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(54) **Multiconductor electrical cable**

(57) A multiconductor electrical cable for use in a subterranean wellbore comprises a plurality of electrical conductors (28) with at least one of the electrical conductors sheathed in at least one inner layer (32) of a semi-conductive material, and at least one layer (34) of an insulating material. A jacket (36) of elastomeric material surrounds the plurality of electrical conductors,

and an outer metal armour (38) covers the jacket of elastomeric material. The semi-conductive material (32) has electrical properties to reduce voltage stress between an outer surface of the electrical conductor (28) and an inner surface of the insulating material (34). The resulting cable has increased resistance to electrical failure when operating at voltages of about 8 kV or more within a subterranean wellbore.

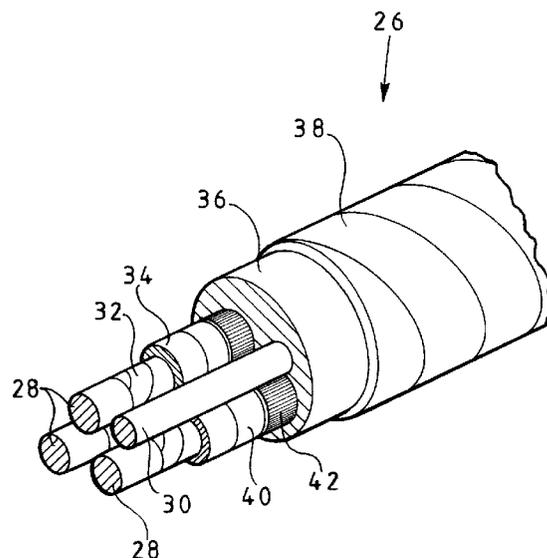


FIG. 2

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Description

The present invention relates to multiconductor electrical cables and, more particularly, to multiconductor electrical cables for use in subterranean wellbores.

Multiconductor electrical cables used to power wellbore equipment, such as electrical submersible pumping systems, must be capable of withstanding the high temperatures, high pressures and/or corrosive fluids often encountered within subterranean wellbores. As used herein, the term "high temperature" means temperatures of greater than about 175 F and as high as about 500 F. The term "high pressure" means pressures of at least 500 psi and as high as about 5,000 psi. Further, the term "corrosive fluids" means liquids and gases which can cause degradation to cable insulating materials and/or corrosion to the electrical conductors, such as liquids and/or gases containing hydrogen sulphide, carbon dioxide, water, and the like.

Existing wellbore power cables are capable of operating in these wellbore conditions if operated at or below about 5 kV (phase to phase operation). Newer pump motors are being designed to operate efficiently at higher voltages. Yet, if these existing wellbore power cables are operated above 5 kV, the electrical fields generated within the power cable cause extreme stress at the micro-interfaces of contact and voids between the electrical conductors and the insulating material. This stress causes a rapid deterioration of the insulating material which directly and quickly leads to electrical shorting and failure of the power cable. Once a power cable fails, the fluid production from the wellbore is ceased, resulting in lost revenue to the operator. In addition, expensive and time consuming cable retrieval, repair and re-installation procedures must be undertaken.

Many power cables for use in surface applications have power ratings far in excess of 5 kV; however, these power cables do not have the type of insulations to withstand the high temperature, high pressure and corrosive environments within a subterranean wellbore. There is a need for a multiconductor power cable for use in subterranean wellbores that can successfully be operated above 5 kV.

The present invention has been contemplated to overcome the foregoing deficiencies and meet the above described needs. The present invention is a multiconductor electrical cable for use in a subterranean wellbore and comprises a plurality of electrical conductors with at least one of the electrical conductors sheathed in at least one inner layer of a semi-conductive material, and at least one layer of an insulating material. A jacket of elastomeric material surrounds the plurality of electrical conductors, and an outer metal armour covers the jacket of elastomeric material. The semi-conductive material has electrical properties to reduce voltage stress between an outer surface of the electrical conductor and an inner surface of the insulating material. The resulting cable has increased resistance to electri-

cal failure when operating at 5 kV or more within a subterranean wellbore.

Brief description of the drawings:

Figure 1 shows an elevational view of an ESP of the present invention within a wellbore.

Figure 2 shows a cross-sectional, perspective view of one preferred embodiment of a multiconductor electrical cable of the present invention.

