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(54) **Title**: AN ELECTRICAL CABLE

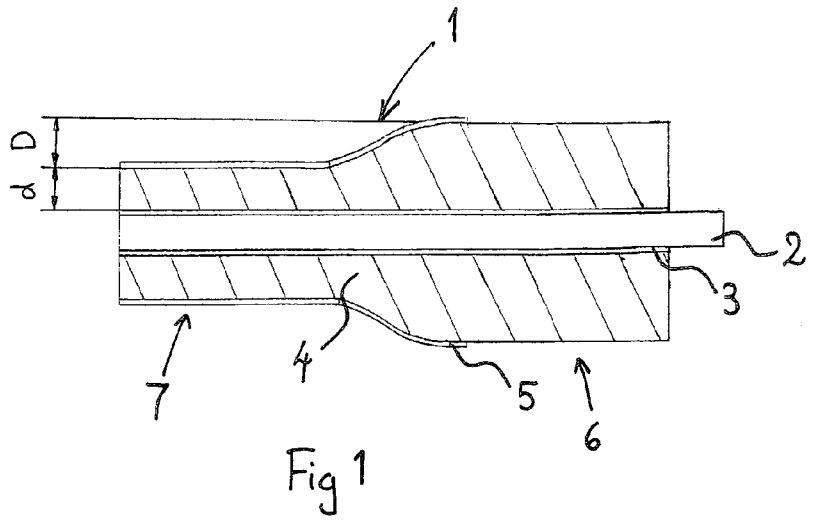


Fig 1

(57) **Abstract**: An electrical cable (1) for DC high voltage applications, wherein the electrical cable comprises a conductor (2), an inner semiconductive layer (3) next to and surrounding the conductor (2), an insulation layer (4) next to and surrounding said inner semiconductive layer (3), an outer semiconductive layer (5) next to and at least partly surrounding said insulation layer (4), wherein the electrical cable (1) at least at one of its end has a cable end part (6), in which said insulation layer (4) is at least 10% thicker than in parts (7) of the electrical cable (1) adjacent to said cable end part (6).

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An electrical cable

FIELD OF THE INVENTION

The present invention relates to an electrical cable for DC high voltage applications and a method for manufacturing an electrical cable.

BACKGROUND ART

Electrical cables for DC high voltage applications usually comprise a conductor, an inner semiconductive layer next to and surrounding said conductor, an insulation layer next to and surrounding said inner semiconductive layer and an outer semiconductive layer next to and surrounding said insulation layer.

In order to connect an electrical cable of the type mentioned above to a cable termination or to connect such an electrical cable to another electrical cable, i.e. to create a cable joint, one of the two following methods is usually used:

1. This first method can only be utilized for joints and is based on creating a cable structure by means of step-wise vulcanization of the different layers. The method comprises step-wise removal of the outer semiconductive layer, the insulation layer and the inner semiconductive layer at the ends of the electrical cables to be jointed. The conductors are thereafter suitably connected and the respective layers are re-created by step-wise application of band shaped vulcanization materials. This method is time consuming due to the fact that the different layers have to be vulcanized separately. The method is also dependent upon the skills of the operator creating the joint.

2. This other method is used for both terminations and joints and initially it comprises a removal of the outer semiconductive layer as in the method first described at an axial end of the cable/cables. A prefabricated accessory, in the form of for instance a stress cone, is thereafter arranged at the cable end/ends. The prefabricated accessory comprises insulation material and semiconductive layers. A drawback with these terminations/joints arises at the physical interface between the original cable/cables and the prefabricated accessory. This contact is only physical and such a contact limits the capacity of the insulation material. This method is less time consuming in comparison with the first method but the drawback is that the connecting part of the electrical cable/cables has a significantly lower performance.

SUMMARY OF THE INVENTION

The object of the present invention is to provide a new electrical cable for DC high voltage applications suitable for the creation of a cable joint and/or a cable termination.

