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(54) Title: SUBSEA CABLE JACKET SPLICE

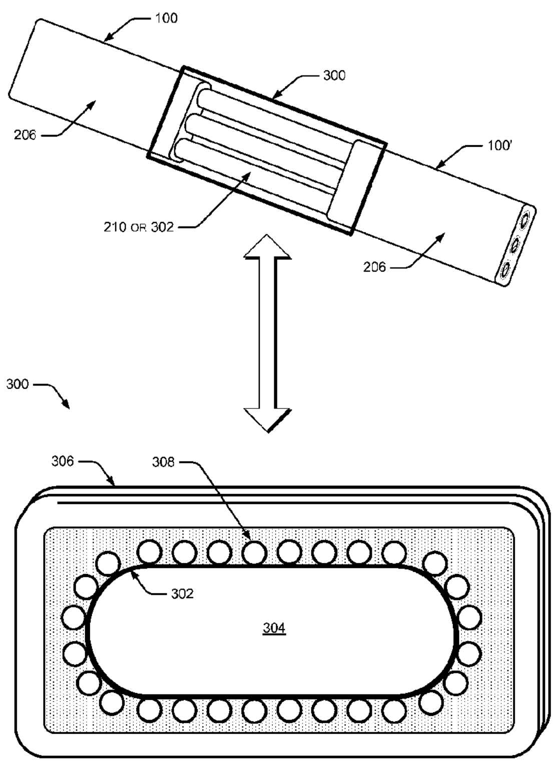

FIG. 6

(57) Abstract: A subsea cable jacket splice is provided. Example materials and techniques can be applied to armorless cables that are used in numerous harsh environments, such as subsea applications. In an implementation, a polymer is molded and fusion-bonded to power cables to splice or repair a nonmetal polymeric jacket for continued use in harsh environments. The splice allows much longer armorless cables to be created. The polymer may be a tetrafluoroethylene (ETFE), a poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) with adjusted copolymer ratio, a fluorinated ethylene propylene (FEP), a polyvinyl fluoride (PVF), a polypropylene (PP), a polyalkyletherketone, a polyaryletherketone, a polyamide, or a nylon. Barrier or reinforcement agents may also be added to the polymer for increased tensile strength, resistance to hot fluids, and resistance to penetration of corrosives.

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SUBSEA CABLE JACKET SPLICE

BACKGROUND

[0001] Power cables for downhole electric submersible pumps (ESPs) are typically rated at 3kV (kilovolts), 4kV, or 5kV and utilize either a flat or round cable profile. Flat cables are more commonly used than round because they prevent spatial clearance issues.

[0002] Sometimes in order to achieve a desired length of cable or to repair these cables, a cable-to-cable splice is performed. Splice and repair techniques replace each layer of the cables, such as insulation, dielectric, and jacketing, with the same or similar materials for that layer over the span of the splice or repair site. Conventional splice techniques consist of welds, tape layers, convection wrap molding, and so forth, to ensure that the splice or repair has sufficient integrity to meet downhole operating conditions. The final component of any splice or repair is a conventional metal armor, a layer that protects all of the underlying components.

[0003] In certain applications, the cable is “armorless,” without conventional metal armor. The jacket material used in lieu of metal armor is robust enough to be exposed to hot, corrosive, and abrasive downhole fluids without need for the conventional metal protective armor. But currently there is no technique for splicing and repairing such armorless cables because the materials used for splicing conventional cables cannot be directly exposed to harsh downhole fluids.

SUMMARY

A subsea cable jacket splice is described. An example method includes detecting a gap in a nonmetallic jacket of a cable for powering a downhole electric submersible pump (ESP), and molding a polymer around at least part of the cable to seal the nonmetallic jacket at the gap. An example method of splicing the power cable for a downhole electric submersible pump (ESP) includes receiving a first power cable and a second power cable, each power cable including a nonmetallic outer jacket, coupling a first conductor of the first power cable to a second conductor of the second power cable to establish an electrical connection between the first power cable and the second power cable, and molding a polymer around at least the electrical connection to create a continuous nonmetallic outer jacket between the first power cable and the second power cable for sealing the electrical connection. A system for splicing a nonmetallic jacket of a cable includes a mold configured to approximate an outside diameter of a first power cable to be spliced to a second power cable, each of the first power cable and the second power cable comprising a nonmetallic outer jacket, a heat source associated with the mold, and a temperature controller associated with the mold for melting a polymer at a temperature suitable for molding and fusing the polymer to the nonmetallic outer jackets of the first power cable and the second power cable.

[0004] This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] Certain embodiments of the disclosure will hereafter be described with reference to the accompanying drawings, wherein like reference numerals denote like elements. It should be understood, however, that the accompanying figures illustrate the various implementations described herein and are not meant to limit the scope of various technologies described herein.

[0006] Fig. 1 is a diagram of an example subsea power cable with a nonmetallic jacket for powering a subsea electric submersible pump (ESP), the subsea power cable having molded polymer splices and a molded polymer repair site.

[0007] Fig. 2 is a diagram of an example splice site between two power cables that have nonmetallic jackets and an example repair site on a cable that has a nonmetallic jacket.

[0008] Fig. 3 is a cross-sectional diagram of an example power cable in a mold or form for injection molding, compression molding, or transfer molding a polymer onto the power cable.

[0009] Fig. 4 is a diagram of example chemical formulae of a moldable polymer for splicing or repairing a power cable that has a nonmetallic jacket.

[0010] Fig. 5 is a cross-sectional diagram of an example power cable including a nonmetallic jacket molded from a mix of polymer and additive agents.

[0011] Fig. 6 is a diagram of an example mold and molding configuration for splicing two power cables that have nonmetallic jackets.

[0012] Fig. 7 is a diagram of an example power cable that has a molded polymer splice between the nonmetallic jackets of two cable segments and in which the molded polymer has a higher melting point than the nonmetal jackets of two cable segments.

[0013] Fig. 8 is a flow diagram of an example method of molding a polymer onto a cable to repair a nonmetallic jacket of the cable.

[0014] Fig. 9 is a flow diagram of an example method of molding a polymer to splice two cable segments that have nonmetallic jackets.

DETAILED DESCRIPTION

Overview

[0015] In the following description, numerous details are set forth to provide an understanding of some embodiments of the present disclosure. However, it will be understood by those of ordinary skill in the art that the system and/or methodology may be practiced without these details and that numerous variations or modifications from the described embodiments may be possible.

[0016] This disclosure describes subsea cable jacket splicing and repairs. The splicing, mold, repair materials, and techniques described herein are not limited to subsea environments, but can be applied to armorless cables used in many types of harsh downhole environments.

[0017] For an armorless cable, a tough and resistant jacket takes the place of conventional metal armor. The splice or repair can be performed in a shop, and then the spliced or repaired cable can be used downhole. The spliced or repaired part of the jacket maintains strength and durability, and resists to abrasion, high temperatures, and surface penetration of corrosives without needing a conventional metal outer armor.

[0018] The splice itself can be considered a molded nonmetal armor. The splice is molded onto at least part of each cable, creating a fusion bond or weld with the existing jackets of the cables. The molding process can be, for example, injection molding, compression molding, transfer molding, and so forth. The molding process uses a form, pre-forms, or a mold as well as heat to fuse the polymer being placed.

Example Systems

[0019] Fig. 1 shows an example power cable 100 being connected to a subsea well 102, and further downhole to an electric submersible pump (ESP) 104 in the well 102. The example power cable 100 is armorless, without an outer metal protective layer. The outer layer of the armorless power cable 100 is a tough polymer jacket. The example power cable 100 may be made of multiple long cable segments, joined together by at least one splice 106. The power cable 100 may also have at least one site on which a repair 108 has been performed. A repair 108 rejuvenates the power cable 100 against a gap in the nonmetallic outer jacket, and against possible damage to underlying layers of insulation, dielectric, barriers, and filler. A “gap,” as used herein broadly means a breach in the continuous nonmetallic outer jacket, such as an opening, aperture, space, holiday, chink, slit, crack, cavity, hole, perforation, pinhole, break, fracture, rift, fissure, or divide in the jacket.

