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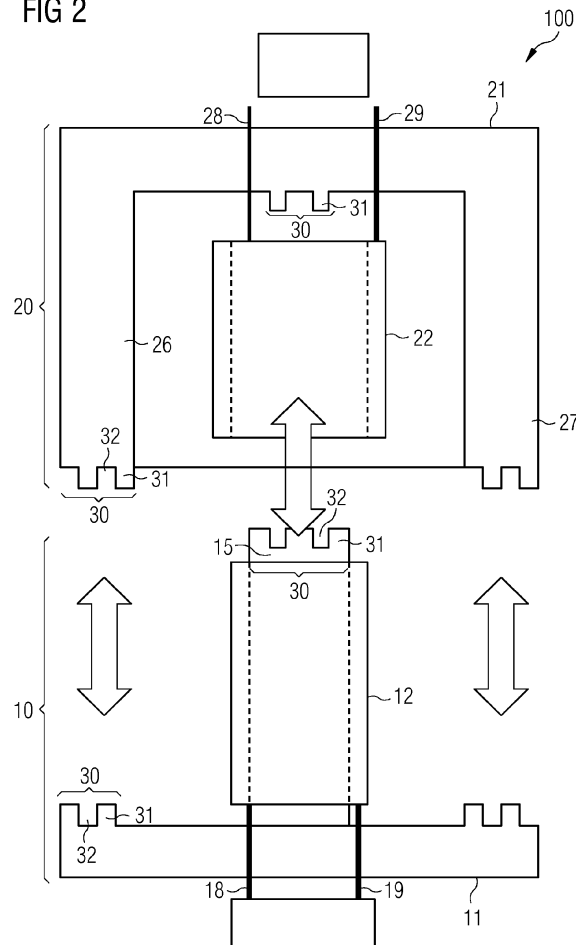
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5236 Rådal (NO)**(54) **Subsea transformer**

(57) A subsea transformer comprising a first transformer part (10) and a second transformer part (20) is provided. The first transformer part includes a first core segment (11) and a first transformer winding (12). The first transformer winding is supported by an elongated core member (15) of the first core segment. The second

transformer part includes a second core segment (21). A second transformer winding (22) is arranged around a hollow cylindrical space which is formed so that the first transformer winding can be inserted into the hollow cylindrical space for enabling a substantially co-axial arrangement of the first and second transformer windings.

FIG 2

Description

Field of the invention

[0001] The invention relates to a subsea transformer having mateable first and second transformer parts. The invention further relates to a subsea installation comprising such subsea transformer and an electric subsea device.

Background

[0002] Oil platforms are often used in offshore oil and gas production. More recently, processing facilities are being relocated to the ocean floor. Such subsea installations often require electric power to operate. Electric power can be provided subsea by means of an umbilical from a topside installation, or it may be provided via a subsea cable from an onshore site. For operating subsea equipment, such as a compressor or a pump, transformation of the electric power, e.g. to a lower voltage, may be necessary.

[0003] The use of electric power transformers in a subsea environment remains a technical challenge. Electric connections to such subsea transformers are necessary. In conventional systems, these connections can be provided by wet mate connectors. Such wet mate connectors are technically challenging. They may for example require flushing operations to remove seawater from electric contacts and several mechanical operations to secure the connection, and accordingly result in complex and expensive designs. Due to their complexity, there is further an increased risk of failure.

[0004] The subsea transformer itself is generally provided either in an atmospheric environment, which requires a transformer enclosure that can withstand the high pressures at the seabed, which may for example exceed 300 bar when the transformer is installed in water depths of more than 3,000 m. Another possibility is to provide the transformer in a pressure compensated enclosure, in which the pressure inside the enclosure is balanced to the pressure prevalent in the surrounding seawater. Since there is almost no pressure difference, the walls of the enclosure can be made thinner, and the enclosure has thus less weight. Such transformer enclosure is generally oil-filled, which improves the cooling of the transformer. Nevertheless, it requires a sophisticated pressure compensation system, which again can be prone to failure.

[0005] For both cases, it is technically challenging to provide an electric connection towards the transformer through the enclosure. Penetrators providing a connection through the wall of the enclosure and the above mentioned wet mate connectors are generally necessary.

[0006] When supplying a subsea installation with electric power, the electric power may exceed 1 MVA. The size of the connectors increases significantly with the electric power that is to be transferred. Also, the voltage

received by the subsea transformer may be in the medium or high voltage range, e.g. within 1,000 to 50,000 V. This imposes serious design challenges on the wet mate connectors.

[0007] The use of dry mate connectors is generally not feasible, since they can only be connected or disconnected above sea level. Accordingly, if a failure occurs for example in a subsea cable, the whole subsea device connected thereto needs to be pulled up to the surface. This would result in significant maintenance costs for such installations.

[0008] It is desirable to provide electric power subsea without the need for such wet mate connectors. Also, it is desirable to be able to service parts of a subsea installation without having to bring the whole subsea installation to the surface.

Summary

[0009] Accordingly, there is a need for mitigating at least some of the drawbacks mentioned above and in particular for providing electric power to a subsea installation without the need for wet mate connectors.

[0010] This need is met by the features of the independent claims. The dependent claims describe embodiments of the invention.

[0011] According to an embodiment of the invention, a subsea transformer comprising a first transformer part and a second transformer part is provided. The first transformer part of the subsea transformer comprises a first core segment of a transformer core of the subsea transformer, and a first transformer winding. The first transformer winding is supported by an elongated core member of the first core segment. The second transformer part comprises a second core segment of the transformer core and a second transformer winding, the second transformer winding being arranged around a hollow cylindrical space which is formed so that the first transformer winding can be inserted into the hollow cylindrical space for enabling a substantially coaxial arrangement of the first and second transformer windings. The first transformer part and the second transformer part are mateable into a position (mated position) in which the second winding is arranged substantially around the first winding and in which the subsea transformer is operable to provide electric power transformation. The first transformer part and the second transformer part can further be separated into a position (separated position) in which the first and second transformer parts are arranged distant to each other. The first transformer part and the second transformer part each comprise a water tight enclosure adapted to enable the mating of the first and second transformer parts in a subsea environment.

[0012] By using such subsea transformer, electric power may be provided to a subsea installation without the need for wet mate connectors. As an example, the subsea installation can be provided with the second transformer part, and can be installed at the ocean floor.

The first transformer part, which can comprise the electric connection to a topside installation or to an onshore installation, can then be installed. Should there be a fault in e.g. the power supply cable, e.g. in an umbilical or in a subsea cable, only the first transformer part needs to be retrieved for servicing the electric connection. The transformer may be a step up, a step down or an isolation transformer.

[0013] By having the second transformer winding arranged around the first transformer winding in the mated position, an efficient transformation of the electric power can be achieved. In the mated position, the second transformer winding may for example be arranged on top of the first transformer winding, so that over some axial distance, both transformer windings extend over the same axial distance.

[0014] In an embodiment, the first and second core segments are formed so that when the first transformer part and the second transformer part are in the mated position, the first and the second core segments form a closed magnetic core circuit. An efficient transformation of electric power may thus be achieved.

[0015] In an embodiment, the first transformer winding is a primary winding of the transformer, i.e. the winding to which electric power that is to be transformed as provided, while the second transformer winding is a secondary winding that is connectable to the load to which the transformed electric power is supplied. In other embodiments, the function of the first and second transformer windings may reverse.

[0016] When the first transformer part and the second transformer part are mated, at least 50 % of the axial extension of the first transformer winding may be arranged inside the second transformer winding. In some embodiments, the axial extension of the first transformer winding may be larger than the axial extension of the second transformer winding. In other embodiments, the axial extension of the second transformer winding may be larger than the one of the first transformer winding, or they may be equal.