This object is according to the invention obtained by providing an electrical cable having the features defined in claim 1, wherein the electrical cable comprises a conductor, an inner semiconductive layer next to and surrounding the conductor, an insulation layer next to and surrounding said inner semiconductive layer, an outer semiconductive layer next to and at least partly surrounding said insulation layer. The electrical cable has at least at one of its ends a cable end part, in which said insulation layer is at least 10% thicker than in parts of the electrical cable adjacent to said cable end part.

The electrical cable as disclosed above is ideal for use with a prefabricated accessory since the thicker insulation layer causes

a lowering of the radial electric field which always arises at a physical interface between a prefabricated accessory and a cable end to which said accessory is attached when the electrical cable is in use.

According to one embodiment of the invention the cable end part has an extension in the longitudinal direction of the electrical cable of at least 0.1 m, preferably at least 0.3 m, most preferred at least 0.5 m. The cable end part with a thickened insulation layer has to be of a certain length for achieving lowering of the radial electric field at the physical interface between the prefabricated accessory and the cable end part. For a joint or termination the cable end part should have an axial length of at least half the length of the accessory to be attached to the electrical cable.

According to another embodiment of the invention the cable end part is configured for being connected to a prefabricated accessory, whereby a physical interface is created between the cable end part and said accessory.

According to another embodiment of the invention the additional thickness of the insulation layer of the cable end part as compared to the thickness of the insulation layer in parts of the electrical cable adjacent to said cable end part is given by the equation (i)

$$D = d\left(\frac{E_c}{E_i} - 1\right) \qquad \text{(i)}$$

when $E_i < E_c$, wherein D is the additional thickness of said insulation layer in the cable end part, d is the thickness of the insulation layer in parts of the electrical cable adjacent to said cable end part, E_i is the maximum allowable radial design electric field of the physical interface (10) of the electrical cable (1) at said cable end part (6), and E_c is the electrical field at the

physical interface (10) of a similar electrical cable which not has said additional thickness (D). The radial design field is the acceptable field for the accessory to work safely and the electrical field at said physical interface is the calculated field at the interface of a given cable connection. If E_c is higher than E_i the accessory will not work properly, and the field at the physical interface must thereby be decreased. This decrease is achieved by the thickening of the insulation layer of the cable end part according to the equation (i).

According to another embodiment of the invention the cable end part is configured for being connected to a prefabricated accessory in the form of a cable joint or a cable termination.

According to another embodiment of the invention the insulation layer in the cable end part comprises a polymeric material. The insulation layer of a cable usually comprises a polymeric material, for instance a cross-linked polyethylene, a thermoplastic polyethylene or a thermoplastic polypropylene. A polymeric material provides good electrical insulating properties for the electrical cable.

According to another embodiment of the invention the outer semiconductive layer partly surrounds said insulation layer of the cable end part. A complementary outer semiconductive layer is thus added outside and surrounding said insulation layer. The outer semiconductive layer orients the electrical field radially which is advantageous from an insulation point of view.

According to another embodiment of the invention the cable end part has a conical shape tapering towards the cable end. This arrangement provides for further reduction of the radial electrical field when the cable joint or termination is in use, because of the fact that electric field vectors perpendicular to the created interface does not point in the radial direction.

A further object of the present invention is to provide a method for manufacturing a thickened end part on an electrical cable.

This further object is according to the invention obtained by providing a method having the features defined in claim 9, wherein the electrical cable comprises a conductor, an inner semiconductive layer next to and surrounding the conductor, an insulation layer next to and surrounding said inner semiconductive layer, an outer semiconductive layer next to and at least partly surrounding said insulation layer, wherein the method comprises the steps of:

- removing the outer semiconductive layer at a cable end part of the electrical cable to expose the insulation layer of said cable end part,
- winding a polymer tape around the exposed insulation layer of said cable end part, and
- chemically binding the polymer tape to the exposed insulation layer so as to form a polymer layer chemically bonded to and surrounding said exposed insulation layer of said cable end part.

