the outer sheath 91, because the phenomenon of water diffusion is taken into account from the design of the conduit. However, this phenomenon of water diffusion can become important in the case where the duration of use of the flexible conduit has to be prolonged beyond the lifetime initially planned, typically beyond 20 years of service, in order to continue to operate an old oil deposit in which the water content has significantly increased.

Thus, the main risk of corrosion is associated with an accidental flooding by seawater of the annular space situated between, on the one hand, the outer face of the inner sealing sheath 98 and, on the other hand, the inner face of the outer sheath 91, and it is therefore important to be able to detect, in service, the presence of saltwater in this annular space.

The flexible conduit 90 can be fixed in a stiffener 8 at its top end. The conduit 90 can thus pass through a bore 81 of such a stiffener 8 and be fixed by an end-fitting 82 to such a stiffener 8, as illustrated in Figure 11.

The detection system 1 is, here, configured to determine the presence of saltwater under the outer sheath 91, that can be synonymous with a leak and a risk of accelerated corrosion, for example potentially affecting the plies of tensile armourings 93, 95 and/or the pressure vault 97. The incorporation of the detection system with the flexible conduit 90 can of course be realized for any other type of flexible conduit structure.

To determine the presence of saltwater, the flexible conduit 90 comprises several pairs of modules 11 and 12 (each pair forming a detection block 18 of the system 1), distributed over its circumference, as illustrated in the cross-sectional view of Figure 12. Several detection blocks 18 of the system 1 are also advantageously distributed over the length of the flexible conduit, under the outer sheath 91. The modules 11 and 12 are, here, disposed inside the holding layer 92, under the outer sheath 91. The modules 11 and 12 are disposed on the outside of the metal reinforcing layers situated in the annular space 93, 95 and 97, which would prevent communication with these modules 11 and 12 from the outside of the flexible conduit in order to be able to detect the different detection blocks 18 of the detection system 1. Apertures can be formed in the layer of holding strips 92, in order to position the modules 12 facing the outer sheath 91, and thus be potentially in contact with saltwater that has accidentally penetrated between the sheath 91 and the layer of holding strips 92. The layer of holding strips 92 can form a separation with the outer ply of tensile armourings 93. The detection blocks 18 are held at a distance from the outer surface of the outer ply of metal tensile armourings 93 (for example with a thickness of between 1 and 4 mm), inside the layer of woven holding strips 92 or between the layer 92 and the outer sheath 91.

Advantageously, the detection blocks 18 are previously incorporated in a holding strip which is then wound around the outer ply of tensile armourings 93 to form the layer of holding strips 92.

Furthermore, advantageously, a thermal insulation layer is disposed around each detection block 18 in order to prevent it from being damaged by heat during the extrusion of the outer sheath 91. In addition, this thermal insulation layer is both amagnetic and electrically insulating so as not to disturb the communications by electromagnetic wave between the detection block and the outside of the conduit.

The detection system 1 here comprises a contactless reader 10, positioned on the outside of the outer sheath 91. The reader 10 is, for example, fixed onto a mobile robot travelling along an outer face of the outer sheath 91, in order to be able to read the different declaration modules 11, and thus be able to determine if an infiltration of water has occurred at different locations. The presence of a detection block 18 can thus be performed by the reading of the declaration module 11 associated with this detection block 18, by a reader 10.

The invention makes it possible to avoid a surface marking of the outer sheath 91 of the conduit 90, in order to indicate the presence of a detection module 12. It is in fact desirable to avoid a surface marking of the outer sheath 91, this surface being able to be affected by abrasion and/or by deposits in a marine environment. The identification of the presence of a detection module 12 can thus be performed by a reader 10 independently of the surface condition of the outer sheath 91.

If the reader 10 is borne by an inspection robot, the system 1 according to the invention makes it possible to decide between the two following hypotheses if no declaration module is detected:

- the inspected zone does not contain a detection block 18;
- the inspected zone contains a detection block 18 whose declaration module 11 is defective (in which case detection modules may be accessible but the information that they return is unusable).

If a declaration module is detected or identified, the readout device 10 can analyse the detection device in order to determine the state of the associated detection modules. The analysis of the detection block 18 can be performed by a reading of its frequency response or else by an inventory of the RFID chips read by the readout device 10.

Thus, a method for inspecting a flexible conduit 90 can be implemented as follows. An inspection robot moves over the surface of the outer sheath 91. The inspection robot is provided with a reader 10, of RFID reader type, to detect each declaration module 11 of a detection block 18, and verify the state of the associated detection module 12.