The electrical cable of the present invention can be used in any situation where an electrical cable needs to be able to withstand relatively high temperatures, high pressures and corrosive fluids; however, it should be understood that the electrical cable of the present invention can also be used in less difficult applications. As used herein, the term "high temperature" means temperatures of greater than about 175 F and as high as about 500 F. The term "high pressure" means pressures of at least 500 psi and as high as about 5,000 psi. Further, the term "corrosive fluids" means liquids and gases which can cause degradation to insulating materials and/or corrosion to the electrical conductors, such as liquids and/or gases containing hydrogen sulphide, carbon dioxide, water, and the like. As described above, the present invention comprises a multiconductor electrical cable for use in a subterranean wellbore that has the capability of operating at greater than 5 kV without degradation of the insulation material. The electrical cable comprises a plurality of electrical conductors, with at least one of the electrical conductors sheathed in at least one layer of a first material, and in at least one layer of a second material. The first material has electrical properties to reduce voltage stress between an outer surface of the electrical conductor and an inner surface of the second material. A jacket of elastomeric material surrounds the plurality of electrical conductors, and metal armour covers the jacket of elastomeric material.

To better understand the present invention, reference is made to the accompanying drawings. Figure 1 shows an electric submersible pumping system or "ESP" 10 set within a casing 12, which is cemented within a subterranean wellbore 14 that penetrates one or more subterranean earthen formations 16. The ESP 10 comprises an electric motor 18, a motor protector 20, and a multi-stage pump 22 connected to production tubing 24. An electrical cable 26 extends from a surface power source downwardly within the casing 12 and is operatively connected to the electric motor 18.

Figure 2 shows one preferred embodiment of the cable of the present invention, with the cable 26 having a plurality of electrical conductors 28. There are three electrical conductors 28 made from copper or copper alloys having a diameter or gauge thickness of from about 0.125 inch to about 0.500 inch, for typical wellbore applications. These conductors 28 may have a relatively thin coating of lead, tin or lead-tin alloy to aid in the pre-

vention of corrosion of the copper, as is well known to those skilled in the art. One or more ground wires 30 may be included, as well as other wires, conductors, conduits, fibre optics, and the like, as may be used to transmit fluids and/or information and command signals through the power cable 28.

At least one of the electrical conductors 28, and preferably all of the conductors, is sheathed in at least one inner layer of a semi-conducting material 32, and in at least one layer of an insulating material 34. The semi-conductive material 32 reduces the voltage stress between an outer surface of the electrical conductor 28 and an inner surface of the insulating material 34. For this purpose, the semi-conductive material 32 preferably has a volume resistivity of less than about 10 Kohm-meter, whereas the insulating material 34 preferably has a volume resistivity of greater than about 10 Kohm-meter. The semi-conductive material 32 is used to prevent any voltage stress at surface irregularities of the conductor 28 and at voids between the conductor 28 and its insulating material 34.

The semi-conductive material 32 is selected from the group consisting of tapes and weaves of fibreglass, carbon fibre and aramid fibre, and tapes and one or more extruded layers of ethylene propylene copolymer, ethylene vinyl acrylate copolymer, ethylene ethyl acrylate copolymer, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, and copolymers, mixtures, blends and alloys thereof. Whereas, the insulating material 34 is selected from the group consisting of one or more extruded layers of ethylene propylene diene methylene, ethylene propylene rubber, polychloroprene, fluoroelastomers, polypropylenes, polyethylenes, polyethers, and copolymers, mixtures, blends and alloys thereof. Most preferably, the insulating material 34 is ethylene propylene diene methylene.

Some electrical power cables used within wellbores include one or more longitudinal threads or ribbons of semi-conductive material, such as carbon-impregnated nylon, adjacent the outer metal armour to aid in dissipating static electricity buildup within the cable. These prior semi-conductive threads cannot be considered equivalent to the semi-conductive material 32 of the present invention because the prior semi-conductive threads were not placed adjacent the copper conductors 28 and, most importantly, the semi-conductive material 32 must form a complete sheath or covering of the conductors 28 in order to completely prevent any voltage stress at surface irregularities of the conductor 28 and at voids between the conductor 28 and its insulating material 34.