The above described method for manufacturing a thickened end part on an electrical cable is relatively inexpensive and quick. A cable having a cable end part produced using this method is suitable for use together with an accessory for jointing cables and/or cable termination as discussed above. If the polymer tape and the exposed insulation layer are bonded to each other chemically the radial electric field will be significantly lowered in the physical interface between the cable end part and an accessory to which the cable end part is connected.

According to an embodiment of the invention the method comprises the step of chemically binding the polymer tape to the exposed insulation layer by vulcanization. Vulcanization is a reliable way to create a suitable interface with chemical bonds between the polymer tape and the exposed insulation layer.

According to another embodiment of the invention the method further comprises the step of removing parts of the exposed insulation layer of the cable end part prior to winding the polymer tape around it.

According to another embodiment of the invention the removal of parts of the exposed insulation layer creates a remainder of exposed insulation which has a conical shape around the inner semiconductive layer. This arrangement provides for further reduction of the radial electrical field when the cable joint or termination is in use, because of the fact that electric field vectors perpendicular to the created interface does not point in the radial direction.

According to another embodiment of the invention the method comprises the step of providing a complementary outer semiconductive layer next to and surrounding said polymer layer. The outer semiconductive layer helps reducing the radial electrical field when the cable is in use together with for instance an accessory as mentioned above.

According to another embodiment of the invention the complementary outer semiconductive layer is provided by means of vulcanization. By vulcanization the complementary outer semiconductive layer is chemically bonded to the outer semiconductive layer of the electrical cable.

Other advantages and advantageous features of the invention will appear from the dependent claims and the subsequent description.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the appended drawings, below follows a specific description of embodiments of the invention cited as examples.

In the drawings:

Fig 1 shows an electrical cable according to a first embodiment of the invention,

Fig 2 shows an electrical cable according to a second embodiment of the invention,

Fig 3 shows an electrical cable according to a third embodiment of the invention,

Fig 4 shows an electrical cable according to an embodiment of the invention inserted into an accessory in the form of a stress cone, and

Fig 5 shows two electrical cables according to an embodiment of the invention jointed by an accessory in the form of a cable joint.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Explained herein are electrical cables according to embodiments of the invention and an inventive method of manufacturing the same. The invention may, however, be embodied in many different forms and should not be construed as being limited to the exemplary embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the concept of the invention to those skilled in the art.

The figures should not be construed as representing the electrical cable according to the invention in scale; but are provided so that a person skilled in the art can conceive different embodiments of the invention by viewing the figures.

Fig 1 shows an electrical cable 1 for DC high voltage applications, wherein the electrical cable comprises a conductor 2, e.g. of aluminium or copper, an inner semiconductive layer 3, which purpose is to even out the electrical field, next to and surrounding the conductor 2, an insulation layer 4, preferably comprising a polymeric insulation material e.g. cross-linked polyethylene, next to and surrounding said inner semiconductive layer 3, an outer semiconductive layer 5 next to and at least partly surrounding said insulation layer 4 to make the electrical field radial which is advantageous from an insulation point of view. The electrical cable can also have other outer layers for instance for protecting the cable. The electrical cable 1 has at least at one of its end a cable end part 6, in which said insulation layer 4 is at least 10% thicker than in parts 7 of the electrical cable 1 adjacent to said cable end part 6. The cable end part 6 has an extension in the longitudinal direction of the electrical cable 1 of at least 0.1 m, preferably at least 0.3 m, most preferred at least 0.5 m. The additional thickness of the insulation layer 4 of the cable end part 6 as compared to the thickness of the insulation layer 4 in parts 7 of the electrical cable 1 adjacent to said cable end part 6 is roughly given by the equation (i)

$$D = d\left(\frac{E_c}{E_i} - 1\right) \qquad \text{(i)}$$

when $E_i < E_c$, wherein D is the additional thickness of said insulation layer in the cable end part, d is the thickness of the insulation layer in parts of the electrical cable adjacent to said cable end part, E_i is the maximum allowable radial design electric field of the physical interface (10) of the electrical cable

(1) at said cable end part (6), and E_c is the electrical field at the physical interface (10) of a similar electrical cable which not has said additional thickness (D).