[0017] In an embodiment, the first core segment is T-shaped and the second core segment is C-shaped. Mating of the first and second transformer parts may thus be facilitated.

[0018] In another embodiment, the first core segment is E-shaped and the second core segment is I-shaped. In such configuration, the transformer part having the I-shaped core segment may be the one that is retrievable, resulting in a lower weight and thus in an easier retrieval of the transformer part. Further, the subsea transformer may be a multi-phase transformer, and it is possible to provide all transformer windings of the same type of the multi phase transformer on the E-shaped core segment (i.e. all first transformer windings are located on the E-shaped core segment).

[0019] When the first transformer part and the second transformer part are mated, the first and second core segments may be configured such that they form in com-

bination a three-limbed transformer core having two side legs and an inner leg. One of the side legs or the inner leg may provide the elongated core member which supports the first transformer winding; the first transformer winding may for example be wound around the respective leg. In such configuration, the two side legs can close the magnetic flux path, thus providing for an efficient power transformation. Furthermore, the two side legs may be used for further transformer windings, e.g. for providing a three phase subsea transformer.

[0020] In an embodiment, the subsea transformer is a three phase transformer, and the first and second windings are provided for a first phase of the three phases. The transformer may then further comprise a third and a fourth transformer winding for the second phase and a fifth and a sixth transformer winding for the third phase. The third and fifth transformer windings may be part of the first transformer part, and the fourth and sixth transformer windings may be part of the second transformer part. The additional windings may be configured similar to the first and second transformer windings. In particular, they may be configured such that when the first and second transformer parts are mated, each pair of windings is arranged around one leg of a three-limbed transformer core. Windings 1, 3 and 5 may for example be primary windings, while windings 2, 4 and 6 may be secondary windings, or vice versa.

[0021] In particular, when the subsea transformer is in the mated position, the transformer windings for each phase may be coaxially arranged around one of the three legs of the transformer core.

[0022] In an embodiment, the first core segment and the second core segment each have corresponding mating surfaces at which the first core segment abuts the second core segment in the mated position to close the magnetic core circuit. Corresponding mating surfaces on the first and second core segments (i.e. the surfaces that abut each other when the subsea transformer is in the mated position) may have complementary protrusions and recesses which allow the mating of the corresponding mating surfaces and generate overlaps of the core segments. Generally, there will be a small gap at the positions at which the first and second core segments meet, i.e. at the mating surfaces. By using the protrusions and recesses in the mating surfaces to generate an overlap, the effect of this gap can be reduced. Accordingly, the efficiency of the subsea transformer can be improved. Such gaps may for example be caused by an enclosure or encapsulation of the respective core segments by the water tight enclosure.

[0023] The protrusions may for example include at least two fingers on one or both mating surfaces. These may engage corresponding recesses on the respective other mating surface. An effective overlap is thus achieved.

[0024] In an embodiment, the water tight enclosure is formed around the first and/or second transformer winding by embedding the respective transformer winding in

a synthetic material. Preferably, the first and/or second transformer windings are embedded in a polymer material, such as POM (polyoxymethylene) or PEEK (polyetheretherketone). As an example, the enclosure for the second transformer winding may be manufactured by winding the second transformer winding on a tube and coating it with the synthetic material, e.g. by dipping the winding into the synthetic material, such as a resin. Afterwards, it may be machined in order to remove access coating material. The first transformer winding may be manufactured in a similar process.

[0025] The water tight enclosure may be adapted to embed the respective transformer winding and to be in direct contact with sea water when the subsea transformer is installed subsea. By using such type of casing or enclosure around the first and/or second transformer windings, an efficient transfer of heat from the respective transformer winding to a surrounding ambient medium, such as seawater, can be achieved, since the heat only needs to be transported across the layer of synthetic material, which may be relatively thin. On the other hand, the first and/or second transformer windings can be effectively protected from the ambient medium, e.g. from the surrounding seawater.

[0026] In an embodiment, the water tight enclosure may be formed around the first and/or second core segments by embedding a section of the respective core segment, in particular a section including the mating surfaces, in synthetic material, preferably in a polymer material, such as the above mentioned POM or PEEK. Again, the enclosure may be manufactured as described above with respect to the transformer windings, i.e. by coating the transformer core segments with the synthetic material, for example by dipping the core segments into such material. The water tight enclosure can be configured such that the material embedding the core section is in direct contact with surrounding sea water when the subsea transformer is installed subsea. Again, an efficient heat exchange with surrounding ambient medium can be achieved via the synthetic material. The first or second transformer winding and the respective core segment may be coated together in a single step, or they may be coated separately with the synthetic material. It should be clear that not the whole respective transformer part may be embedded in the synthetic material. As an example, the water tight enclosure of the respective transformer part may comprise an opening, such as a small service hatch, through which the electric connection between the respective cable and the transformer winding can be accessed and can be established/serviced.

[0027] In some embodiments, the first and/or the second transformer part may include a heat transfer device for transporting heat from the vicinity of the first or second transformer winding towards ambient seawater when the subsea transformer is installed subsea. Such heat transfer device may for example be a heat pipe. Accordingly, a more efficient cooling of the first and/or second trans-

former winding may be achieved. This is particularly beneficial for the first transformer winding, which, in the mated position, is located within the second transformer winding, and furthermore is wound around the elongated core member of the first core segment. The operating temperature of the first transform winding may thus be reduced effectively by means of the heat transfer device.

[0028] The first transformer part may for example comprise a heat pipe arranged between the elongated core member and the first transformer winding.

[0029] The heat pipe may comprise a closed fluid circuit, wherein the fluid is evaporated at a hot section or end of the heat pipe, from which heat is to be conducted away, and thereby takes up heat, wherein the vapor condenses at the other end of the heat pipe, which is in contact with a cooling medium, e.g. surrounding seawater or a heat sink conducting the heat to the surrounding seawater. At the cold end of the heat pipe, the vapor condenses, thereby transferring the heat to the cold end. The condensed fluid then returns to the hot end, e.g. by means of capillary action or gravity action. An efficient heat transfer away from the respective transformer winding can thus be achieved.

[0030] The subsea transformer may be adapted to provide a transformation of electric power within a power range of about 100 kVA to about 10 MVA, preferably within a range of about 500 kVA to about 5 MVA. Accordingly, the subsea transformer may be capable of providing transformed electric power for operating processing equipment, such as a subsea pump or subsea compressor.

[0031] The subsea transformer may for example be adapted for transforming an received voltage which is within a voltage range of about 10,000 V to about 100,000 V, e.g. at 38,000 V or 66,000 V into a voltage at the secondary winding which is within a range of about 500 V to about 10,000 V, e.g. to a voltage of 690 V, 900 V, 6 kV or the like. It should be clear that the subsea transformer will be dimensioned in accordance with the particular application for which it is used.

[0032] The subsea transformer may furthermore comprise a fastening element for holding the first transformer part and the second transformer part in the mated position. The fastening element may for example comprise a clamp. Other fastening elements, such as bolts, interlocking elements or the like are also conceivable. In particular, the fastening element can be adapted to be operable by an ROV (remotely operated vehicle). The fastening element can thus be engaged and disengaged while the subsea transformer is installed at the subsea location.

[0033] One of the first or second transformer parts may further comprise an electric connection to a power source. It may for example comprise a dry mate connection to an umbilical or a subsea cable. The first of second transformer part may comprise a termination assembly for terminating a cable providing a connection to a power source, such as an umbilical or a subsea cable.