[0020] Fig. 2 shows an example site 200 for a splice 106 between two example power cables 100 & 100’. Fig. 2 also shows example sites 202 & 204 for repair 108 to the example power cable 100. The splice 106 or repair 108 uses a process of molding a polymeric covering onto the power cable 100, to replace or rejuvenate the nonmetallic outer jacket 206 already in place on the power cable 100 to be repaired or spliced. The splice 106 or repair 108 may also involve coupling electrical conductors 208 and repairing or extending other layers of the cable 100 occurring between the inner electrical conductors 208 and the outer jacket 206, such as insulation 210 and so forth.

[0021] Fig. 3 shows an example power cable 100 in cross-section. The example power cable 100 is shown within a mold 300 (form or pre-form) for molding the polymer around at least part of the power cable 100. Molds 300 for injection molding, compression molding, or transfer molding are well-described in the respective arts.

[0022] The example power cable 100 may have one or multiple electrical conductors 208 (wires), for example three electrical conductors 208 for 3-phase AC electrical service to an induction motor of the ESP 104. Each wire or electrical conductor 208 of the example power cable 100 is surrounded by electrical insulation 210. The insulation 210, in turn, may be surrounded by various other layers, such as a barrier 302. For example, an inner barrier layer 302, when present, may be made of lead metal or a fluoropolymer. An example splicing process molds a polymer around the electrical conductors 208, the insulation 210, and the other layers, such as the barriers 302, to complete or repair the nonmetallic outer jacket 206 of the example power cable 100.

[0023] Thus, in an implementation, a pair of cable ends can be spliced 106 or repaired 108 by molding an example outer jacket material 206 between the two cable ends, after the conductors 208 and other underlying layers 210

& 302 of the cable 100 have been made continuous between the two cable ends.

[0024] Such an example splice 106 allows for longer lengths of an armorless power cable 100 to be made and installed downhole, for example in deep well 102 applications. In an implementation, splicing 106 and repairing 108 with the same jacket material as the original cables 100 maintains the same performance of the cable 100 at the splice site 200 or repair locations 202 & 204. A cable 100 can also be repaired 108 using the example polymer molding technique when there is an error or equipment malfunction during manufacture of the cable 100, thereby saving the resources that would be used to make a new, full length of the cable 100.

[0025] In Fig. 3, the electrical conductors 208 may be high purity copper and may be solid, stranded or compacted-stranded. Stranded and compacted-stranded conductors offer improved flexibility, which is an advantage in some installations. The conductors 208 may also be coated with a corrosion- resistant coating to prevent degradation of the conductor 208 from the hydrogen sulfide (H_2S) gas which is commonly present in downhole environments. Examples of such corrosion-resistant coatings include tin, zinc, lead, nickel, silver, and other corrosion-resistant alloys and metals. The conductors 208 can be spliced using a welding technique or copper sleeve.

[0026] In an implementation, the example power cable 100 may also have a conductor shield, which is a semiconductive layer around each conductor 208 that controls electrical stress in the cable 100 to minimize discharge. This layer can be between 0.002 inches and 0.020 inches thick. The conductor shield layer can be bonded to the conductor 208 and insulation 210 to prevent gas migration, or the conductor shield layer can be made strippable. Whether or not the shield is bonded depends on the application. In a splice 106 or a repair 108, the conductor shield layer may be made of a semiconductive tape wrap or an extruded semiconductive polymer. The layer may be an elastomer or thermoplastic co-extruded with the insulation 210 allowing the layers to crosslink together. The co-extrusion may eliminate the possibility of voids at the critical conductor shield / insulation interface. Materials used for the conductor shield layer may be semiconductive, having a resistivity less than about 5000 ohm-cm. An elastomer compound, such as ethylene propylene diene monomer / terpolymer (EPDM), loaded with conductive fillers may be used for this layer. In high-temperature applications or where reliability is a concern, a polyether ether ketone (PEEK) compound containing conductive fillers can be used. The insulation shield and the insulation 210 do not have to use the same base material, however, using the same base material may allow for easier processing. The conductor shield layer may be spliced 106 or repaired 108 using tape layers, shrink tube, or a molding process directly onto the conductor 208.

[0027] Material for the insulation layer 210 may be EPDM or PEEK. When EPDM is selected, compound formulations for oil and decompression-resistance may be used. The insulation layer 210 adheres or is completely bonded to the conductor shield, when present. The insulation layer 210 should also be continuous with an insulation shield, if present, but does not have to be completely bonded. An advantage of PEEK in this instance is improved mechanical properties that allow for improved damage resistance during cable installation and cable operation. The much higher stiffness of PEEK also allows for much greater ease in sealing over the cable members at cable termination points (motor potheads, well connectors, feed-throughs, and so forth). This is an important factor in improving reliability not only of the cable 100, but of the system. The insulation layer 210 can be spliced 106 or repaired 108 using tape layers, shrink tube, or a molding process directly onto each conductor 208.

[0028] An insulation shield may be applied over the insulation 210 as a semiconductive layer to minimize electrical stresses in the cable 100. The insulation shield may be bonded to the insulation 210 or may be strippable. Some adhesion between the layers is ideal to prevent voids and defects in the cable 100. The material for the insulation shield can be a semiconductive tape or a semiconductive polymer, for example having a resistivity less than 5000 ohm-cm. Like the conductor shield, the insulation shield can be co-extruded with the insulation 210 to ensure complete contact between the surfaces. The same material can be used for the insulation shield as for the conductor shield. Conversely, a different material can also be used if the different material is more workable. The insulation shield layer can be repaired 108 or spliced 106 using tape layers, shrink tube, or a molding process directly onto the conductor 208.

[0029] In an implementation of the example cable 100, a conductive layer can optionally be applied to serve as an electrical ground plane outside of the insulation shield. This conductive layer can isolate the effects of the different electrical phases of the cable 100 from each other. Copper, aluminum, lead, or another conductive material, tape, braid, paint, or extrusion can be applied over the insulation shield to provide the conductive layer. The conductive layer may also serve as a barrier to downhole gases and fluids, protecting the inner cable layers. The conductive layer can be repaired 108 or spliced 106 using tape layers, shrink tube, or a molding process directly onto the conductor 208.

[0030] The barrier layer 302 can protect the cable 100 from corrosive downhole gases and fluids. Additional barrier layers 302 may then be applied if needed. The barrier layer 302 can be made up of extruded or taped layers of fluoropolymers, lead, or other material sufficient for protection against well fluids. A combination of extruded and taped layers may also be used. This barrier layer 302 can be repaired 108 or spliced 106 using tape layers, shrink tube, welding, or a molding process directly onto the conductor 208.

[0031] The cable jacket 206 takes the place of conventional metal armor, so the polymer selected for the nonmetallic outer jacket 206 has characteristics of toughness and resistance to harsh downhole environments. In an implementation, the nonmetallic outer jacket 206 may have a metal filler agent or metal atoms as part of a polymer mix. So the descriptive term “nonmetallic” just means that the nonmetallic outer jacket 206 is an extrudable and moldable polymer that avoids the disadvantages of being a conventional metal armor, but “nonmetallic” does not mean that metallic agents are avoided in the polymer jacket 206 at all costs.

[0032] During manufacture, the nonmetallic jacket 206 is continually extruded with no gaps, holidays, or voids in the jacket layer 206 that allow for ingress of fluids. The polymeric makeup of the nonmetallic jacket 206 imparts excellent fluid and gas resistance at the surface of the jacket 206, low surface energy to prevent adhesion of fluids during retrieval out of hole, and high mechanical properties, preferably with low cost and good workability. The polymeric jacket 206 could be spliced 106 or repaired 108 using tape layers or shrink tubing, but because the nonmetallic jacket 206 is in contact with moving well fluid, which can contain abrasives, tapes or elastomers with low mechanical strength are easily damaged, resulting in early failure of the splice 106 or repair 108.

[0033] In an implementation, the cable jacket 206 is molded with a polymeric splice between the two cables 100 & 100’ being spliced 106, preferably using the same materials as the jackets 206 of the two cables 100 & 100’. This allows creation of long lengths of the cable 100 and enables repair 108 if there is damage or errors in manufacturing, without reducing the overall quality of the cable.