The robot can implement a step of positioning of its RFID reader facing a declaration module 11, for example by stopping at a fixed position, or by a slowing down of the movement of the robot, to have sufficient time to detect and analyse the closest declaration module 11 to analyse the detection block 18.

The reader 10 identifies the closest declaration module 11 (either directly by the response from an RFID chip of the declaration module 11, or by consulting a database identifying the declaration module 11 according to the position of the reader 10). The declaration module 11 can return information relating to the detection modules 12 and 13 which are associated with it, for example the number of detection modules which are associated with it, their type, their identifier if they have an RFID chip, or their order in a distribution of tuning frequencies.

A detection module, if it has an RFID chip, can return information relating to the declaration module with which it is associated, the identification number of the declaration module for example, and information concerning it. When each of the detection modules 12 includes an RFID chip, the reader 10 can take an inventory of the responding RFID chips to determine the state of each of these detection modules 12, by comparing with the inventory of the RFID chips declared by the declaration module 11. All the RFID chips identified in response are considered to be in nominal mode of operation. By contrast, if the declaration module 11 lists a detection module 12 whose RFID chip does not respond, it can be considered that this detection module 12 has detected a variation of an environmental parameter and is in degraded mode of operation.

When the detection modules 12 do not include an RFID chip, the reader 10 can make a frequency response analysis over a predefined frequency range, for example a few MHz for a centre frequency of 13.56 MHz. The electromagnetic field level produced by the reader 10 in the investigation zone can be changed by a change of power delivered to the antenna of the reader 10, within a given range, for example by switching from 1 W to 5 W. The electromagnetic field level produced in the investigation zone can also be changed by a variation of the distance between the antenna of the reader 10 and the investigation zone. This field level parameter can be used in the analysis of the detection block 18. It is thus possible to qualify the list of the RFID chips identified by inventory. This can be a means for revealing intermediate states of a detection module in its transition between its first mode and its second mode of operation. The interpretation of the frequency response makes it possible to decide if the resonator of each of the detection modules 12 is degraded or not.

A detection system 1 has been described here that is composed of a detection block 18 comprising two detection modules 12 and 13. It will be noted that the invention is in no way limited to this particular case and could also be implemented with a detection block comprising a single detection module or more than two detection modules.

Although the invention has been described in the case where the detection module is suitable for detecting saltwater, it could also be implemented with a second detection module suitable for detecting freshwater. Thus, it is possible to distinguish the case where the annular space is filled with freshwater from the case where it is filled with saltwater.

Patentkrav

1. Fleksibel ledning til transport af et fluidum (90), kendetegnet ved, at den omfatter et system til detektering af en miljøparameters (1) udvikling, der omfatter:

- mindst ét detekteringsmodul (12), der indeholder en LC-resonanskreds, som er følsom over for en ændring i miljøparameteren, og som er konfigureret til, afhængigt af miljøparameterens værdi, at fungere enten i en første tilstand, hvor resonanskredsen har en resonansfrekvens, der ligger i et forud fastlagt område, for hvilket detekteringsmodulet er detekterbart ved magnetisk kobling ved excitation i området, eller i en anden tilstand, hvor resonanskredsen har en resonansfrekvens uden for området eller ikke har nogen resonansfrekvens
- et meddelelsesmodul (11), der er anbragt i nærheden af detekteringsmodulet (12), og som er konfigureret til kontaktløs nærfeltskommunikation selv i tilfælde af en variation af miljøparameterens værdi, og som er konfigureret til at meddele tilstedeværelsen af detekteringsmodulet,

kendetegnet ved, at detekteringsmodulets (12) LC-resonanskreds omfatter et elektrisk element (125), der er i kontakt med et omgivende fluidum, og som kan få modificeret sine elektriske egenskaber i overensstemmelse med miljøparameterens værdi i det fluidum, som det er i kontakt med.

2. Fleksibel ledning til transport af et fluidum (90) ifølge krav 1, hvor meddelelsesmodulet (11) er dækket af et beskyttelseselement (191), der ikke dækker det elektriske element (125) i detekteringsmodulets (12) LC-resonanskreds.

3. Fleksibel ledning til transport af et fluidum (90) ifølge krav 1 eller 2, hvor det elektriske element er en kondensator (125), hvis ledende eller dielektriske dele kan ændres ved variation af miljøparameterens værdi.

4. Fleksibel ledning til transport af et fluidum (90) ifølge krav 3, hvor kondensatoren (125) omfatter interdigiterede ledende spor.