In Fig 2 it is shown an electrical cable 1 according to another embodiment of the invention. The electrical cable of Fig 2 is similar to the electrical cable of Fig 1, but in the electrical cable of Fig 2 an interface 8 between an original insulation layer 4a, here also denominated exposed insulation layer, of an electrical cable 1 and an additional insulation layer 4b, here also denominated polymer layer, is shown. This interface 8 is a chemical interface, i.e. the original insulation layer 4a is chemically bonded to the additional insulation layer 4b. In Fig 2 the interface 8 is conically arranged parallel to the axial direction of the electrical cable 1, but this interface can of course be arranged in other ways, for instance conically which is shown in Fig 3.

The invention also relates to a method for manufacturing a thickened cable end part 6 on an electrical cable 1. The method can be understood by viewing Figs 2 and 3. According to the method an ordinary electrical cable for DC high voltage applications is used. The electrical cable comprises a conductor 2, an inner semiconductive layer 3 next to and surrounding the conductor 2, an insulation layer 4a next to and surrounding said inner semiconductive layer 3, an outer semiconductive layer 5a next to and at least partly surrounding said insulation layer 4a. The method comprises the steps of:

- removing the outer semiconductive layer at a cable end part 6 of the electrical cable 1 to expose the insulation layer 4a of said cable end part 6,
- winding a polymer tape around the exposed insulation layer 4a of said cable end part 6, and
- chemically binding, preferably by vulcanization, the polymer tape to the exposed insulation layer 4a so as to form a

polymer layer 4b chemically bonded to and surrounding said exposed insulation layer 4a of said cable end part 6.

For manufacturing an electrical cable 1 of the type seen in Fig 3 the method further comprises the step of removing parts of the exposed insulation layer 4a of the cable end part 6 prior to winding the polymer tape around it. The removal of parts of the exposed insulation layer 4a creates a remainder of exposed insulation 4a which has a conical shape around the inner semiconductive layer 3. The method can also comprise the step of providing a complementary outer semiconductive layer 5b, preferably by vulcanization, next to and surrounding said polymer layer 4b. The complementary outer semiconductive layer 5b can also be the original outer semiconductive layer 5a, which has been temporarily removed during the production of the polymer layer 4b. The polymer layer 4b can of course also be added as a prefabricated body which is vulcanized, e.g. press vulcanized, to the exposed insulation layer 4a to produce a thickened cable end part 6 on an electrical cable 1.

In Fig 4 it is shown an electrical cable 1 according to an embodiment of the invention inserted into an accessory in the form of a stress cone 9. The stress cone 9 can for instance be a part of a termination. A physical interface 10 is created between the stress cone 9 and the outer surface of the cable end part 6. The outer surface mentioned can be the outer surface of the insulation layer 4, but there can also be an outer semiconductive layer between said insulation layer 4 and the stress cone 9.

In Fig 5 it is shown two essentially identical electrical cables 1 according to an embodiment of the invention jointed by an accessory in the form of a cable joint 11. A physical interface 12 is created between the cable joint 11 and the outer surface of the cable end part 6. The outer surface mentioned can be the outer surface of the insulation layer 4, but there can also be an

outer semiconductive layer between said insulation layer 4 and the cable joint 11.

The invention is of course not in any way limited to the embodiments described above. On the contrary, several possibilities to modifications thereof should be apparent to a person skilled in the art without departing from the scope of the invention as defined in the appended claims.