[0034] According to a further embodiment of the present invention, a subsea installation comprising a subsea transformer in any of the above described configurations is provided. The subsea installation further comprises an electric subsea device. The electric subsea device is electrically connected to the subsea transformer to receive electric power via the subsea transformer. The first or the second transformer part may be mechanically attached to the electric subsea device. In particular, the respective transformer part may be attached to the electric subsea device before being installed subsea. Such subsea installation has advantages similar to the ones outlined further above.

[0035] In particular, the subsea device together with one transformer part can be installed subsea. The power supply connection to the electric subsea device can then be established by mating the other transformer part (which has an electric connection to a topside installation or a land-based installation for power supply) with the transformer part which was installed subsea. This can be done without the need for wet mate connectors, and no electric contacts are exposed to the seawater during the connection process.

[0036] The subsea electric device may for example be a subsea switchgear, a subsea drive of a subsea motor, such as a pump or compressor motor, a variable speed drive (VSD), a subsea power distribution unit or the like. In other embodiments, the subsea electric device may be a control and/or communication device.

[0037] In an embodiment, the subsea installation further comprises a frame or a skid, wherein the first or second transformer part and the electric subsea device are mechanically mounted to the frame or skid, respectively. Installation and retrieval of the subsea installation is thus facilitated. The skid can first be installed without any electric connection and the connection to the power source can then be established by mating the two transformer parts.

[0038] The subsea installation may comprise a dry mate electric connection between the transformer part that is mounted to the frame or skid and the electric subsea device. Such electric connection does generally not need to be replaced or disconnected after installation subsea, so that a dry made connection is feasible at this position.

[0039] In a further embodiment of the present invention, a subsea connector may be provided comprising a subsea transformer according to any of the above configurations, wherein the first connector part may comprise the first transformer part and a second connector part may comprise the second transformer part. An electric connection may thus be established without making use of a wet mate connector and without exposing any electric contact to seawater.

[0040] The features of the embodiments of the invention mentioned above on those yet to be explained below can be combined with each other unless noted to the contrary.

Brief description of the drawings

[0041] The foregoing and other features and advantages of the invention will become further apparent from the following detailed description read in conjunction with the accompanying drawings. In the drawings like reference numerals refer to like elements.

Figure 1 is a schematic diagram illustrating a prior art transformer.

Figure 2 is a schematic diagram illustrating a subsea transformer according to an embodiment of the invention, the subsea transformer being in a separated position.

Figure 3 is a schematic diagram illustrating the subsea transformer of figure 2 in the mated position.

Figures 4A to 4C are schematic diagrams illustrating the mating of two parts of a subsea transformer according to an embodiment of the invention, wherein figure 4A is a sectional side view, figure 4B is a top view and figure 4C is a sectional side view in the mated position.

Figure 5 is a schematic diagram illustrating a transformer core having two core segments which can be used in embodiments of the present invention.

Figure 6 is a schematic diagram illustrating a subsea installation according to an embodiment of the invention.

Detailed description

[0042] In the following, embodiments of the invention will be described in detail with reference to the accompanying drawings. It is to be understood that the following description of the embodiments is given only for the purpose of illustration and is not to be taken in a limiting sense.

[0043] It should further be noted that the drawings are to be regarded as being schematic representations only, and elements in the drawings are not necessarily to scale with each other. Rather, the presentation of the various elements is chosen such their function in general purpose become apparent to a person skilled in the art.

[0044] Figure 1 is a schematic drawing showing a conventional transformer 200 having a primary winding 201, a secondary winding 202 and a transformer core 203. A primary AC voltage applied to primary coil 201 by the power source 204 results in the generation of a magnetic field. The transformer core 203 confines the magnetic flux and closely couples the primary and secondary windings 201, 202. Since the transformer core 203 has essentially a ring or toroidal shape, it forms a closed magnetic circuit. The transformer core 203 may for example

be a laminated steel core made out of high permeability steel or a similar metal alloy. The closed magnetic circuit design reduces transformer losses since it reduces the leakage of magnetic flux.

[0045] The transformer 200 can be configured as a step up or step down transformer, which depends on the ratio of the turns of the primary and secondary windings 201, 202. A larger number of turns of the secondary winding results in a step up transformer, while a lower number of turns of the secondary windings results in a step down transformer, in which the voltage supplied at the secondary winding 202 to the load 205 is lower than the primary voltage.

[0046] Figure 2 shows a subsea transformer 100 according to an embodiment of the invention. The subsea transformer 100 has a first transformer part 10 and a second transformer part 20. The first transformer part 10 comprises a first core segment 11 of the transformer core. The second transformer part 20 comprises a second core segment 21 of the transformer core. In the example of figure 2, the first core segment 11 is T-shaped, while the second core segment 21 is C-shaped. When put together, both transformer core segments 11, 21 form a complete transformer core of the subsea transformer 100. Note that in other configurations, different types of core segments may be used, for example E-shaped and I-shaped core segments as illustrated in figure 5.

[0047] The first core segment 11 of the first transformer part 10 comprises an elongated core member 15, which supports the first transformer winding 12, which is also comprised in the first transformer part 10. In the example of figure 2, the first transformer winding 12 is wound around the elongated core member 15, which is the central (or inner) leg of the three-limbed transformer core formed by core segments 11 and 21.

[0048] The second transformer part 20 comprises the second transformer winding 22, which is mounted to the second core segment 21. The second transformer winding 22 may for example be mechanically attached to the second core segment 22, e.g. by fastening elements such as a bracket, screws or the like (not shown). The second transformer winding 22 encloses a cylindrical space, which is sized so that the first transformer winding 12 fits into it. In particular, the arrangement of the first and second transformer windings 12 and 22 is such that when the first and second core segments 11, 21 are put together to form the three-limbed transformer core, the first transformer winding 12 is substantially coaxially arranged within the second transformer winding 22. When the first transformer part 10 and the second transformer part 20 are placed in the mated position, the first transformer winding 12 is located within the second transformer winding 22. This corresponds to a situation in which the first transformer winding 12 is wound onto a leg of the transformer core, and the second transformer winding 22 is wound on top of the first transformer winding 12. This results in an efficient transformation of electric power by the subsea transformer 100.

[0049] As can be seen in figure 2, the first and second core segments 11 and 21 each have mating surfaces 30 at which one core segment abuts the other core segment when the two transformer parts 10 and 20 are mated (see also figure 3). The mating surfaces 30 may have protrusions 31 and recesses 32. These are complementary on respective mating surfaces of the first and second transformer core segments. This way, there will not be a single gap at the positions at which the two transformer core segments meet, but there will be an interlocking between the two core segments. A gap in the transformer core will generally lead to a greater portion of the magnetic flux through the core not contributing to linking the primary and secondary transformer windings, thus increasing the leakage inductance. By the illustrated interlocked configuration of the mating surfaces, the leakage inductance may be reduced and the efficiency of the transformer 100 can be improved. Besides the tooth configuration of the mating surfaces 30, other configurations are certainly conceivable which provide an interlocking of the first and second core segments 11, 21 and which improve the efficiency of transformer 100.

[0050] In the example of figure 2, each mating surface 30 has at least two protrusions and two recesses, which are arranged such that corresponding mating surfaces 30 can engage each other in an interlocking manner. Different numbers of protrusions (or "teeth") are certainly also conceivable.

[0051] By engaging the first transformer part 10 with the second transformer part 20, as indicated by arrows in figure 2, the transformer 100 is brought into the mated position, in which the core segments 11 and 21 form a closed magnetic circuit, and in which the first transformer winding 12 is arranged within the second transformer winding 22. Either one of the first and second transformer windings 12, 22 can be operated as a primary winding, i.e. the winding connected to the voltage source and receiving the voltage that is to be transformed. The other of the two windings acts as a secondary winding, and is for example connected to a power distribution system/switchgear or directly to a load. It will depend on the particular application which one of the first and second transformer windings 12, 22 is connected to the power source and which one to the load.