A jacket of elastomeric material 36 surrounds the plurality of electrical conductors 28 and is selected from the group consisting of nitrile rubber, ethylene propylene, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, polyethylene, polypropylene, polyethylene, polyether, and copoly-

mers, mixtures, blends and alloys thereof. An outer metal armour 38 covers the jacket of elastomeric material 36, as is well known to those skilled in the art.

As shown in Figure 2, the cable 26 includes an optional insulation shield 40 between the insulating material 34 and the jacket of elastomeric material 36, and preferably is applied onto the insulating material 34. The insulation shield 40 is used to confine the electrical field within the insulating material 34, and to symmetrically distribute the electrical stress within the insulating material 34. Preferably, the insulation shield 40 has a maximum volume resistivity of about 500 Kohm-meter. The insulation shield 40 is selected from the group consisting of tapes and weaves of metal, such as lead, fibreglass, carbon fibre and aramid fibre, and tapes and/or one or more extruded layers of ethylene propylene copolymer, ethylene vinyl acrylate copolymer, ethylene ethyl acrylate copolymer, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, and copolymers, mixtures, blends and alloys thereof.

The cable 26 includes an optional fluid barrier 42 between the insulating material 34 and the jacket of elastomeric material 36, and preferably is applied to the insulation shield 40. The fluid barrier 42 further protects the insulating materials 32, 34 and 40 and the conductors 28 from the deleterious effects of corrosive fluids, such as hydrocarbon gases and liquids, other gases, and most importantly, hydrogen sulphide. The fluid barrier 42 is selected from the group consisting of tapes, films, weaves and one or more extruded layers of metal, such as lead, and fluropolymers, such as TEFLON.

To prove the efficacy of the addition of the layer of semi-conductive material 32, tests were conducted on samples of a prior cable without the semi-conductive material 32 and on samples of the cable of the present invention. The principle tests to determine the suitability of a power cable for a particular voltage application are AC breakdown strength (ACBD) and partial discharge (PD or corona) performance. According to IEC 502, for a cable to pass these tests the cable must withstand 3.0 U_o test voltage or about 13.8 kV phase to ground test voltage for the ACBD of more than 50 V/mil, and to have less than 20 pC at 1.5 U_o or about 6.9 kV phase to ground test voltage for the PD.

The test results showed that the prior cable surpassed the ACBD criteria with a Weibull analysis showing a 63% probability of failure of 409 V/mil at 13.8 kV. The new cable of the present invention also surpassed the ACBD criteria with a Weibull analysis showing a 63% probability of failure of 457 V/mil. As for the PD tests, the prior cable did not consistently meet the 20 pC requirement at 6.9 kV, and had values ranging from 15 pC to 35 pC. On the other hand, the new cable easily met the 20 pC requirement with values ranging from about 0 pC to about 2 pC.

Whereas the present invention has been described in particular relation to the drawings attached hereto, it should be understood that other and further modifica-

tions, apart from those shown or suggested herein, may be made within the scope of the present invention as defined by the claims.

Claims

1. A multiconductor electrical cable for use in a subterranean wellbore, comprising: a plurality of electrical conductors; at least one of the electrical conductors sheathed in at least one inner layer of a semi-conductive material, and in at least one layer of an insulating material; and a jacket of elastomeric material surrounding the plurality of electrical conductors.
2. A multiconductor electrical cable of Claim 1, wherein the semi-conductive material has a volume resistivity of less than about 10 Kohm - meter.
3. A multiconductor electrical cable of Claim 1 or Claim 2, wherein the semi-conductive material is selected from the group consisting of tapes and weaves of fibreglass, carbon fibre and aramid fibre, and tapes and/or one or more extruded layers of ethylene propylene copolymer, ethylene vinyl acrylate copolymer, ethylene ethyl acrylate copolymer, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, and copolymers, mixtures, blends and alloys thereof.
4. A multiconductor electrical cable of any of the preceding claims, wherein the insulating material is selected from the group consisting of one or more extruded layers of ethylene propylene diene methylene, ethylene propylene rubber, polychloroprene, fluoroelastomers, polypropylenes, polyethylenes, polyethers, and copolymers, mixtures, blends and alloys thereof.
5. A multiconductor electrical cable of Claim 4, wherein the insulating material is ethylene propylene diene methylene.
6. A multiconductor electrical cable of any of the preceding claims, wherein the jacket of elastomeric material surrounding the plurality of electrical conductors is selected from the group consisting of nitrile rubber, ethylene propylene, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, polyethylene, polypropylene, polyethylene, polyether, and copolymers, mixtures, blends and alloys thereof.
7. A multiconductor electrical cable of any of the preceding claims, and further comprising shield means between the insulating material and the jacket of elastomeric material for confining an electrical field

within the insulating material.