5. Fleksibel ledning til transport af et fluidum (90) ifølge et hvilket som helst af de foregående krav, hvor detekteringsmodulet (12) indeholder en radiofrekvensidentifikationschip (121), der er forbundet med LC-resonanskredsen.

6. Fleksibel ledning til transport af et fluidum (90) ifølge et hvilket som helst af de foregående krav, hvor meddelelsesmodulet (11) omfatter en LC-resonanskreds, der indeholder et antennekredsløb (110) til kontaktløs kommunikation.

7. Fleksibel ledning til transport af et fluidum (90) ifølge krav 6, hvor detekteringsmodulets (12) LC-resonanskreds indeholder et antennekredsløb (120), hvilket antennekredsløb er magnetisk koblet til antennekredsløbet i meddelelsesmodulets resonanskreds (11), idet signaturen af en frekvensrespons for meddelelsesmodulets (11) antennekredsløb er forskellig som funktion af den første eller anden tilstand for detekteringsmodulets (12) resonanskreds.

8. Fleksibel ledning (90) ifølge et hvilket som helst af de foregående krav, hvor detekteringsmodulet og meddelelsesmodulet er fastgjort i ledningens tykkelse i nærheden af dens ydre overflade.

9. Fleksibel ledning ifølge et hvilket som helst af de foregående krav, hvor LC-resonanskredsen er konfigureret til at være følsom over for tilstedeværelse af saltvand ved kontakt dermed.

10. Fleksibel ledning ifølge et hvilket som helst af de foregående krav, hvor den fleksible ledning, indefra og udad, omfatter en indvendig tætningskappe, et lag af trækarmeringer

og en udvendig kappe, og detekteringsmodulet og meddelelsesmodulet er fastgjort mellem laget af trækarmeringer og den udvendige kappe.

11. Fleksibel ledning til transport af et fluidum (90) ifølge krav 6, hvor meddelelsesmodulet (11) indeholder en radiofrekvensidentifikationschip (111), der er forbundet med LC-resonanskredsen.

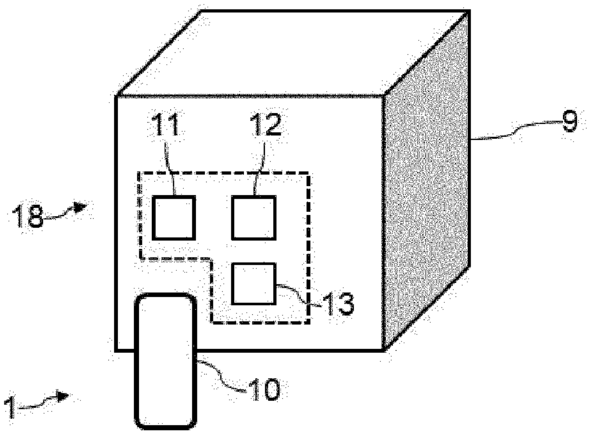
12. Fleksibel ledning til transport (90) af et fluidum ifølge krav 5 og 11, hvor meddelelsesmodulets (11) radiofrekvensidentifikationschip (111) gemmer en identifikator for detekteringsmodulet (12).

13. System, der omfatter:
- en fleksibel ledning til transport af et fluidum (90) ifølge krav 12
- en kontaktløs nærfeltslæser (10), som er konfigureret til at hente den i meddelelsesmodulet (11) gemte identifikator for detekteringsmodulet (12), og som er konfigureret til at anmode detekteringsmodulet (12) om levering af dets identifikator, samt konfigureret til at bestemme, om detekteringsmodulet (12) er i sin første tilstand eller i sin anden tilstand som funktion af et svar eller manglende svar fra detekteringsmodulet (12).