Claims

1. An electrical cable (1) for DC high voltage applications, wherein the electrical cable comprises a conductor (2), an inner semiconductive layer (3) next to and surrounding the conductor (2), an insulation layer (4) next to and surrounding said inner semiconductive layer (3), an outer semiconductive layer (5) next to and at least partly surrounding said insulation layer (4), **characterized in** that the electrical cable (1) at least at one of its end has a cable end part (6), in which said insulation layer (4) is at least 10% thicker than in parts (7) of the electrical cable (1) adjacent to said cable end part (6).

2. An electrical cable (1) according to claim 1, **characterized in** that the cable end part (6) has an extension in the longitudinal direction of the electrical cable (1) of at least 0.1 m, preferably at least 0.3 m, most preferred at least 0.5 m.

3. An electrical cable (1) according to claim 1 or 2, **characterized in** that the cable end part (6) is configured for being connected to a prefabricated accessory (9, 11), whereby a physical interface (10) is created between the cable end part and said accessory (9, 11).

4. An electrical cable (1) according to claim 3, **characterized in** that the additional thickness (D) of the insulation layer (4) of the cable end part (6) as compared to the thickness of the insulation layer (4) in parts (7) of the electrical cable (1) adjacent to said cable end part (6) is roughly given by the equation (i)

$$D = d\left(\frac{E_c}{E_i} - 1\right) \qquad \text{(i)}$$

when $E_i < E_c$, wherein D is the additional thickness of said insulation layer (4) in the cable end part (6), d is the thickness of the insulation layer (4) in parts (7) of the electrical cable (1) adjacent to said cable end part (6), E_i is the maximum allowable radial design electric field of the physical interface (10) of the electrical cable (1) at said cable end part (6), and E_c is the electrical field at the physical interface (10) of a similar electrical cable which not has said additional thickness (D).

5. An electrical cable (1) according to claim 3 or 4, **characterized in** that the cable end part (6) is configured for being connected to a prefabricated accessory in the form of a cable joint (11) or a cable termination (9).

6. An electrical cable (1) according to any of the preceding claims, **characterized in** that the insulation layer (4) in the cable end part (6) comprises a polymeric material.

7. An electrical cable (1) according to any of the preceding claims, **characterized in** that the outer semiconductive layer (5) partly surrounds said insulation layer (4) of the cable end part (6).

8. An electrical cable according to any of the preceding claims, **characterized in** that the cable end part has a conical shape tapering towards the cable end.

9. A method for manufacturing a thickened cable end part (6) on an electrical cable (1), wherein the electrical cable (1) comprises a conductor (2), an inner semiconductive layer (3) next to and surrounding the conductor (2), an insulation layer (4) next to and surrounding said inner semiconductive layer (3), an outer semiconductive layer (5) next to and at least partly surrounding said insulation

layer (4), **characterized in** that the method comprises the steps of:

- removing the outer semiconductive layer (5) at a cable end part (6) of the electrical cable (1) to expose the insulation layer (4a) of said cable end part (6),
- winding a polymer tape around the exposed insulation layer (4a) of said cable end part (6), and
- chemically binding the polymer tape to the exposed insulation layer (4a) so as to form a polymer layer (4b) chemically bonded to and surrounding said exposed insulation layer (4a) of said cable end part (6).

10. A method according to claim 9, **characterized in** that the method comprises the step of chemically binding the polymer tape to the exposed insulation layer (4a) by vulcanization.

11. A method according to claim 9 or 10, **characterized in** that the method further comprises the step of removing parts of the exposed insulation layer (4a) of the cable end part (6) prior to winding the polymer tape around it.

12. A method according to claim 11, **characterized in** that the removal of parts of the exposed insulation layer (4a) creates a remainder of exposed insulation (4a) which has a conical shape around the inner semiconductive layer (3).

13. A method according to any of claims 9-12, **characterized in** that the method comprises the step of providing a complementary outer semiconductive layer (5b) next to and surrounding said polymer layer (4b).

14. A method according to claim 13, **characterized in** that the complementary outer semiconductive layer (5b) is provided by means of vulcanization.

15. Use of an electrical cable (1) as defined in any of claims 1-8 for connection to a prefabricated accessory, preferably a cable joint (11) and/or a cable termination (9).