8. A multiconductor electrical cable of any of the preceding claims, and further comprising shield means between the insulating material and the jacket of elastomeric material for symmetrically distributing electrical stress within the non-conductive insulating material.
9. A multiconductor electrical cable of any of the preceding claims, and further comprising an insulation shield between the insulating material and the jacket of elastomeric material, the insulation shield is selected from the group consisting of tapes and weaves of metal, fibreglass, carbon fibre and aramid fibre, and tapes and/or one or more extruded layers of ethylene propylene copolymer, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, and copolymers, mixtures, blends and alloys thereof.
10. A multiconductor electrical cable of any of the preceding claims, and further comprising an insulation shield between the insulating material and the jacket of elastomeric material, the insulation shield having a maximum volume resistivity of about 500 Kohm-meter.
11. A multiconductor electrical cable of Claim 9, and further comprising a fluid barrier between the insulation shield and the jacket of elastomeric material, the fluid barrier is selected from the group consisting of tapes, films, weaves and one or more extruded layers of metal and fluropolymers.
12. A multiconductor electrical cable for use in a subterranean wellbore, comprising: a plurality of electrical conductors; at least one of the electrical conductors sheathed in at least one inner layer of a first material, and in at least one layer of a second material; the first material having a volume resistivity of less than about 10 Kohm-meter, and the second material having a volume resistivity of greater than about 10 Kohm-meter; and a jacket of elastomeric material surrounding the plurality of electrical conductors.
13. A multiconductor electrical cable of Claim 12 and further comprising insulation shield means between the second material and the jacket of elastomeric material for confining an electrical field within the second material.
14. A multiconductor electrical cable for use in a subterranean wellbore, comprising: a plurality of electrical conductors; at least one of the electrical conductors sheathed in at least one layer of a first material, and in at least one layer of an insulating ma-

terial; the first material having electrical properties to reduce voltage stress between an outer surface of the electrical conductor and an inner surface of the insulating material; and a jacket of elastomeric material surrounding the plurality of electrical conductors.