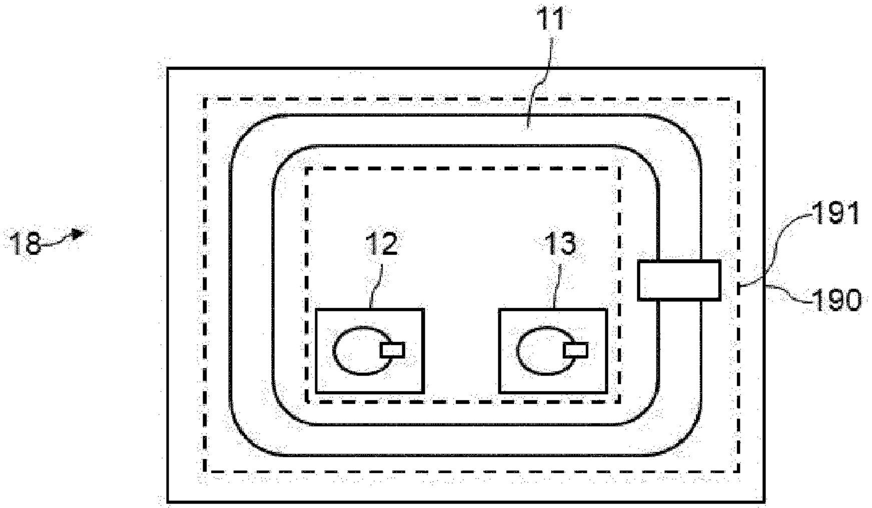
14. System ifølge krav 13, hvor den kontaktløse læser (10) anmoder om levering af detekteringsmodulets (12) identifikator i overensstemmelse med flere niveauer af påført felt.

15. System, der omfatter:
- en fleksibel ledning ifølge et hvilket som helst af kravene 1 til 12, hvor detekteringssystemet indeholder en læseindretning (10), der er konfigureret til at bevæge sig langs en flade af den fleksible ledning (90) samt konfigureret til at kommunikere med meddelelsesmodulet.

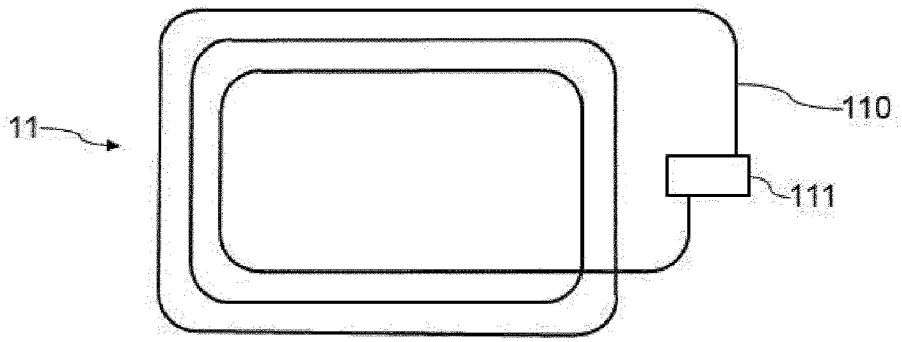
[Fig. 1]



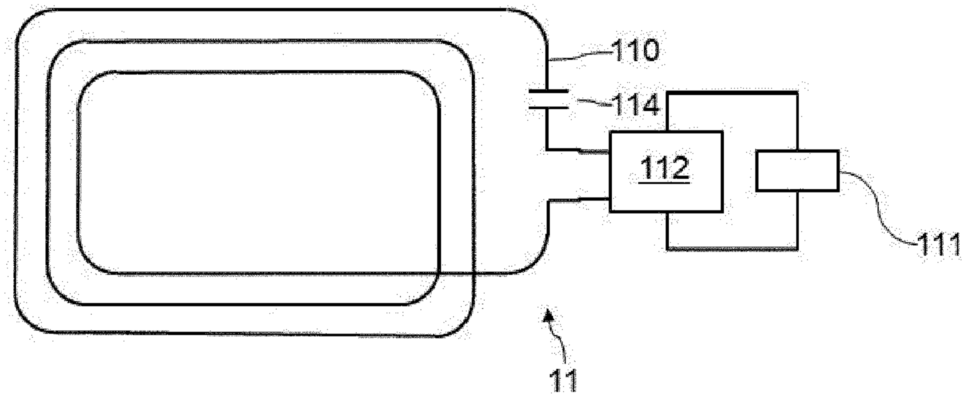
[Fig. 2]



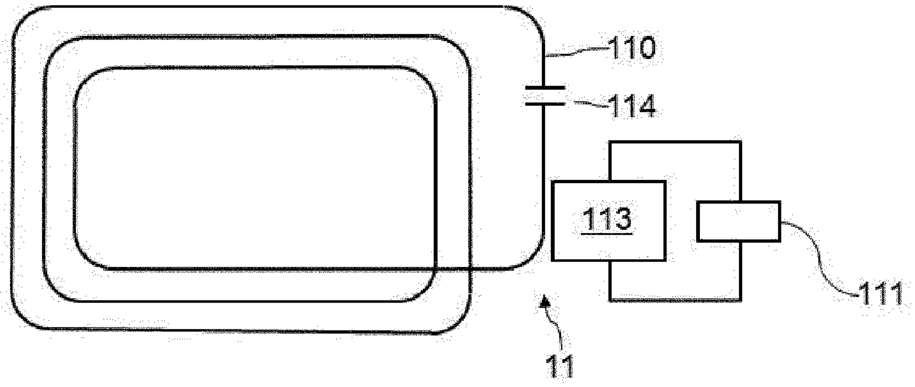
[Fig. 3]