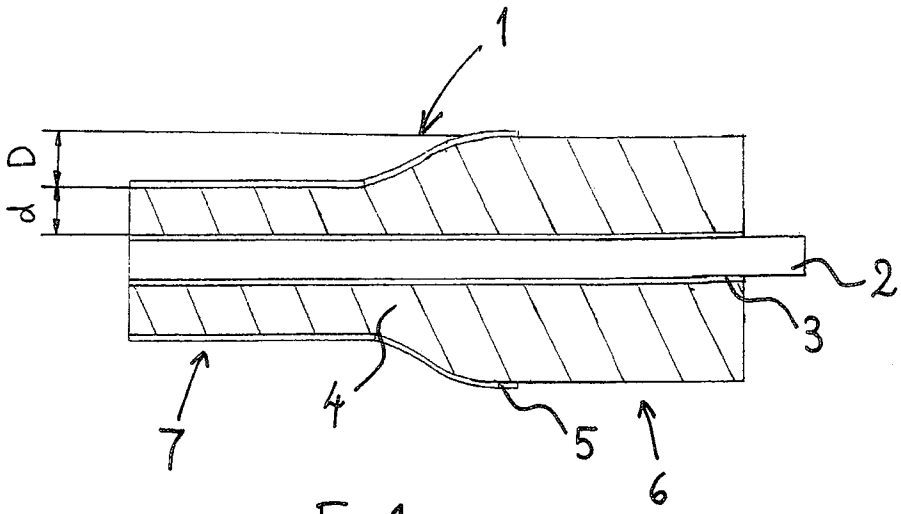


Fig 1

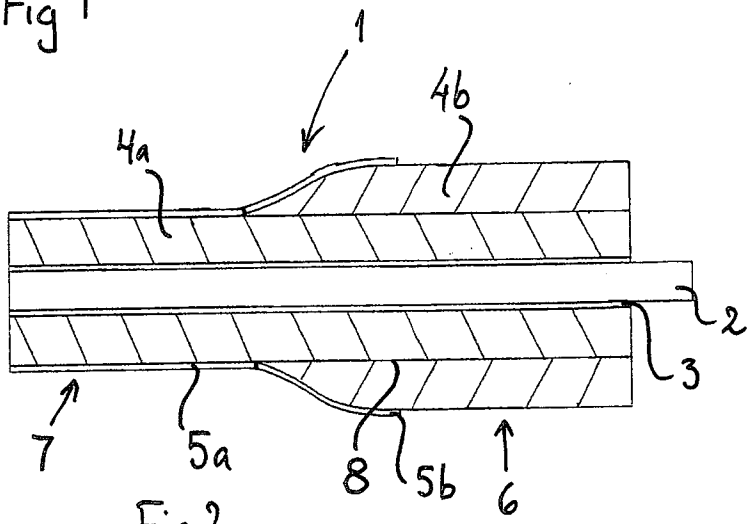


Fig 2

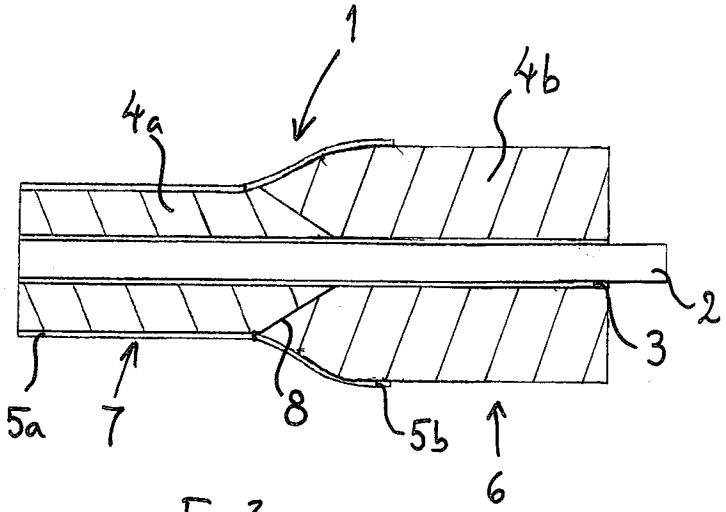


Fig 3

2/2

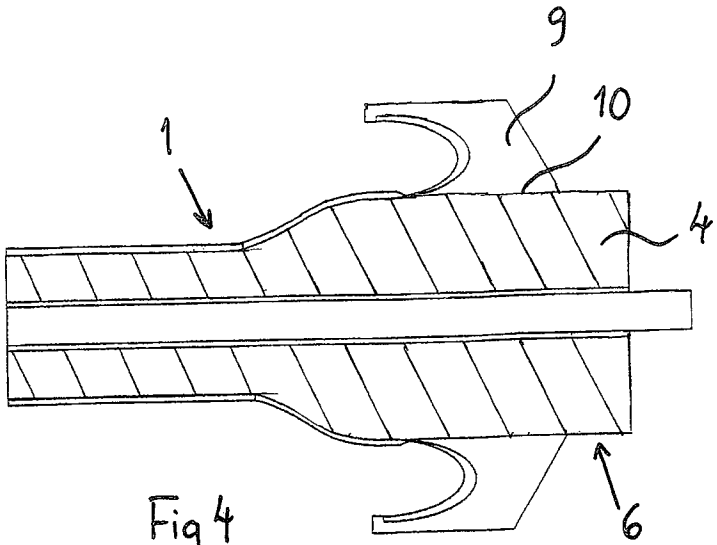


Fig 4

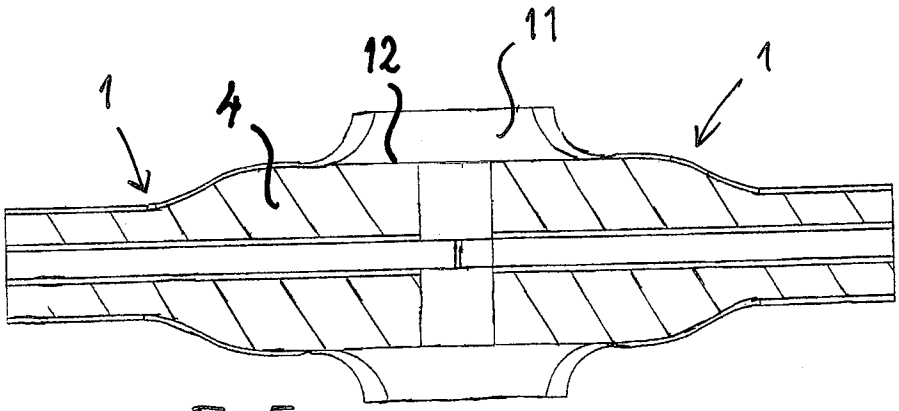


Fig 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2009/058070

A. CLASSIFICATION OF SUBJECT MATTER
INV. H01B9/02

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)
H01B H02G H01R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 510 453 A (FUJIKURA LTD [JP]) 28 October 1992 (1992-10-28)	1,2,8
Y	column 1, line 21 - line 40 column 2, line 39 - column 3, line 53; figure 4 column 5, line 31 - line 48	3-7
X	EP 0 742 628 A (NKT CABLES AS [DK]) 13 November 1996 (1996-11-13)	9,10, 13-15
Y	column 2, line 45 - column 3, line 41 column 5, line 39 - column 6, line 39; figures 3-8	3-7,11, 12
Y	US 3 356 788 A (CALLAHAN THOMAS W ET AL) 5 December 1967 (1967-12-05) column 3, line 5 - line 16 column 8, line 6 - line 36; figures 11-15	11,12

☐ 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 document 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	Date of mailing of the international search report
21 January 2010	02/02/2010

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Knack, Steffen

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2009/058070

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