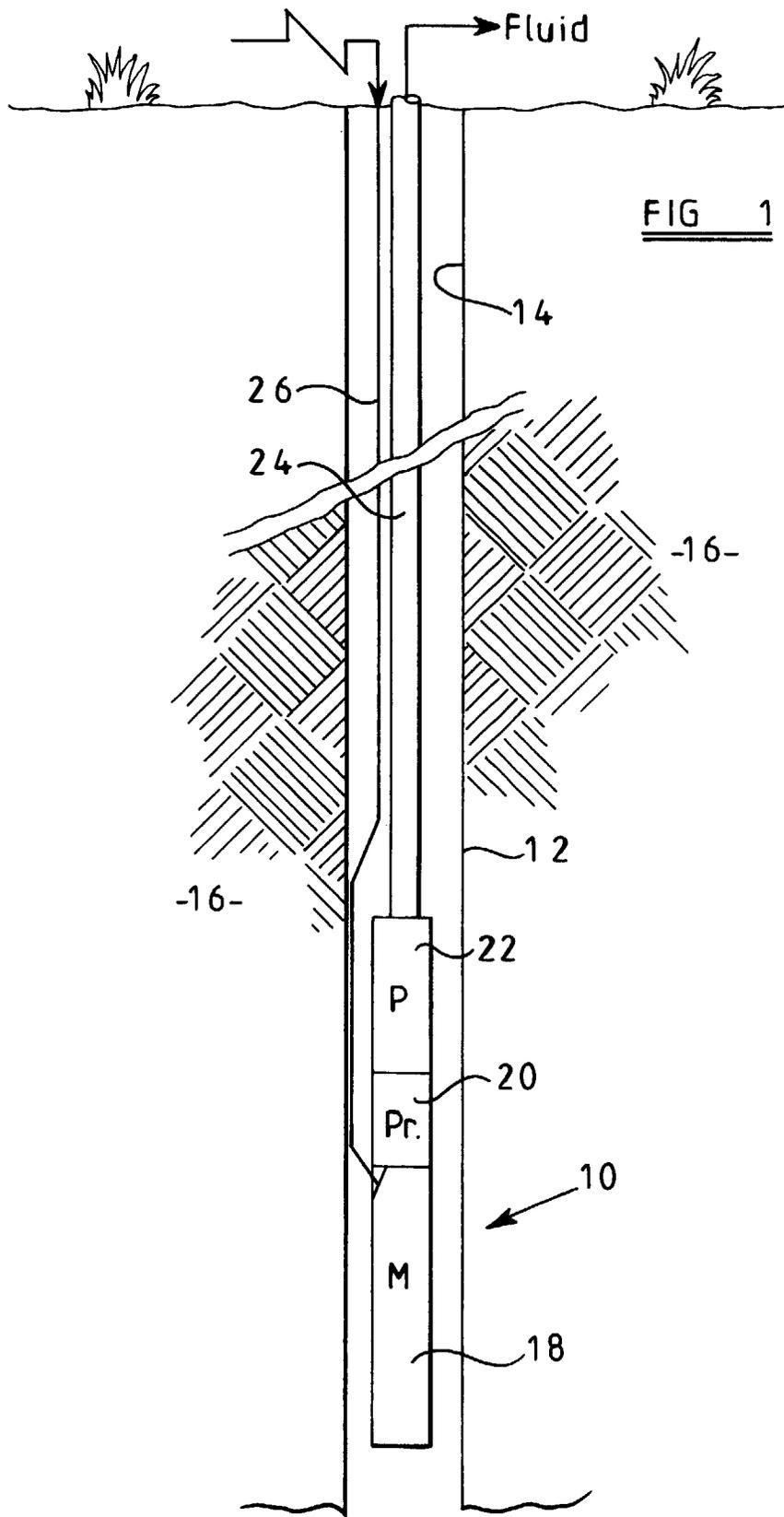
15. A multiconductor electrical cable of Claim 14 and further comprising shield means between the insulating material and the jacket of elastomeric material for confining an electrical field within the insulating material.

16. A multiconductor electrical cable for use in a subterranean wellbore, comprising: a plurality of electrical conductors; at least one of the electrical conductors sheathed in at least one layer of a first material, and in at least one layer of an insulating material; the first material is selected from the group consisting of tapes and weaves of fibreglass, carbon fibre and aramid fibre, and tapes and/or one or more extruded layers of ethylene propylene copolymer, ethylene vinyl acrylate copolymer, ethylene ethyl acrylate copolymer, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, and copolymers, mixtures, blends and alloys thereof. the second material is selected from the group consisting of one or more extruded layers of ethylene propylene diene methylene, ethylene propylene rubber, polychloroprene, fluoroelastomers, polypropylenes, polyethylenes, polyethers, and copolymers, mixtures, blends and alloys thereof; and a jacket of elastomeric material surrounding the plurality of electrical conductors selected from the group consisting of nitrile rubber, ethylene propylene, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, polyethylene, polypropylene, polyethylene, polyether, and copolymers, mixtures, blends and alloys thereof.

17. A multiconductor electrical cable of Claim 16 and further comprising an insulation shield adjacent the second material, the insulation shield is selected from the group consisting of tapes and weaves of metal, fibreglass, carbon fibre and aramid fibre, and tapes and one or more extruded layers of ethylene propylene copolymer, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, and copolymers, mixtures, blends and alloys thereof.

18. A multiconductor electrical cable of Claim 17 and further comprising a fluid barrier adjacent the insulation shield, the fluid barrier is selected from the group consisting of tapes, films, weaves and one or more extruded layers of metal and fluropolymers.