[0034] In an implementation, the splice 106 or repair 108 is made by molding a polymer derived from a high-strength resin to the cable 100, for example, an ethylene tetrafluoroethylene (ETFE), such as TEFZEL (DuPont Corporation, Wilmington, Delaware).

[0035] As shown in Fig. 4, in an implementation, a copolymer of polyvinylidene fluoride (PVDF) and hexafluoropropylene (HFP) can be used for the splice 106 or repair 108 of the cable jacket 206 by molding this copolymer combination over the conductors 208. The high crystallinity of the PVDF component gives high strength and stiffness, but can tend toward environmental stress cracking in some oilfield conditions. Incorporation of a size disparate copolymer such as HFP disrupts the crystallinity, creating amorphous regions where crack propagation is stopped. Because the HFP is one-hundred percent fluorinated, the inclusion of HFP in the polymer structure also improves the fluid resistance of the jacket surface, while reducing the likelihood of crack propagation. Unlike conventionally applied splicing and repair techniques for armorless cables, molding the jacket splice 106 or jacket repair 108 into place eliminates the need for a protective metal armor layer at the splice site 200 or the repair sites 202 & 204. Using the same polymeric material as the original cable jacket enhances the reliability of this example method.

[0036] The physical and chemical properties of a PVDF-HFP copolymer, including moldability and fusion bonding adhesion to preexisting jacket materials, may be selected by adjusting the copolymer ratio of HFP to PVDF in the PVDF-HFP copolymer. In an implementation, as shown in Fig. 4, there are m copolymers of PVDF and n copolymers of HFP in a ratio m/n, where m

>> n, resulting in a high-strength, crack-resistant moldable polymer for making the cable jacket 206.

[0037] In an implementation, an optimized copolymer of PVDF-HFP that is predominantly PVDF with a small copolymer ratio or proportion of HFP provides a splice 106 or repair 108 with high tensile strength and modulus yet excellent toughness and resistance to environmental stress cracking. For example, a KYNAR FLEX grade of PVDF copolymer resin may be used (Arkema, Colombes France). While the PVDF-HFP copolymer jacket 206 provides a cost-effective jacket material, other materials may be used, such as a fluorinated ethylene propylene (FEP), a polyvinyl fluoride (PVF), a polypropylene (PP), a polyalkyletherketone, a polyaryletherketone, a polyamide, nylon 12, and so forth.

[0038] Fig. 5 shows the example power cable 100 with additive agents 500 included with the molding polymer. Such additive agents 500 can be fillers that provide a beneficial property. The additive agents 500 can be incorporated into a thermoplastic jacketing material, for example, to improve or manipulate properties such as tensile strength, abrasion resistance, thermal conductivity, resistance to surface penetration, and other key properties. For example, the additive agent 500 may be a barrier agent 500 or a reinforcement agent 500 added to the polymer to be molded around at least part of the cable to seal the nonmetallic jacket at a gap. The barrier agent 500 or the reinforcement agent 500 can consist of glass fibers, carbon fibers, carbon nanotubes, carbon black, graphene, boron nitride, an aluminum oxide (for example, alumina or aluminum (III) oxide), a clay, a mica, a silica, and so forth.

[0039] Fig. 6 shows an example splice 106 or repair 108 scenario in which the splice site 200 or repair site 204 of the cable 100 is placed into a form, pre-form, or mold 300 for injection-molding, compression molding, or transfer molding. Underlying layers of the cable 100, such as insulation 210 or barriers 302 are repaired or extended as needed, before the selected polymer is molded onto a section of nonmetallic outer jacket 206. The selected polymer for the splice 106 or repair 108 is introduced into the mold 300 according to the molding operation selected. The molded polymer fusion-bonds or welds to the existing jackets 206 on the cables being spliced 100 & 100'. The molded polymer may also bond or at least adhere to the underlying insulation layer 210 or barrier layer 302.

[0040] An example mold 300 for splicing the existing nonmetallic jackets 206 of two cables 100 can be configured to approximate an outside diameter of the cables 100. A heat source melts or achieves the fusion temperature of the polymer being used to splice the jackets 206 of the cables 100. A temperature controller for precise adjustment can be useful in controlling the degree and the quality of the fusion bond achieved between the polymer selected for the splice and the nonmetallic jackets 206 of two cables 100.

[0041] The mold 300 may utilize an induction heat source for rapid heating of the polymer and the nonmetallic outer jackets 206, and for precise control of the extent of the fusion bond or weld between the molded polymer and the nonmetallic outer jackets 206 of the cables 100.

[0042] In an implementation, the induction heating source may include a conductor 302 near or constituting the barrel 304 of the mold 300 where the splice takes place. An induction coil 306, or electromagnet, causes heating in the conductor 302 through electromagnetic induction using high-frequency alternating current (AC). The example mold 300 may also have a cooling assembly 308 including, for example, cooling tubes, that circulates a fluid such as water or oil. The cooling assembly 308 rapidly reduces the temperature after molding for achieving a reduced cycle time, a higher mold throughput, and control of the extent of the fusion bond between the molded polymer and the nonmetallic outer jackets 206 of the cables 100.

[0043] The induction heating also improves energy efficiency for the molding process. Since heat is generated directly in the barrel 304 of the example mold 300, warm-up and energy consumption are reduced. The induction coil 306 can reside outside of thermal insulation to operate at low temperatures, for increased lifespan.

[0044] Terminated cable sections constituting cable ends to be spliced 106 may be surface-prepared so that the molded polymer bonds well to the jackets of the terminated cable sections. Mechanical abrasion, plasma treatment, or etching of the preexisting jacket surfaces of the cables 100 & 100' to be spliced 106 or repaired 108 ensure reliable bonding with the molded polymer of the splice 106 or repair 108.

[0045] Fig. 7 shows example cables 100 & 100’ spliced 106 with a molded polymer 700. In an implementation, the molecular structure of the molded polymer 700 is adjusted, e.g., by varying the proportion of a copolymer or by including additive agents 500, to provide a slightly higher melting temperature of the molded polymer 700. The higher melting temperature of the molded polymer 700 improves the fusion bond between the jackets 206 of the terminated cable ends and the molded polymer 700 that makes up the splice section 106.

[0046] When the cable 100 includes an underlying lead metal layer, e.g., for barrier properties, the melting temperature of the molded polymer 700 is selected to be below the melting temperature of the lead jacket (approximately 320-327 ºC). This is because during the molding process the lead jacket can be exposed to the molten polymer 700, and if the molten polymer 700 is hot enough it can melt the lead layer. For such scenarios, the melting point of the molded polymer 700 selected is less than 320 ºC, to provide a safety factor for the thermal vulnerability of the lead layer. For example, an ETFE polymer with a melting temperature in the range of 240-260 ºC may be used. A polymer such as polyether ether ketone (PEEK), with a melting point of ~335 ºC, should be avoided for use as a molten polymer over a cable 100 that has an underlying lead layer.

Example Methods

[0047] Fig. 8 shows an example method 800 of molding a polymer to repair a nonmetallic jacket of a cable. In the flow diagram, operations are shown in individual blocks.

[0048] At block 802, a gap is detected in a nonmetallic jacket of a cable for powering a downhole electric submersible pump (ESP).

[0049] At block 804, a polymer is molded around at least part of the cable to seal the nonmetallic jacket at the gap.

[0050] Molding the polymer around at least part of the cable to seal the nonmetallic jacket at the gap may further comprise molding a thermoplastic polymer or a thermosetting polymer around at least part of the cable by applying a molding process, such as an injection molding process, a compression molding process, or a transfer molding process.

[0051] In molding the polymer around at least part of the cable to seal the nonmetallic jacket at the gap, the polymer may be an ethylene tetrafluoroethylene (ETFE) polymer or a poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) copolymer, for example.

[0052] The poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) copolymer may be predominately PVDF, in excess of the HFP.