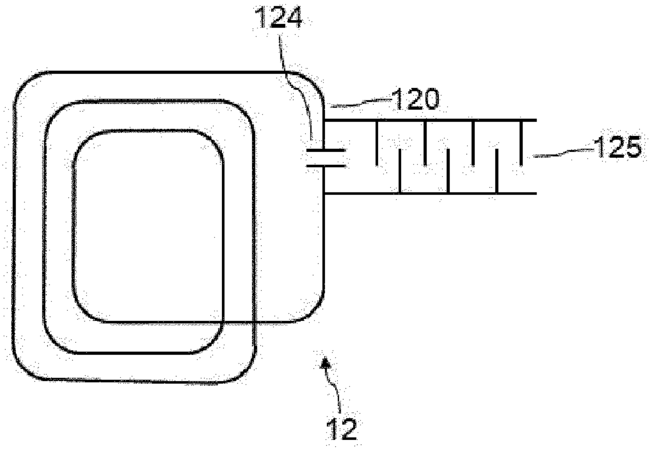
[Fig. 4]



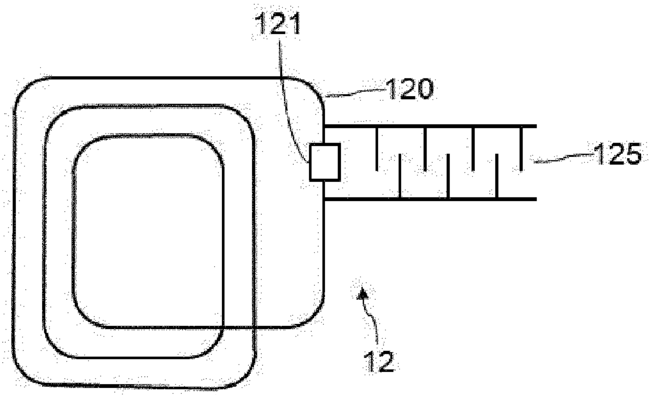
[Fig. 5]



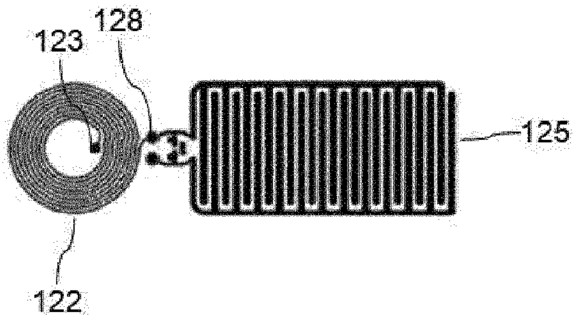
[Fig. 6]



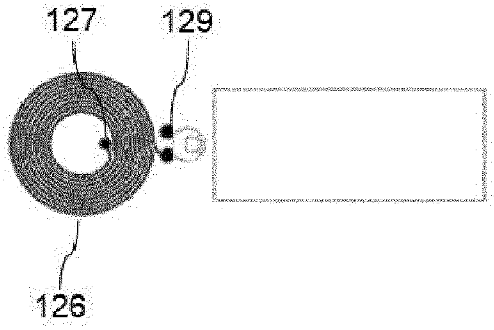
[Fig. 7]



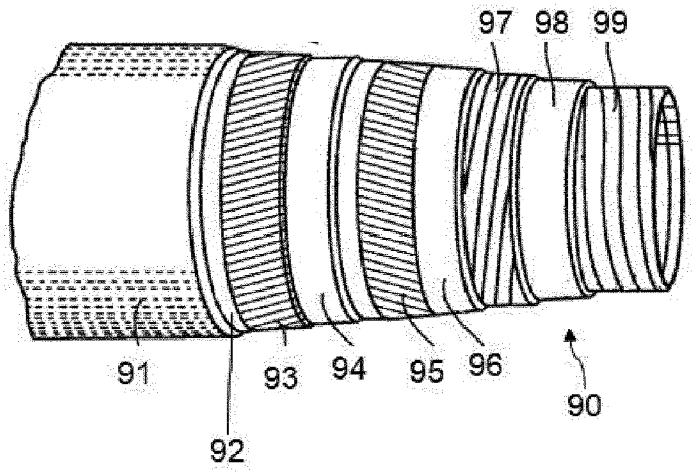
[Fig. 8]