[0052] The first transformer winding 12 has electric connections 18 and 19 for enabling a connection to the power source or load, whereas the second transformer winding 22 has the electric connections 28 and 29 for enabling a connection to the power source or load. The electric connections 18, 19 or 28, 29 may for example be implemented in form of a dry mate connector, a cable termination assembly or the like.

[0053] The mated position is shown in figure 3. As can be seen, the first core segment 11 is engaged with the second core segment 22, wherein respective mating surfaces 30 are engaged in an interlocking manner. The elongated core member 15 now forms the central leg of the three-limbed transformer core, which further compris-

es the outer core legs 26 and 27. The first transformer winding 12 is now arranged within the second transformer winding 22.

[0054] The operation of transformer 100 will now be described assuming that the first transformer winding 12 is the primary winding, although it should be clear that in other configurations, the first transformer winding 12 may be the secondary winding. An AC voltage applied as a primary voltage to the electric connections 18 and 19 of the first transformer winding 12 induces magnetic flux in the transformer core made up of the core segments 11 and 21. The magnetic field which is largely confined to the transformer core induces a current in the second transformer winding 22, which is connected directly or indirectly to a load via the electric connections 28 and 29. The electric connections 18, 19 and 28, 29 (input and output connections, respectively, in the present example), can be provided by respective connections to input and output cables. These input and output cables can be terminated to the first and second transformer windings (termination assembly) with proper field control.

[0055] When the first and second core segments are brought together in the mated position, the magnetic path through the transformer core is closed. The closing of the magnetic path in the outlined configuration introduces a small gap. Generally, a gap in the transformer core may be undesirable since it may increase the required magnetization force and may store energy that can not be used. For reducing the effect of such gap, it may be made as small as possible. The overlaps generated by the mating surfaces 30 between the first and second core segments reduce the gap effect. Furthermore, to improve the efficiency of the transformer, numerical optimization methods, such as simulation of the transformer or numerical calculation of the magnetic design may be used in order to optimize the winding/core layout.

[0056] The subsea transformer 100 can be configured to operate as a isolation transformer, or as a step up or step down transformer. The configuration can be achieved by choosing the appropriate turn ratio (or winding ratio) of the first and second transformer windings 12, 22. Since the first and second transformer windings are overlapping each other, a good magnetic coupling between the windings is enabled.

[0057] The subsea transformer illustrated in figures 2 and 3 is a single phase transformer. The subsea transformer 100 may also be configured as a three-phase transformer. By making use of the transformer core as shown in figures 2 and 3, a three-phase transformer may be achieved by providing two additional pairs of first and second transformer windings, one around each of the outer legs 26 and 27 of the three limbed transformer core. As an example, a third and a fourth transformer winding may be provided around leg 26, and a fifth and a sixth transformer winding may be provided around the leg 27. Of each pair of transformer windings, one winding is attached to the first core segment 11, while the other is attached to the second core segment 21, so that each

pair of windings can be separated by separating the first transformer part 10 from the second transformer part 20. Preferably, the inner transformer winding of each pair is wound around the respective leg of the transformer core, while the outer transformer winding of the pair forms a hollow space into which the other winding can be inserted.

[0058] In such three-phase configuration of subsea transformer 100, the use of a E-I core shape may be beneficial, in which one core segment is E-shaped and the other core segment is I-shaped. In such configuration, all primary windings may for example be the inner windings wound around the legs of the E-shaped core segment, while the secondary windings may be attached to the I-shaped core segment, or vice versa. A symmetric arrangement of the transformer windings of the subsea transformer 100 can thus be achieved.

[0059] Each transformer part 10, 20 further comprises an enclosure, which is not in detail shown in the figures. For most of each transformer part 10, 20, the enclosure is formed by embedding the respective transformer winding and core segment into a synthetic material, such as a polymer material. As an example, around each of the transformer parts, the material may be molded so as to protect the respective transformer winding and core segment from the ambient seawater when installed subsea. Furthermore, the material in which the transformer windings are embedded (designated by reference numerals 51 and 52 in figure 3) may serve as an isolating material for insulating the windings from each other. Furthermore, the material may be adapted to conduct the heat generated by the copper and core losses of the respective transformer part to the surrounding seawater. Embedding the transformer core segment and the transformer winding in the material may for example be performed under vacuum, so that no gas is confined within the molding material, thereby making it very pressure resistant. Accordingly, each transformer part 10, 20 only needs to comprise a very compact and lightweight enclosure, which greatly improves heat exchange with ambient seawater, and furthermore facilitates transport and installation of the subsea transformer 100. The enclosure may for example comprise a polymer material such as polyetheretherketone (PEEK) or polyoxymethylene (POM). Other types of material are also conceivable. In some embodiments, different parts of the respective transformer part 10, 20 may be embedded in different types of material.

[0060] The above mentioned input and output cables can be terminated at a particular cable termination assembly provided at each transformer part 10, 20. The termination may for example comprise an oil filled or gel filled chamber, and it may be accessible, e.g. via a service hatch or the like. The cable termination can be connected to the remaining part of the enclosure in a water tight manner, e.g. by molding around parts of the cable termination assembly.

[0061] As can be seen, by such enclosure, it is possible

to avoid the exposure of any electric contact to seawater. The two transformer parts 10, 20 can be engaged subsea without requiring any further measures with respect to the cleaning of electric contacts or the like. Since the electric power is inductively transferred from the primary to the secondary winding via the transformer core segments 11, 22, there is no need for such exposure. During installation, one transformer part of the subsea transformer 100 may for example be mounted to the frame of a subsea installation, which may for example comprise a pump, a compressor or the like receiving power via the subsea transformer 100. After installation of the subsea installation, and electric connection can simply be established by engaging the other transformer part with the already installed part of the subsea transformer, the other part comprising the cable connection to the topside installation or an onshore site. As an example, mating may be performed in a vertical manner as illustrated in figure 2 or 6, so that the other transformer part would only need to be lowered down on the first transformer part which is already installed subsea. Power supply to the subsea installation can thus be achieved without requiring any wet mate or dry mate connectors. In particular, the wet mate functionality of the typically used wet mate electrical connectors is now transferred to the two transformer parts of subsea transformer 100. Since the mating of the two transformer parts is relatively simple, complicated mechanical mechanisms, such as typically used inside wet mate connectors, can be avoided, thereby simplifying the construction and improving reliability. Both transformer parts can be directly exposed to sea water without requiring a further subsea canister, thereby greatly improving the cooling. Even in the mated position, the cooling will generally be sufficient.

[0062] If cooling is not sufficient, the subsea transformer 100 may additionally comprise one or more heat pipes, which may for example be arranged between the elongated core member 15 and the first transformer winding 12, for conducting heat away from this intermediate space towards the sea water. The general function of a heat pipe is known to the skilled person, so it will not be explained in greater detail here. Such heat pipe may also be provided for example between turns of the outer transformer winding, here the second transformer winding 22. Another possibility can be the providing of a hollow elongated core member 15, through which seawater can flow for supporting the cooling of the core.

[0063] In embodiments of the subsea transformer 100, all parts can thus be passive parts; no moving mechanical parts are required for establishing an electric connection to the subsea installation. Subsea transformer 100 can thus be a truly solid state construction which brings about several advantages, such as low maintenance, reduced component count and increased reliability.

[0064] The molded material which may be cast around each of the transformer parts 10, 20 can also be properly shaped to achieve the proper alignment of the first and second transformer parts 10 and 20. The inside of the

second transformer winding 22 is for example made hollow in such way that its inner diameter essentially corresponds to the outer diameter of the material molded around the first transformer winding 12, so that the first transformer winding 12 can be slidably received inside the hollow space. Furthermore, the shape of the mating surfaces 30 can be made so as to provide a guidance for the mating process, in particular in the final stage of engagement of the two transformer parts 10, 20. A secure and properly aligned engagement of the two transformer parts can thus be ensured.