[0053] The method 800 may further include molding the polymer around at least part of the cable to seal the nonmetallic jacket at the gap, wherein the polymer is formulated to be suitable for protecting the cable from a downhole environmental attack, such as a subsea environment, a high temperature environment, a corrosive environment, a hydrogen sulfide-rich environment, or an abrasive environment, and the polymer may be a fluorinated ethylene propylene (FEP), a polyvinyl fluoride (PVF), a polypropylene (PP), a polyalkyletherketone, a polyaryletherketone, a polyamide, or a nylon, such as nylon 12.

[0054] The method 800 may further include adding a barrier agent or a reinforcement agent to the polymer to be molded around at least part of the cable to seal the nonmetallic jacket at the gap. The barrier agent or the reinforcement agent may be glass fibers, carbon fibers, carbon nanotubes, carbon black, graphene, boron nitride, an aluminum oxide (e.g., alumina), a clay, a mica, or a silica.

[0055] The polymer may be formulated by adjusting a copolymer ratio to provide a polymer melting temperature for properly fusing to the cable. The polymer melting temperature can be incrementally higher than a jacket melting temperature of the nonmetallic jacket already in place on the cable to enhance the fusion bond or weld between the nonmetallic jacket and the molded polymer.

[0056] When a layer of lead metal is present in the cable, then a polymer may be selected for molding to the cable that has a melting temperature lower than the melting point of lead metal at approximately 320-327 ºC.

[0057] The surface of the nonmetallic jacket may be prepared for bonding to the molded polymer by mechanical abrasion of the nonmetallic jacket surface, plasma treatment, or etching the nonmetallic jacket surface.

[0058] Fig. 9 shows an example method 900 of molding a polymer to splice a nonmetallic jacket between two cable ends. In the flow diagram, operations are shown in individual blocks.

[0059] At block 902, a first power cable and a second power cable are received, each power cable including a nonmetallic outer jacket.

[0060] At block 904, a first conductor of the first power cable is coupled to a second conductor of the second power cable to establish an electrical connection between the first power cable and the second power cable.

[0061] At block 906, a polymer is molded around at least the electrical connection to create a continuous nonmetallic outer jacket between the first power cable and the second power cable for sealing the electrical connection.

[0062] The method 900 may further include extending one or more underlying layers of the respective power cables across the electrical connection by applying a respective material of each underlying layer across the electrical connection, the underlying layers occurring between the respective inner conductors and the respective nonmetallic outer jackets of the power cables.

[0063] The moldable polymer may be an ethylene tetrafluoroethylene (ETFE) polymer or a poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) copolymer. The moldable polymer can also be a fluorinated ethylene propylene (FEP), a polyvinyl fluoride (PVF), a polypropylene (PP), a polyalkyletherketone, a polyaryletherketone, a polyamide, or a nylon, such as nylon 12.

Conclusion

[0064] Although a few embodiments of the disclosure have been described in detail above, those of ordinary skill in the art will readily appreciate that many modifications are possible without materially departing from the teachings of this disclosure. Accordingly, such modifications are intended to be included within the scope of this disclosure as defined in the claims.

CLAIMS

1. A method, comprising:

detecting a gap in a nonmetallic jacket of a cable for powering a downhole electric submersible pump (ESP); and

molding a polymer around at least part of the cable to seal the nonmetallic jacket at the gap.

2. The method of claim 1, wherein molding the polymer around at least part of the cable to seal the nonmetallic jacket at the gap further comprises molding a thermoplastic polymer or a thermosetting polymer around at least part of the cable by applying a molding process selected from the group consisting of an injection molding process, a compression molding process, and a transfer molding process.

3. The method of claim 1, further comprising molding the polymer around at least part of the cable to seal the nonmetallic jacket at the gap, wherein the polymer is selected from the group consisting of an ethylene tetrafluoroethylene (ETFE) polymer and a poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) copolymer.

4. The method of claim 3, wherein the poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) copolymer comprises predominately the PVDF in excess of the HFP.

5. The method of claim 1, further comprising molding the polymer around at least part of the cable to seal the nonmetallic jacket at the gap, wherein the polymer is formulated to be suitable for protecting the cable from a downhole environmental attack selected from the group consisting of a subsea environment, a high temperature environment, a corrosive environment, a hydrogen sulfide-rich environment, and an abrasive environment; and

wherein the polymer is selected from the group consisting of a fluorinated ethylene propylene (FEP) polymer, a polyvinyl fluoride (PVF) polymer, a polypropylene (PP) polymer, a polyalkyletherketone polymer, a polyaryletherketone polymer, a polyamide polymer, and a nylon 12 polymer.

6. The method of claim 1, further comprising adding a barrier agent or a reinforcement agent to the polymer to be molded around at least part of the cable to seal the nonmetallic jacket at the gap; and

wherein the barrier agent or the reinforcement agent is selected from the group consisting of glass fibers, carbon fibers, carbon nanotubes, carbon black, graphene, boron nitride, an aluminum oxide, a clay, a mica, and a silica.

7. The method of claim 1, further comprising formulating the polymer, including adjusting a copolymer ratio, to provide a polymer melting temperature for molding to the cable, wherein the polymer melting temperature is incrementally higher than a jacket melting temperature of the nonmetallic jacket already in place on the cable to enhance a bond between the nonmetallic jacket and the molded polymer.

8. The method of claim 1, further comprising, when a layer of lead metal is present in the cable, selecting a polymer for molding to the cable, wherein the polymer possesses a polymer melting temperature lower than a melting point of approximately 320-327 °C of the lead metal.

9. The method of claim 1, further comprising performing a preparation of the nonmetallic jacket surface for bonding to the molded polymer, wherein the preparation is selected from the group consisting of performing a mechanical abrasion of the nonmetallic jacket surface, performing a plasma treatment on the nonmetallic jacket surface, and etching the nonmetallic jacket surface.

10. A method of splicing a power cable for a downhole electric submersible pump (ESP), comprising:

receiving a first power cable and a second power cable, each power cable including a nonmetallic outer jacket;

coupling a first conductor of the first power cable to a second conductor of the second power cable to establish an electrical connection between the first power cable and the second power cable; and

molding a polymer around at least the electrical connection to create a continuous nonmetallic outer jacket between the first power cable and the second power cable for sealing the electrical connection.

11. The method of claim 10, further comprising extending one or more underlying layers of the respective power cables across the electrical connection by applying a respective material of each underlying layer across the electrical connection; and

wherein the underlying layers occur between the respective conductors and the respective nonmetallic outer jackets of the power cables.

12. The method of claim 10, wherein molding the polymer further comprises molding a polymer selected from the group consisting of an ethylene tetrafluoroethylene (ETFE) polymer, a poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) copolymer, a fluorinated ethylene

propylene (FEP) polymer, a polyvinyl fluoride (PVF) polymer, a polypropylene (PP) polymer, a polyalkyletherketone polymer, a polyaryletherketone polymer, a polyamide polymer, and a nylon 12 polymer.

13. The method of claim 10, further comprising adding a barrier agent or a reinforcement agent to the polymer to be molded around at least the electrical connection to create the continuous nonmetallic outer jacket between the first power cable and the second power cable for sealing the electrical connection, wherein the barrier agent or the reinforcement agent is selected from the group consisting of glass fibers, carbon fibers, carbon nanotubes, carbon black, graphene, boron nitride, an aluminum oxide, a clay, a mica, and a silica.

14. The method of claim 10, further comprising selecting a polymer for the molding, wherein the polymer possesses a polymer melting temperature incrementally higher than a jacket melting temperature of the nonmetallic outer jacket to improve a bond between the nonmetallic outer jacket and the molded polymer.

15. A system for splicing a nonmetallic jacket of a cable, comprising:

a mold configured to approximate an outside diameter of a first power cable to be spliced to a second power cable, each of the first power cable and the second power cable comprising a nonmetallic outer jacket;

a heat source associated with the mold; and

a temperature controller associated with the mold for melting a polymer at a temperature suitable for molding and fusing the polymer to the nonmetallic outer jackets of the first power cable and the second power cable.

16. The system of claim 15, wherein the cable comprises a power cable for a downhole electric submersible pump (ESP).

17. The system of claim 15, wherein the heat source comprises an induction heater for rapid heating of the polymer and the nonmetallic outer jackets and for control of an extent of a fusion bond between the molded polymer and the nonmetallic outer jackets of the first power cable and the second power cable.