19. A multiconductor electrical cable for use in a subterranean wellbore, comprising: a plurality of electrical conductors with at least one of the electrical conductors sheathed in one or more layers of a first material selected from the group consisting of tapes and weaves of fibreglass, carbon fibre and aramid fibre, and tapes and/or one or more extruded layers of ethylene propylene copolymer, ethylene vinyl acrylate copolymer, ethylene ethyl acrylate copolymer, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, and copolymers, mixtures, blends and alloys thereof; a second material selected from the group consisting of one or more extruded layers of ethylene propylene diene methylene, ethylene propylene rubber, polychloroprene, fluoroelastomers, polypropylenes, polyethylenes, polyethers, and copolymers, mixtures, blends and alloys thereof; an insulation shield selected from the group consisting of tapes and weaves of metal, fibreglass, carbon fibre and aramid fibre, and tapes and one or more extruded layers of ethylene propylene copolymer, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, and copolymers, mixtures, blends and alloys thereof; and a fluid barrier selected from the group consisting of tapes, films, weaves and one or more extruded layers of metal and fluropolymers; a jacket of elastomeric material surrounding the plurality of electrical conductors selected from the group consisting of nitrile rubber, ethylene propylene, ethylene propylene diene methylene terpolymer, polychloroprene, polyolefin elastomer, polyethylenes, polypropylenes, polyethylenes, polyethers, and copolymers, mixtures, blends and alloys thereof; and metal armour covering the jacket of elastomeric material.



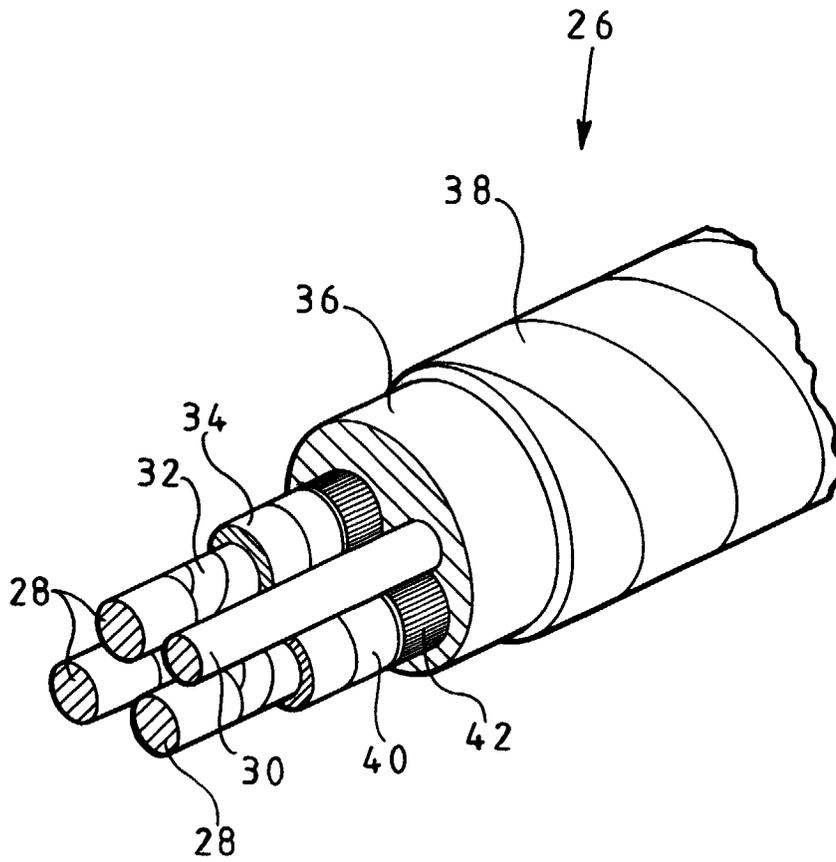


FIG 2



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EUROPEAN SEARCH REPORT

Application Number
EP 98 30 1355

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	GB 2 113 453 A (ELECTRICITY COUNCIL) 3 August 1983 * page 2, line 4 - line 15; figure 1 * ---	1-19	H01B9/02 H01B7/28 H01B7/18
X	US 4 398 058 A (GERTH DIETER ET AL) 9 August 1983 * column 2, line 45 - column 3, line 11; figures 1,2 * ---	1-19	
X	DE 25 04 555 A (SIEMENS AG) 5 August 1976 * page 3, line 9 - line 24; figure 1 * ---	1-19	
X	WO 82 01785 A (JPS ELTEKNIK AS ;STUBKJAER JENS E (DK)) 27 May 1982 * page 4, line 14 - page 6, line 17; figures 1-3 * ---	1-19	
X	US 3 651 244 A (SILVER DAVID A ET AL) 21 March 1972 * column 2, line 55 - line 69 * * column 4, line 44 - line 63; figures 1,8 * -----	1-19	
The present search report has been drawn up for all claims			TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01B
Place of search THE HAGUE		Date of completion of the search 27 August 1998	Examiner Shade, M
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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