[0065] The part of the enclosure comprising material in which the first transformer winding 12 is embedded is designated with reference numeral 51 and the part of the enclosure comprising material in which the second transformer winding 22 is embedded is designated with reference numeral 52 in figure 3.

[0066] Figures 4A to 4C show a sectional side view of the subsea transformer 100 of figures 2 and 3. In figure 4A, the first and second transformer parts 10, 20 are in the separated position before engagement. The electric connections 18, 19 and 28, 29 to the respective first or second transformer windings 12, 22 are visible. The legs of the transformer core are parallel to the image plane in figures 4A and 4C, while the parts of the transformer core connecting the legs run perpendicular to this plane.

[0067] Figure 4B shows a top view. The first (inner) transformer winding 12 and the second (outer) transformer winding 22 are visible. Figure 4C shows the mated position. The first transformer winding 12 and the elongated core member 15 are now inserted into the second transformer winding 22, and both transformer windings now overlap completely. In other configurations, the overlap may be smaller, yet it should in general be more than 50 %, preferably more than 75 % of the length of the inner transformer winding.

[0068] Figure 5 shows an alternative transformer core (E-I type), which may be used in embodiments of the invention. As mentioned above, three primary transformer windings may for example be attached to the first core segment 11, while three secondary transformer windings may be wound around the three core legs 25, 26 and 27. In such configuration, the secondary windings may be inner windings, while the primary windings may be outer windings, into which the inner windings are inserted. In other configurations, the inner windings on the E-shaped core segment may be the primary windings.

[0069] As can be seen, several configurations of the transformer core of subsea transformer 100 are conceivable. As an example, the cores may also be modified to enclose more of the windings, such as for example P-cores. Furthermore, the core shape may be adapted in accordance with the magnetic design of the transformer.

[0070] Figure 6 is a schematic drawing showing a subsea installation 60. The subsea installation 60 comprises a subsea transformer 100 according to any of the above described configurations, and an electric subsea device 61. It should be clear that further electric devices may be

provided in subsea installation 60. Electric subsea device 61 may for example be a switchgear, a motor drive (e.g. variable speed drive), a subsea power distribution unit or the like. Subsea installation 60 further comprises a skid or frame 62, towards which the subsea electric device 61 is mounted. Furthermore, the second transformer part 20 of subsea transformer 100 is mounted to the frame or skid 62. A jumper cable 64 provides an electric connection between the transformer part 20 and the subsea electric device 61. The other first transformer part 10 is connected via umbilical 63 to a topside installation 80. At topside installation 80, electric power may be produced, for example by means of a diesel engine or a gas turbine. The electric power is transmitted subsea via umbilical 63.

[0071] The frame 62 together with the subsea electric device 61 and the second transformer part 20 can now be installed at a subsea location, they may be configured for installation in water depths in excess of 3,000 m. For providing an electric connection, the first transformer part 10 can be lowered down to the second transformer part 20 and can be brought into engagement therewith, such as illustrated with respect to figures 2 and 3.

[0072] In the configuration of figure 6, the three primary windings 12 will be received by the hollow secondary windings 22. Note that a three-phase transformer 100 is depicted in figure 6. Transformed electric power can be provided to subsea electric device 61 without the use of any wet mate connectors. For servicing, the first transformer part 10 can in a similar way be retrieved by the topside installation 80, without the use of any wet mate connector. When installed, both transformer part 10 may be firmly attached to transformer part 20, e.g. by a fastening element such as a clamp, a bolt or the like. The fastening element can be ROV operable, so that it can be engaged and disengaged by remote operation from the topside or onshore installation.

[0073] As can be seen from the above, the subsea transformer according to embodiments of the present invention brings about several advantages. Besides the avoidance of wet mate connectors and the relatively simple mating procedure, the subsea transformer is also relatively compact and light weight. This is in particular achieved by providing an enclosure in form of a molding around the transformer winding and the core segment, thereby avoiding the use of large pressure vessels or of pressure compensated enclosures and respective pressure compensation systems. Also, since the mould around the transformer core and transformer winding is in direct contact with sea water when installed subsea, cooling of the respective transformer part is improved.

[0074] Features of the above outlined embodiments can be combined with each other. The skilled person will appreciate that the above described embodiments are only examples given for the purpose of illustration, and that modifications may be made without departing from the scope of the invention.

Claims

1. A subsea transformer comprising a first transformer part (10) and a second transformer part (20), wherein the first transformer part comprises

- a first core segment (11) of a transformer core of the subsea transformer (100),
- a first transformer winding (12), the first transformer winding (12) being supported by an elongated core member (15) of the first core segment (11),

and wherein the second transformer part (20) comprises

- a second core segment (21) of the transformer core,
- a second transformer winding (22), the second transformer winding (22) being arranged around a hollow cylindrical space which is formed so that the first transformer winding (12) can be inserted into said hollow cylindrical space for enabling a substantially coaxial arrangement of the first and second transformer windings (12, 22),

wherein the first transformer part (10) and the second transformer part (20) can be mated into a position in which the second transformer winding (22) is arranged substantially around the first transformer winding (12) and in which the subsea transformer (100) is operable to provide electric power transformation, and can further be separated into a position in which the first and second transformer parts (10, 20) are arranged distant to each other, wherein the first transformer part (10) and the second transformer part (20) each comprise a water tight enclosure (51, 52) adapted to enable the mating of the first and second transformer parts (10, 20) in a subsea environment.

2. The subsea transformer according to claim 1, wherein the first and second core segments (11, 21) are formed so that when the first transformer part and the second transformer part are in the mated position, the first and second core segments (11, 21) form a closed magnetic core circuit.
3. The subsea transformer according to claim 1 or 2, wherein when the first transformer part (10) and the second transformer part (20) are mated, at least 50% of the axial extension of the first transformer winding (12) is arranged inside the second transformer winding (22).
4. The subsea transformer according to any of the preceding claims, wherein the first core segment (11) is T-shaped and wherein the second core segment

(21) is C-shaped.

5. The subsea transformer according to any of claims 1-3, wherein the first core segment (11) is E-shaped and wherein the second core segment (21) is I-shaped. 5
6. The subsea transformer according to any of the preceding claims, wherein when the first transformer part (10) and the second transformer part (20) are mated, the first and second core segments (11, 21) form in combination a three limbed transformer core having two side legs (26, 27) and an inner leg (15; 25), a side leg or the inner leg providing said elongated core member, the first transformer winding (12) being wound around the respective leg. 10
7. The subsea transformer according to any of the preceding claims, wherein the subsea transformer (100) is a three phase transformer, the first and second windings (12, 22) being provided for a first phase, the transformer further comprising a third and a fourth transformer winding for the second phase and a fifth and a sixth transformer winding for the third phase, the third and fifth transformer windings being part of the first transformer part (10), the fourth and sixth transformer windings being part of the second transformer part (20). 15
8. The subsea transformer according to any of the preceding claims, wherein the first core segment (11) and the second core segment each (21) have corresponding mating surfaces (30) at which the first core segment abuts the second core segment to close the magnetic core circuit, wherein corresponding mating surfaces on the first and second core segments have complementary protrusions (31) and recesses (32) which allow the mating of the corresponding mating surfaces and generate overlaps of the core segments (11, 21). 20
9. The subsea transformer according to any of the preceding claims, wherein the water tight enclosure (51, 52) is formed around the first and/or second transformer winding (12, 22) by embedding the respective transformer winding in a synthetic material, preferably in a polymer material, more preferably in POM or in PEEK. 25
10. The subsea transformer according to any of the preceding claims, wherein the water tight enclosure is formed around the first and/or second core segments (11, 21) by embedding sections of the respective core segment including the mating surfaces in a synthetic material, preferably in a polymer material, more preferably in POM or in PEEK. 30
11. The subsea transformer according to any of the preceding claims, wherein the first and/or second transformer part (10, 20) includes a heat transfer device, preferably a heat pipe, for transporting heat from the vicinity of the first or second transformer winding towards ambient seawater when the subsea transformer is installed subsea. 35
12. The subsea transformer according to any of the preceding claims, wherein subsea transformer (100) is adapted to provide transformation of electric power within a range of about 100 kVA to about 10 MVA, preferably within a range of about 500 kVA to about 5 MVA. 40
13. The subsea transformer according to any of the preceding claims, further comprising a fastening element for holding the first transformer part (10) and the second transformer part (20) in the mated position, the fastening element preferably comprising a clamp. 45
14. A subsea installation comprising a subsea transformer (100) according to any of claims 1-13 and an electric subsea device (61), wherein the electric subsea device (61) is electrically connected to the subsea transformer (100) to receive electric power via the subsea transformer, wherein the first or the second transformer part (10, 20) is mechanically attached to the electric subsea device (61). 50
15. The subsea installation according to claim 14, further comprising a frame or skid (62), wherein said first or second transformer part (10, 20) and the electric subsea device (61) are mechanically mounted to the frame or skid (62). 55