18. The system of claim 15, further comprising a cooling assembly associated with the mold to rapidly reduce the temperature after molding for achieving a reduced cycle time, for a higher mold throughput, and for control of an extent of a fusion bond between the molded polymer and the nonmetallic outer jackets of the first power cable and the second power cable.

19. The system of claim 15, further comprising a polymer suitable for molding and fusing to the nonmetallic outer jackets of the first power cable and the second power cable, the polymer selected from the group consisting of an ethylene tetrafluoroethylene (ETFE) polymer, a poly(vinylidene fluoride-co-hexafluoropropylene) (PVDF-HFP) copolymer, a fluorinated ethylene propylene (FEP) polymer, a polyvinyl fluoride (PVF) polymer, a polypropylene (PP) polymer, a polyalkyletherketone polymer, a polyaryletherketone polymer, a polyamide polymer, and a nylon 12 polymer.

20. The system of claim 19, further comprising a barrier agent or a reinforcement agent in the polymer, the barrier agent or the reinforcement agent selected from the group consisting of glass fibers, carbon fibers, carbon nanotubes, carbon black, graphene, an aluminum oxide, boron nitride, a clay, a mica, and a silica.

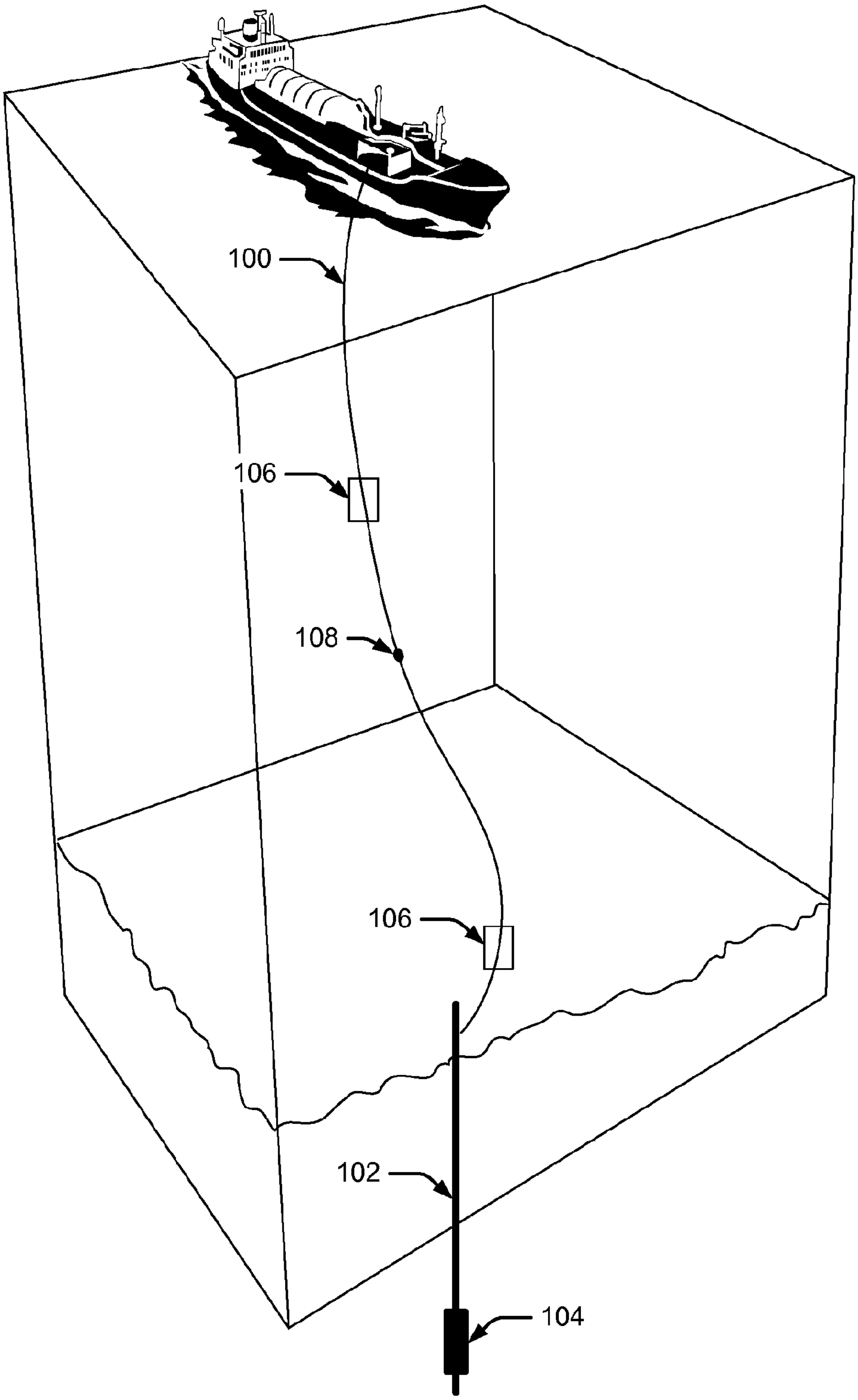

FIG. 1

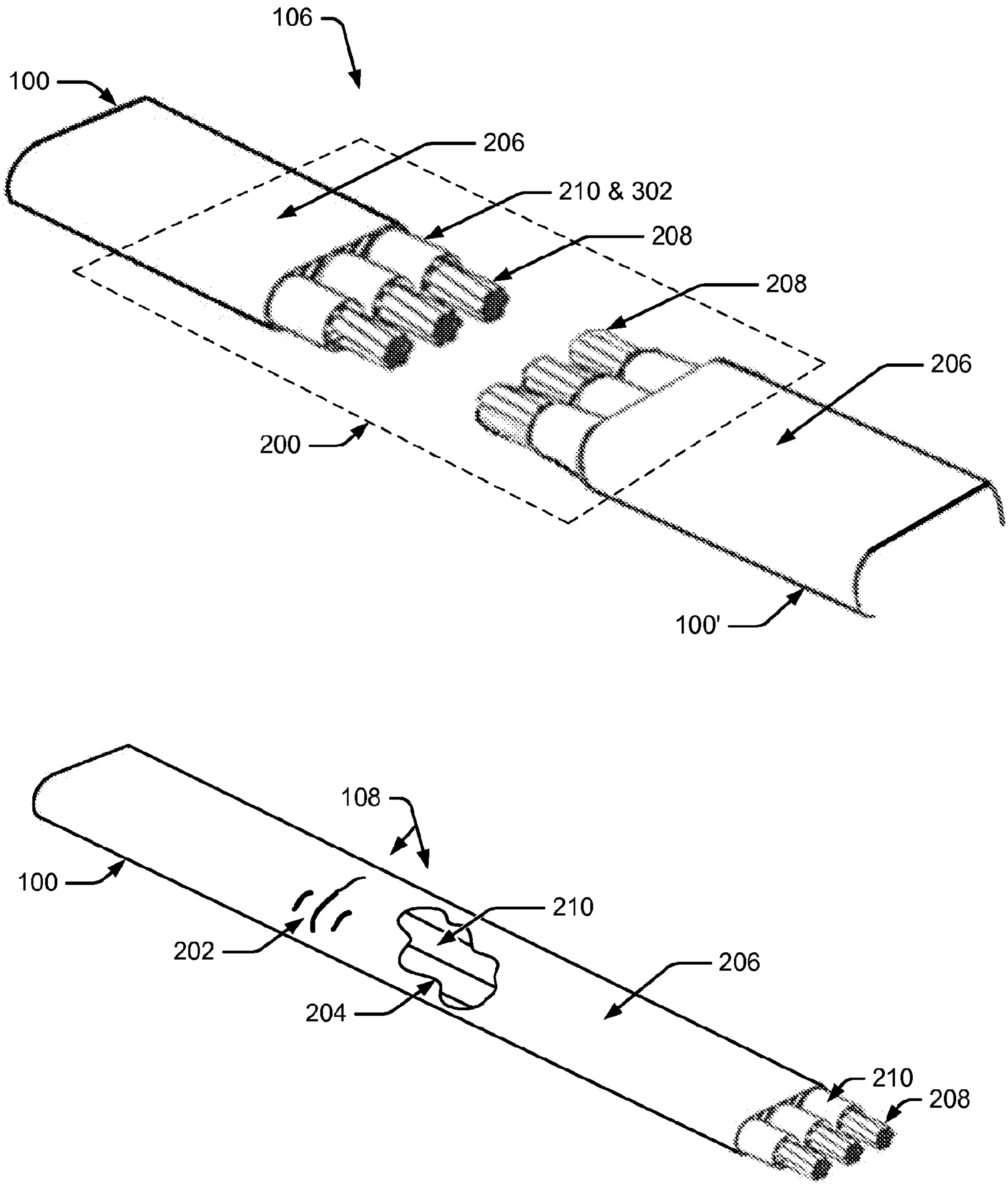
106
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FIG. 2