[Fig. 9]

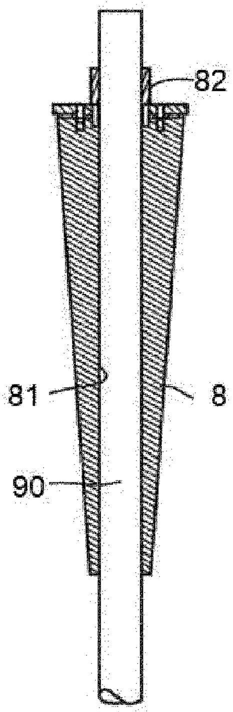


[Fig. 10]

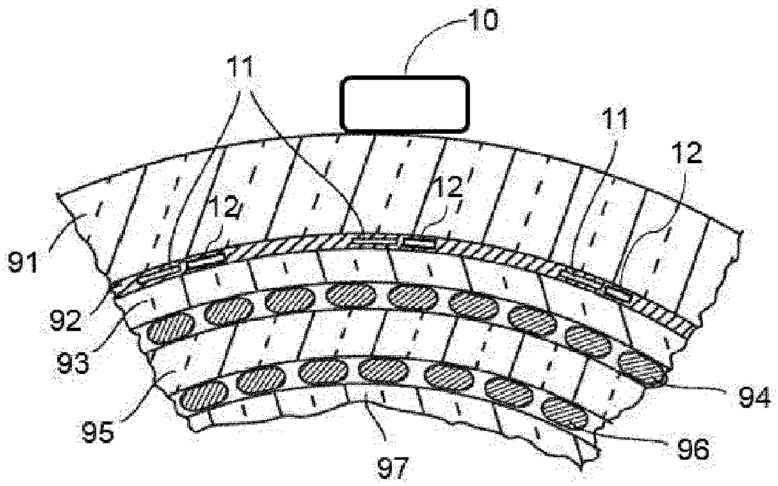


[Fig. 11]

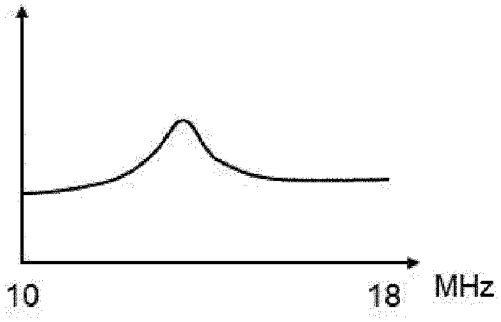
Fig. 11



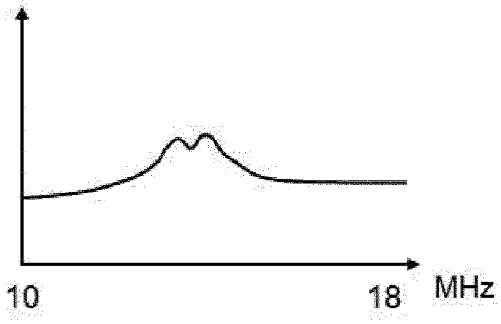
[Fig. 12]



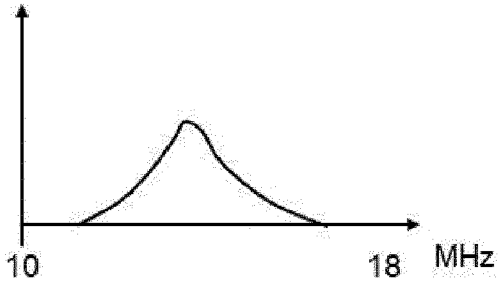
[Fig. 13]



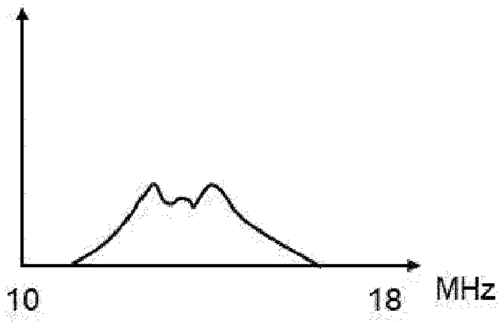
[Fig. 14]



[Fig. 15]



[Fig. 16]



[Fig. 17]