FIG 1

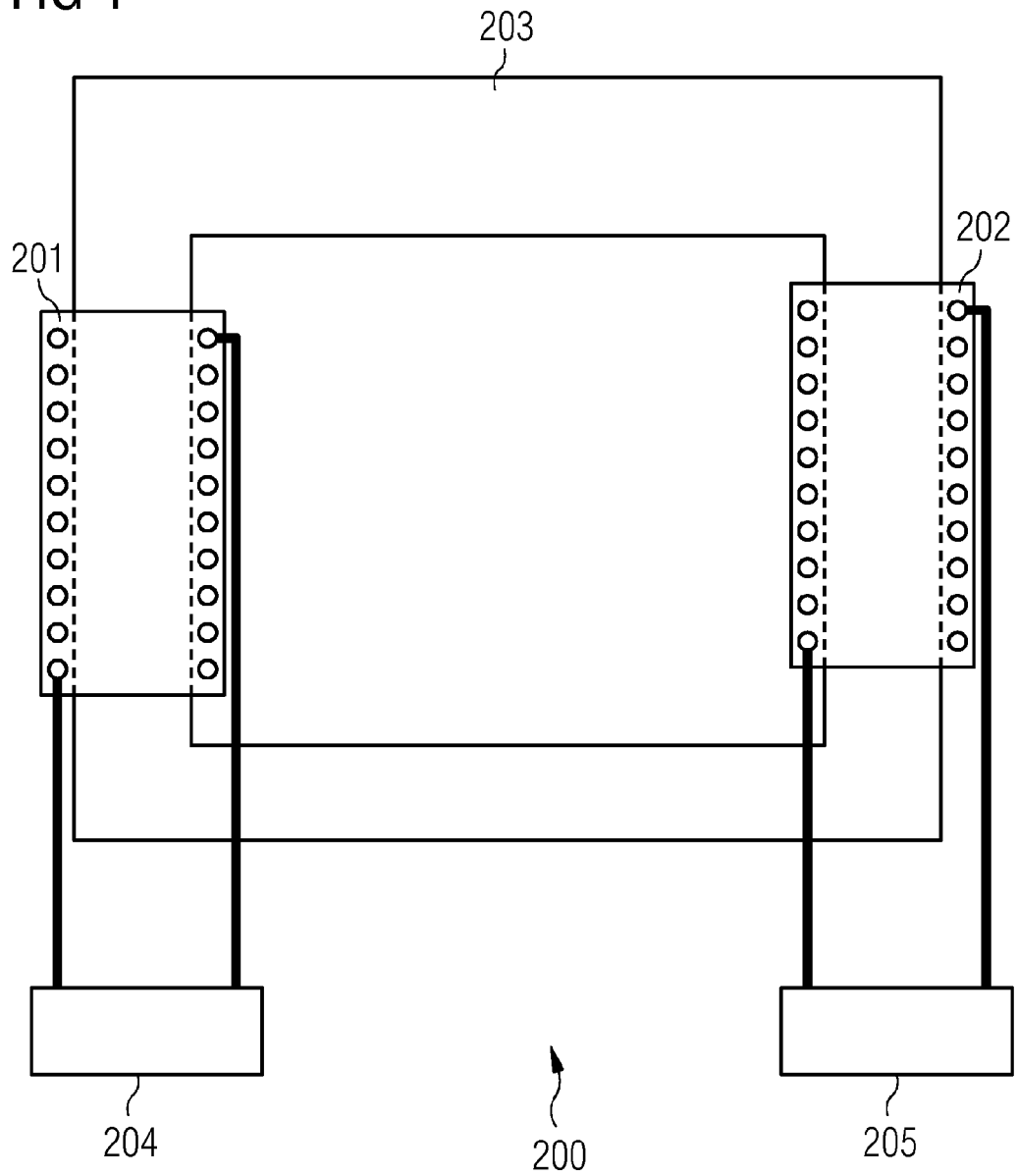


FIG 2

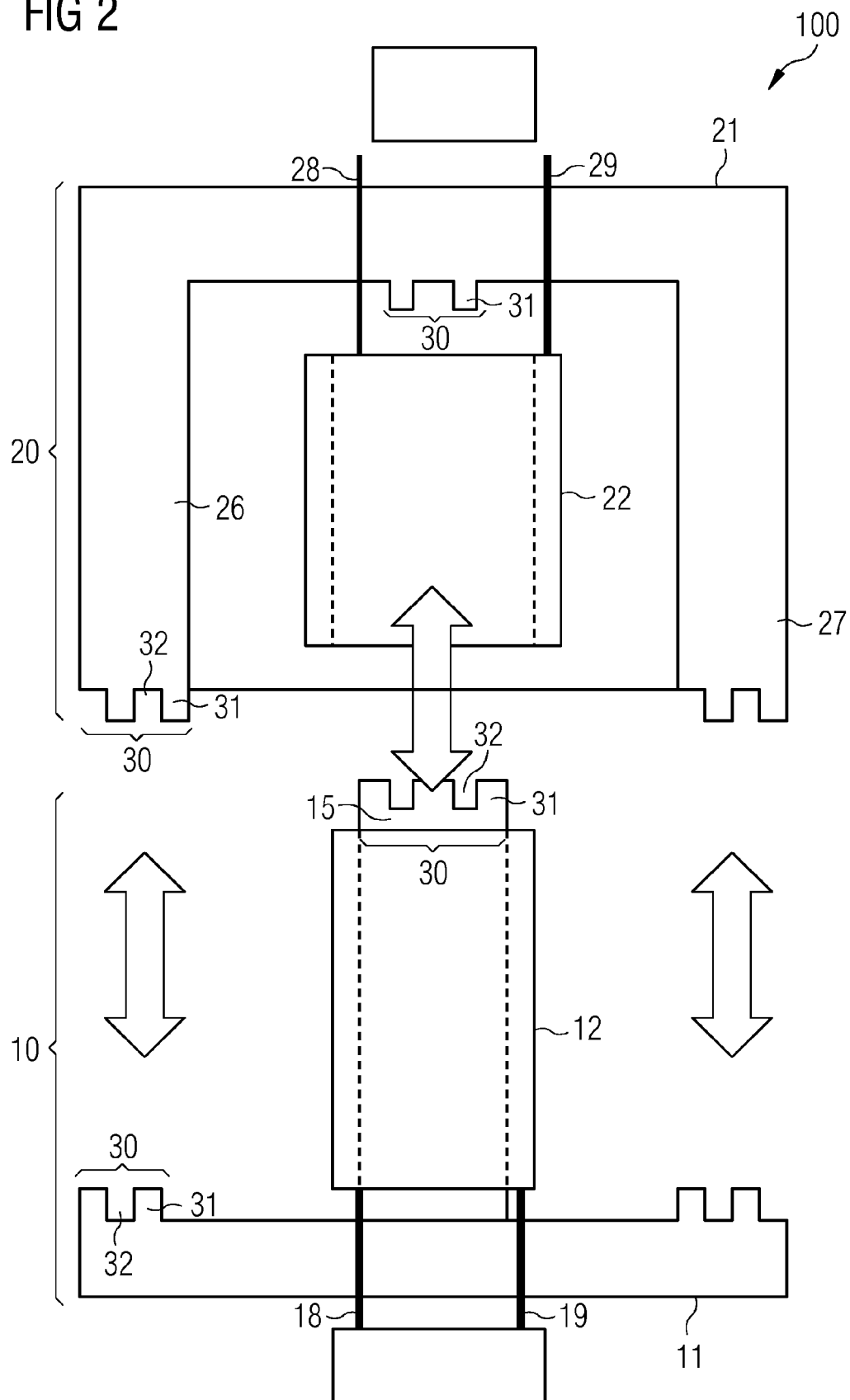


FIG 3

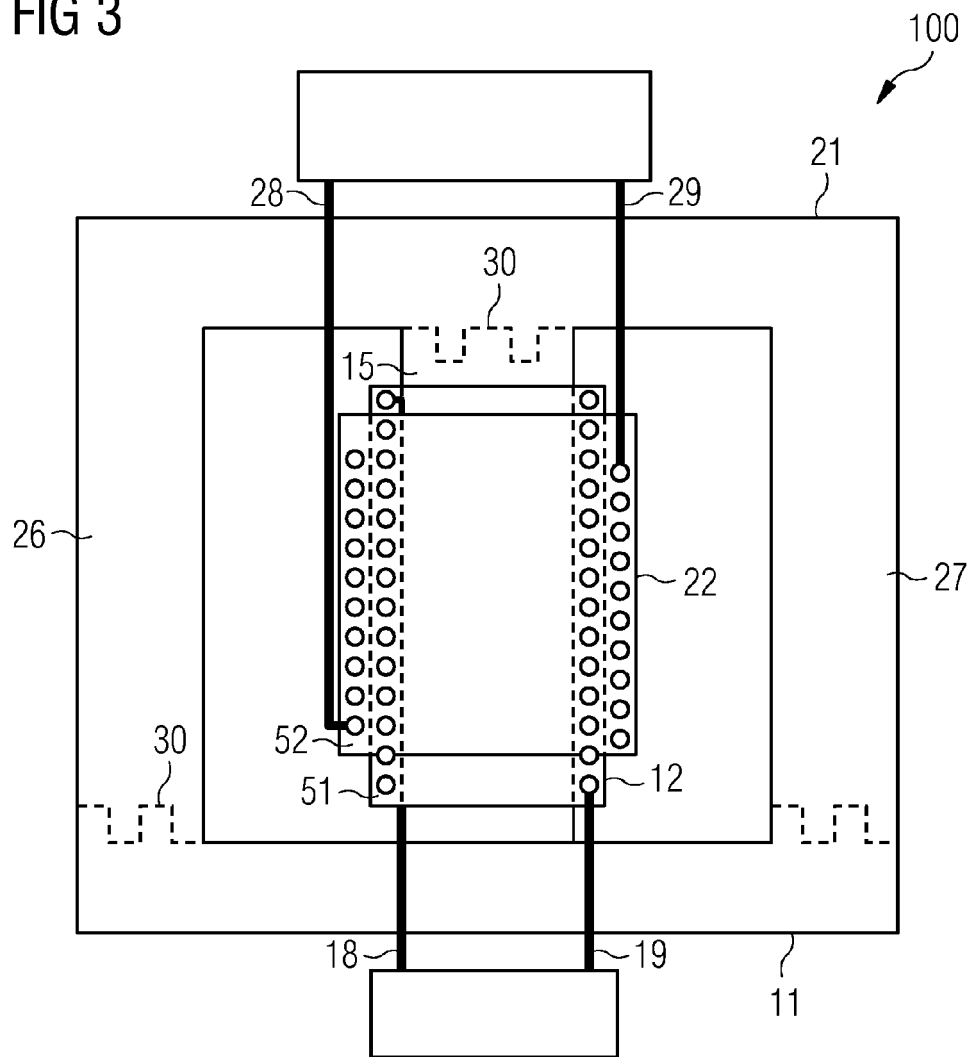


FIG 4A

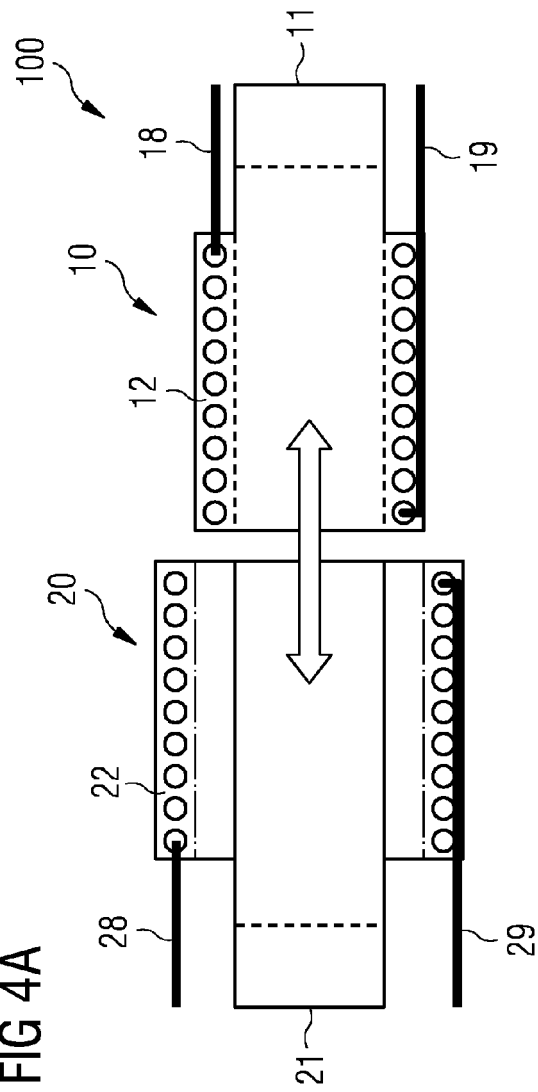


FIG 4B

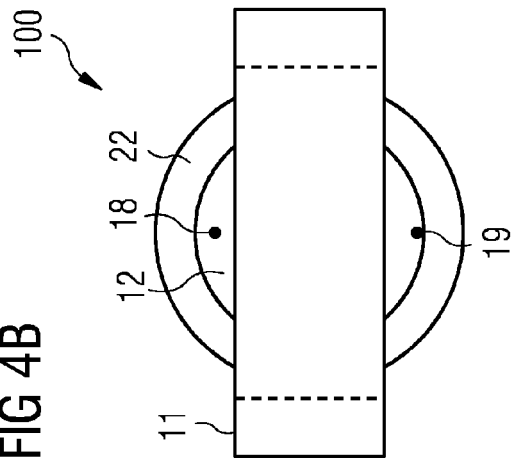


FIG 4C

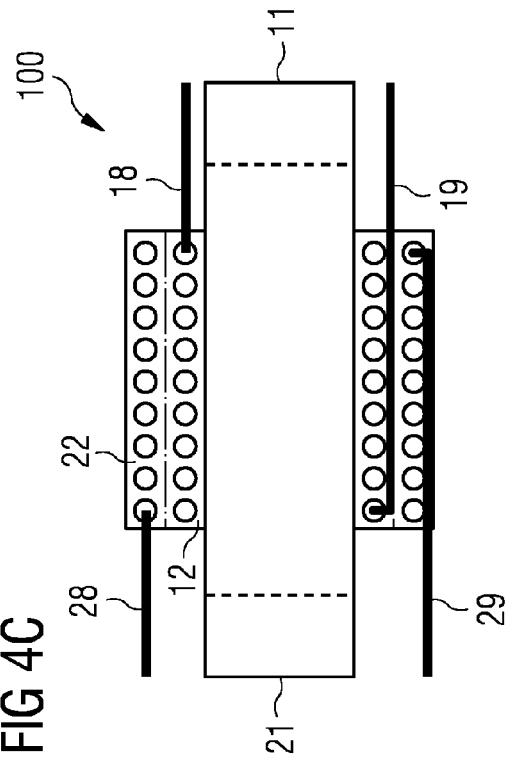


FIG 5

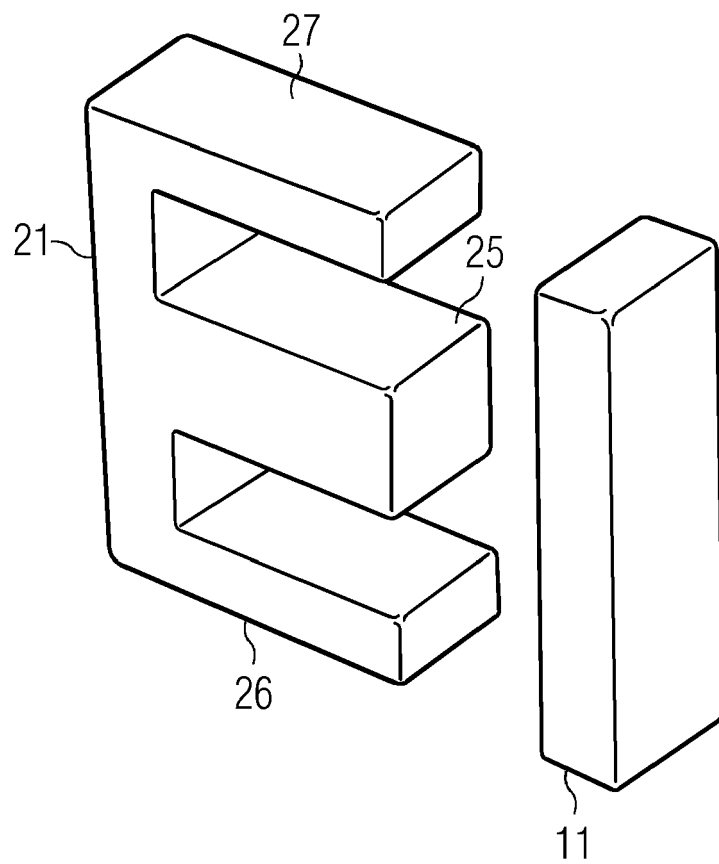
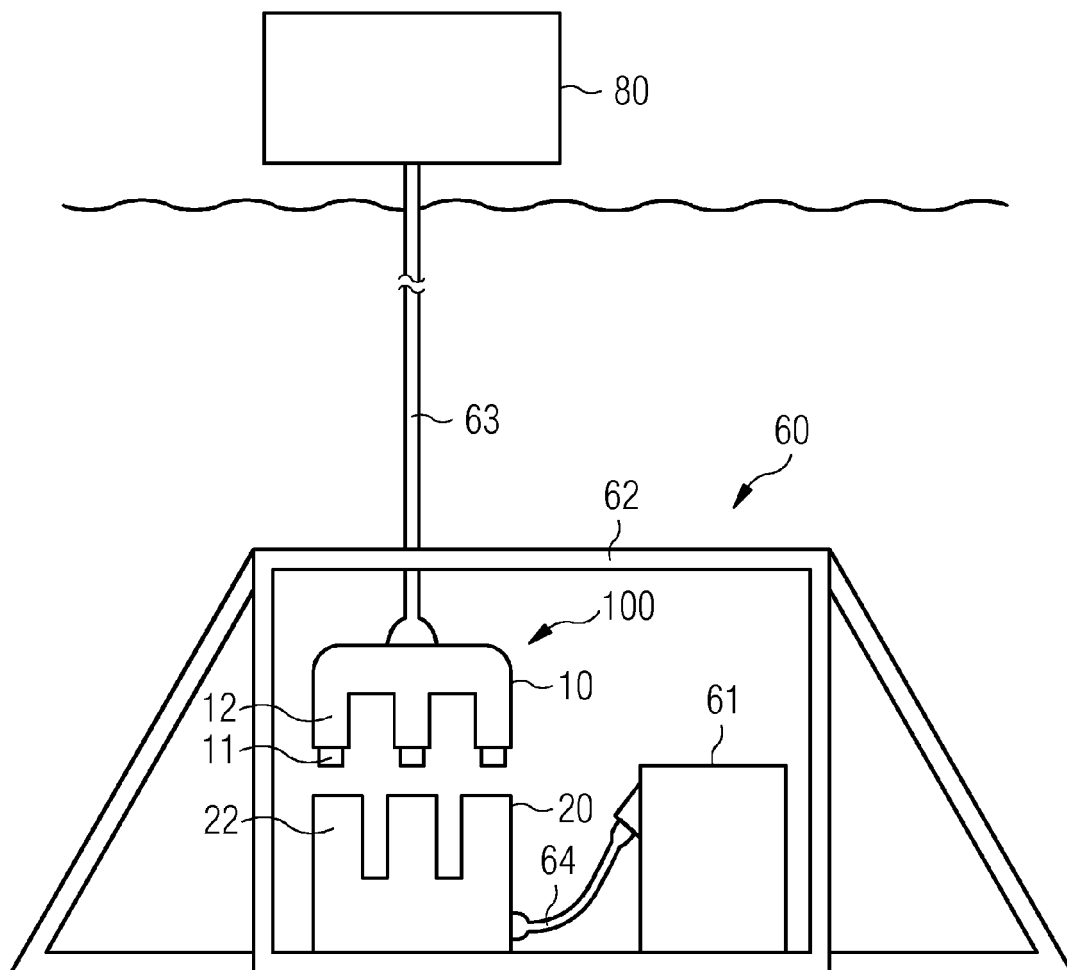


FIG 6





EUROPEAN SEARCH REPORT

Application Number
EP 12 17 8240

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	GB 2 458 476 A (ROLLS ROYCE PLC [GB]) 23 September 2009 (2009-09-23) * abstract * * page 8, line 32 - page 12, line 2; claims 1-19; figures 2,3,4,5,7 * -----	1-8, 10-15	INV. H01F27/26 H01F27/30
A	EP 2 447 962 A1 (NEXANS [FR]) 2 May 2012 (2012-05-02) * paragraph [0022] - paragraph [0025]; claims 1, 8; figures 1, 2a * -----	1-15	ADD. H01F27/02 H01F38/14
			TECHNICAL FIELDS SEARCHED (IPC)
			H01F
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 23 January 2013	Examiner Warneck, Nicolas
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ----- & : member of the same patent family, corresponding document	

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**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 12 17 8240

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The members are as contained in the European Patent Office EDP file on
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23-01-2013

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			US 2012126924 A1	24-05-2012