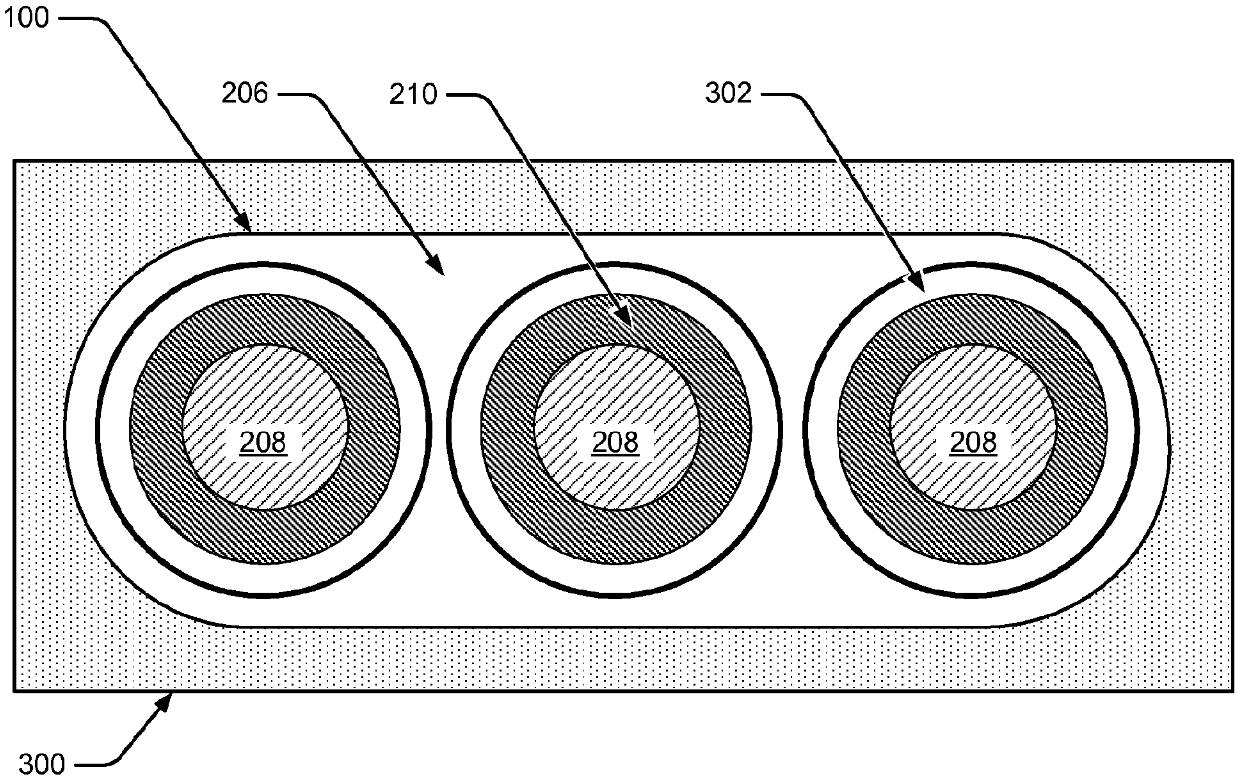
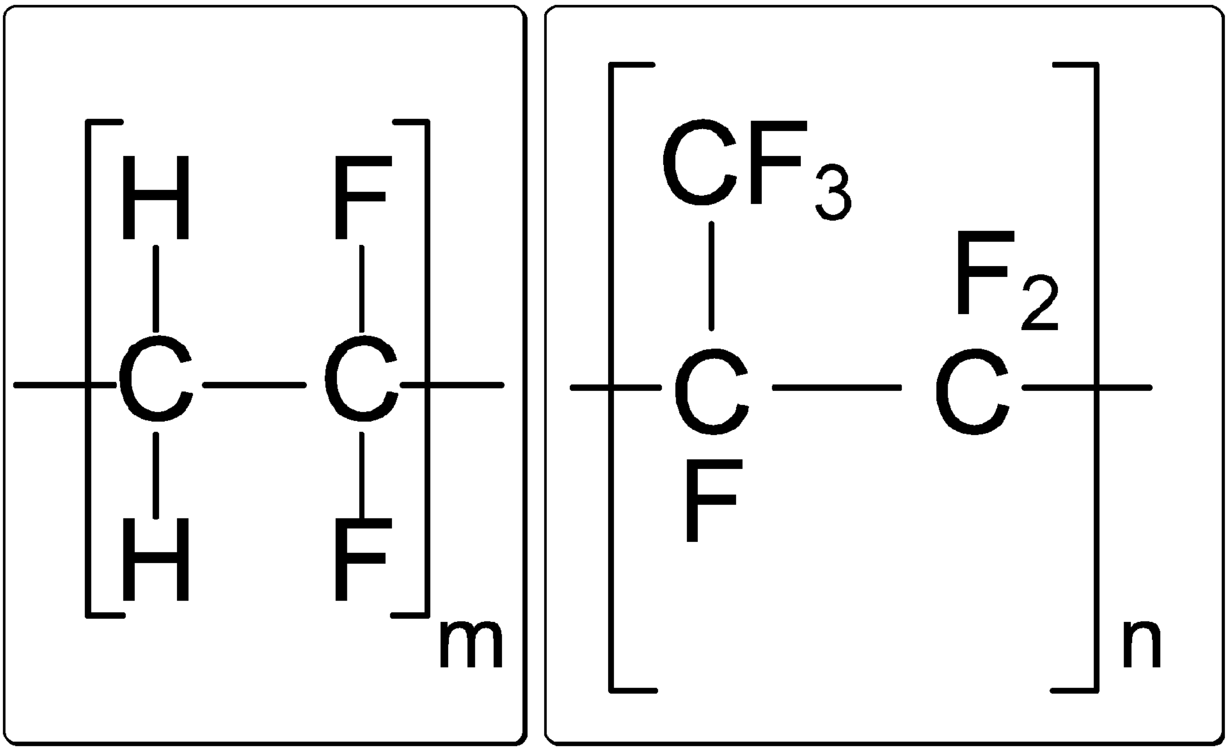
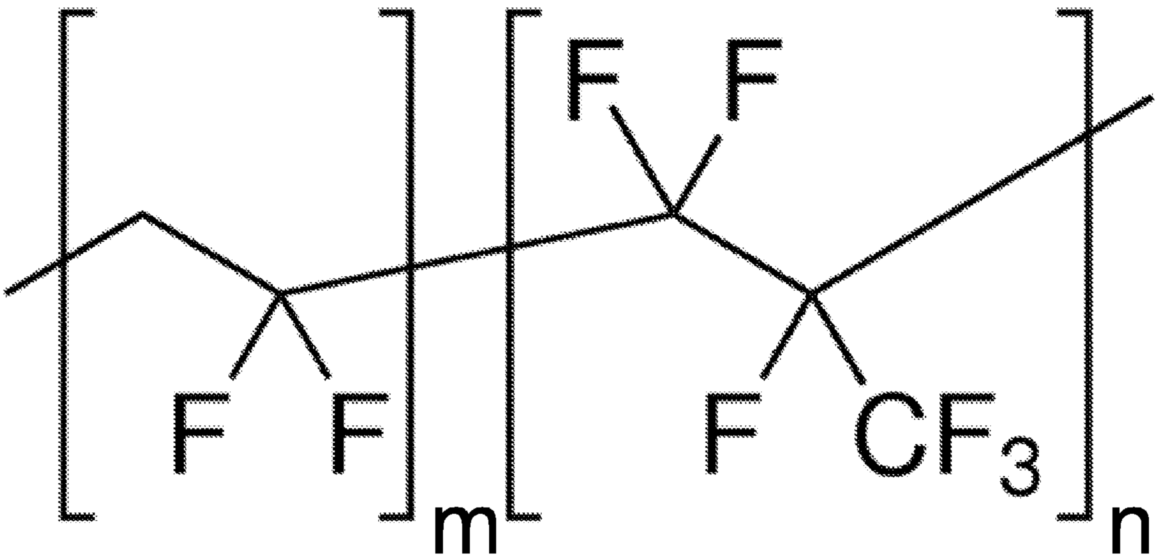


FIG. 3



PVDF HFP



$(\text{-}CH_2CF_2\text{-})_m[\text{-}CF_2CF(CF_3)\text{-}]_n$

FIG. 4

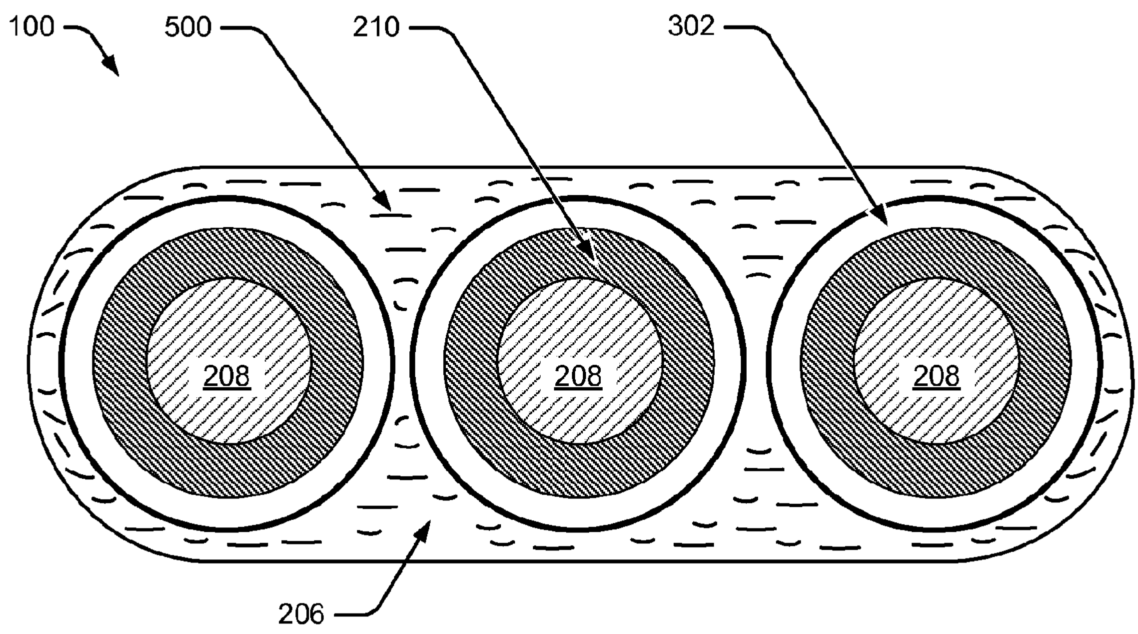


FIG. 5

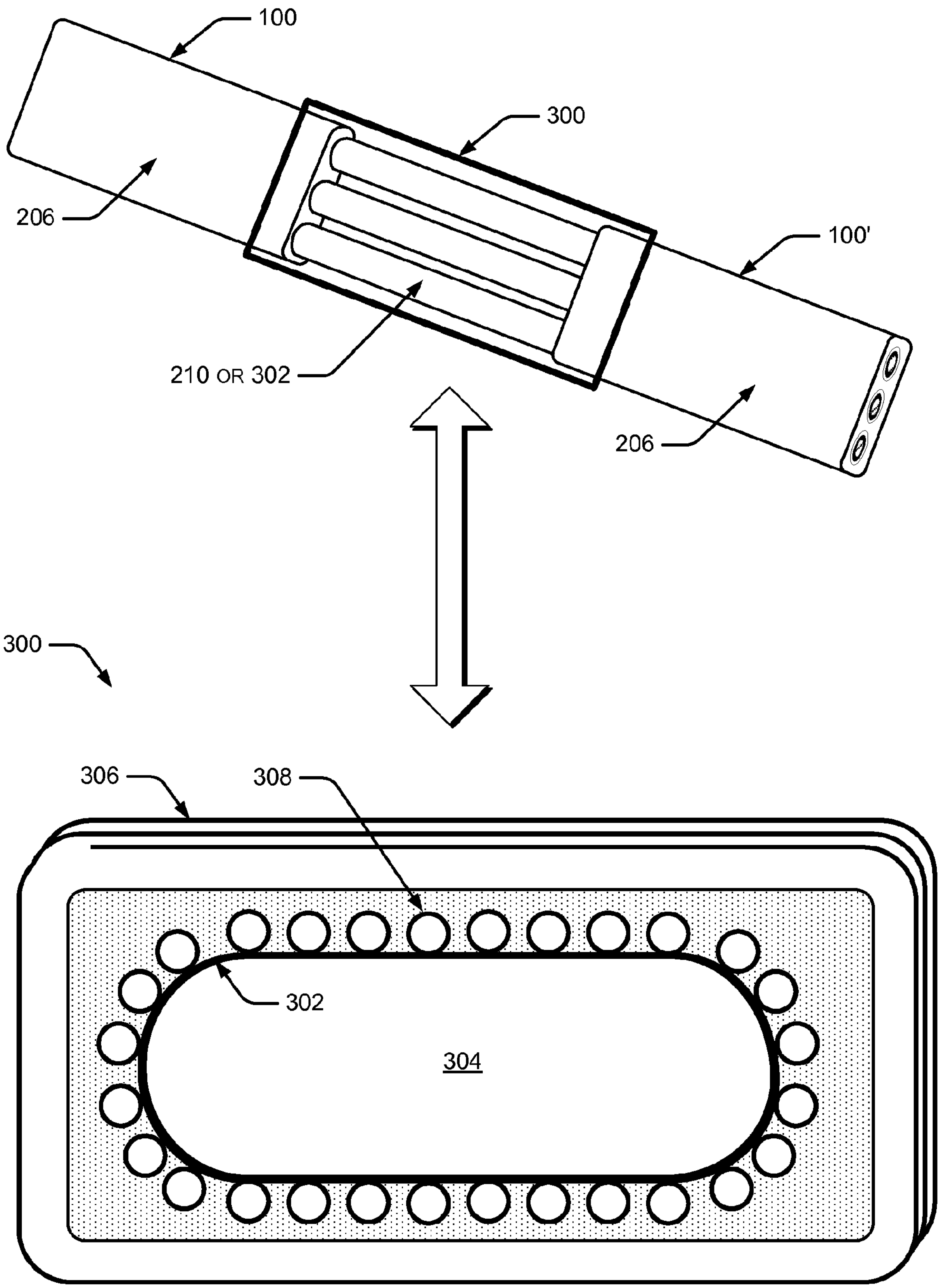


FIG. 6

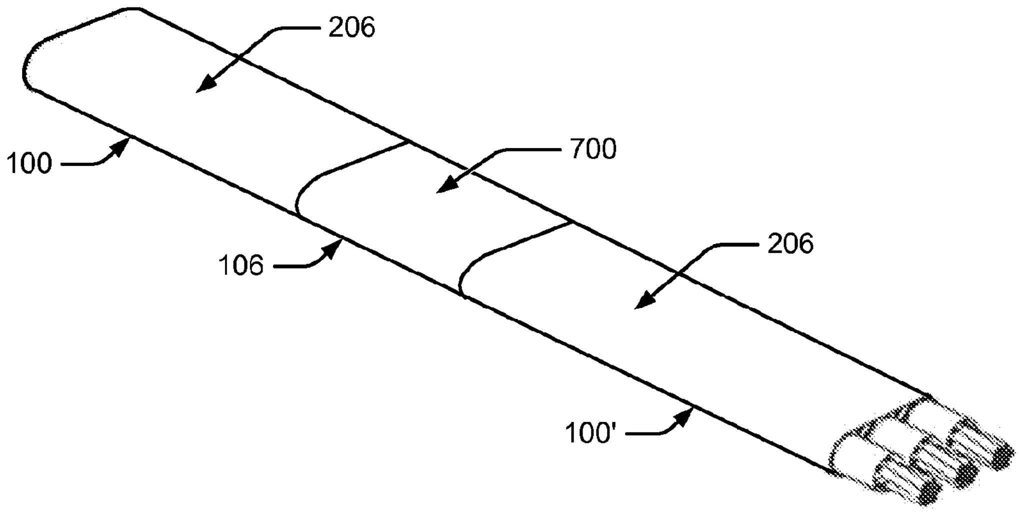


FIG. 7

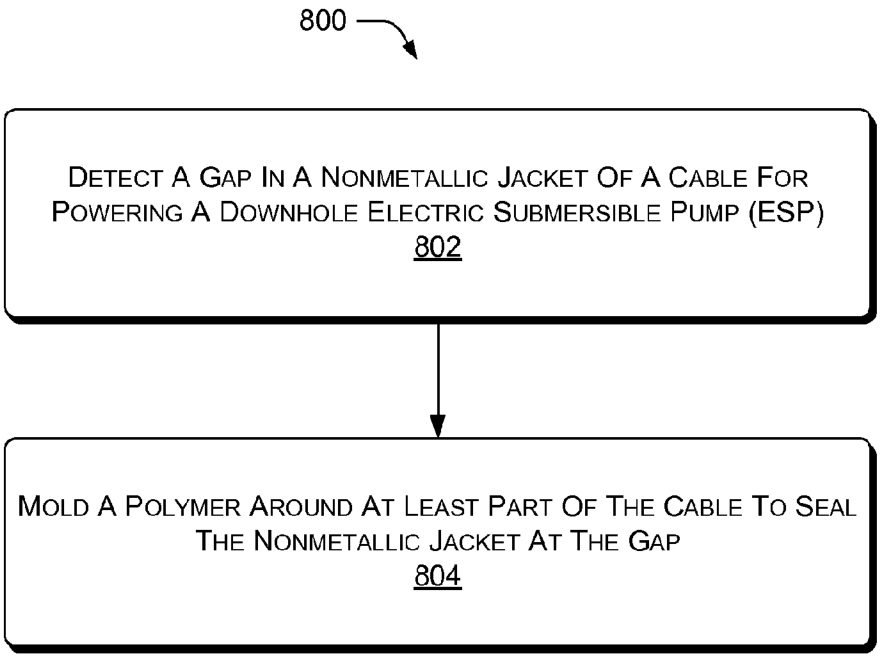

800
DETECT A GAP IN A NONMETALLIC JACKET OF A CABLE FOR POWERING A DOWNHOLE ELECTRIC SUBMERSIBLE PUMP (ESP)
802
MOLD A POLYMER AROUND AT LEAST PART OF THE CABLE TO SEAL THE NONMETALLIC JACKET AT THE GAP
804

FIG. 8

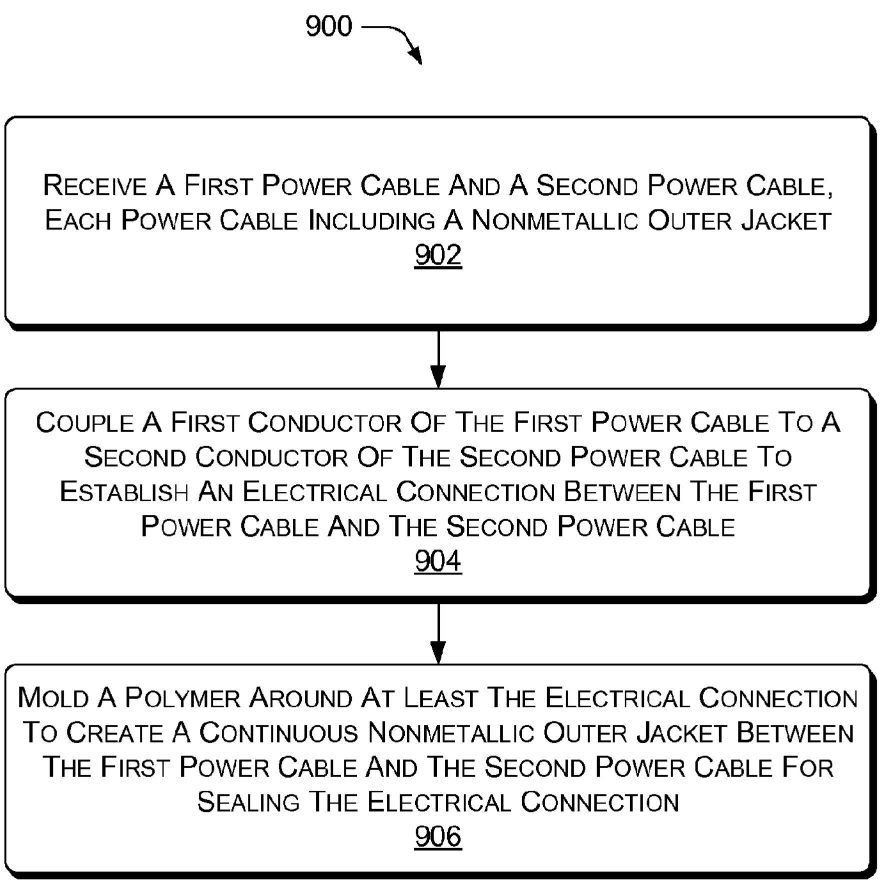

900
RECEIVE A FIRST POWER CABLE AND A SECOND POWER CABLE, EACH POWER CABLE INCLUDING A NONMETALLIC OUTER JACKET
902
COUPLE A FIRST CONDUCTOR OF THE FIRST POWER CABLE TO A SECOND CONDUCTOR OF THE SECOND POWER CABLE TO ESTABLISH AN ELECTRICAL CONNECTION BETWEEN THE FIRST POWER CABLE AND THE SECOND POWER CABLE
904
MOLD A POLYMER AROUND AT LEAST THE ELECTRICAL CONNECTION TO CREATE A CONTINUOUS NONMETALLIC OUTER JACKET BETWEEN THE FIRST POWER CABLE AND THE SECOND POWER CABLE FOR SEALING THE ELECTRICAL CONNECTION
906

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/028391

A. CLASSIFICATION OF SUBJECT MATTER

H02G 15/18(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02G 15/18; H01B 7/00; H02G 15/08; H01B 7/34; H02G 15/00; H01R 43/04; B29C 73/10; H01R 13/44

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & Keywords: splice, power cable, nonmetallic jacket, mold, polymer, heat, temperature

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2008-0087466 A1 (TOD D. EMERSON) 17 April 2008 See abstract, paragraphs [0001], [0019], [0028], [0035], claims 1-8 and figure 5B.	1-4,6,9-11,13
Y		5,7,8,12,14-20
Y	US 6664476 B2 (SERGIO BELLI et al.) 16 December 2003 See abstract, column 5, lines 22-29, column 9, lines 14-21, column 10, lines 30-34, column 15, lines 42-50 and claims 1, 60.	5,7,8,12,14-20
A	US 2012-0097444 A1 (ALBERT J. HILBERTS et al.) 26 April 2012 See abstract, paragraphs [0016], [0017], [0019], claims 1-8 and figures 1-7.	1-20
A	US 2013-0140726 A1 (TYCO ELECTRONICS UK LTD.) 06 June 2013 See abstract, claims 1, 20 and figures 1, 3.	1-20
A	US 6676422 B1 (BRYAN C. BAKER et al.) 13 January 2004 See abstract and claims 1, 5, 8, 9.	1-20

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search
29 January 2016 (29.01.2016)

Date of mailing of the international search report
29 January 2016 (29.01.2016)

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2015/028391

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