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CA 2542986 C 2013/02/05

(11)(21) **2 542 986**

(12) **BREVET CANADIEN**
CANADIAN PATENT

(13) **C**

(86) **Date de dépôt PCT/PCT Filing Date:** 2003/12/18
(87) **Date publication PCT/PCT Publication Date:** 2005/02/17
(45) **Date de délivrance/Issue Date:** 2013/02/05
(85) **Entrée phase nationale/National Entry:** 2006/01/23
(86) **N° demande PCT/PCT Application No.:** EP 2003/014782
(87) **N° publication PCT/PCT Publication No.:** 2005/015576
(30) **Priorité/Priority:** 2003/07/25 (EP PCT/EP03/08194)

(51) **Cl.Int./Int.Cl.** *H01B 13/00* (2006.01), *H01B 13/14* (2006.01), *H01B 13/26* (2006.01)

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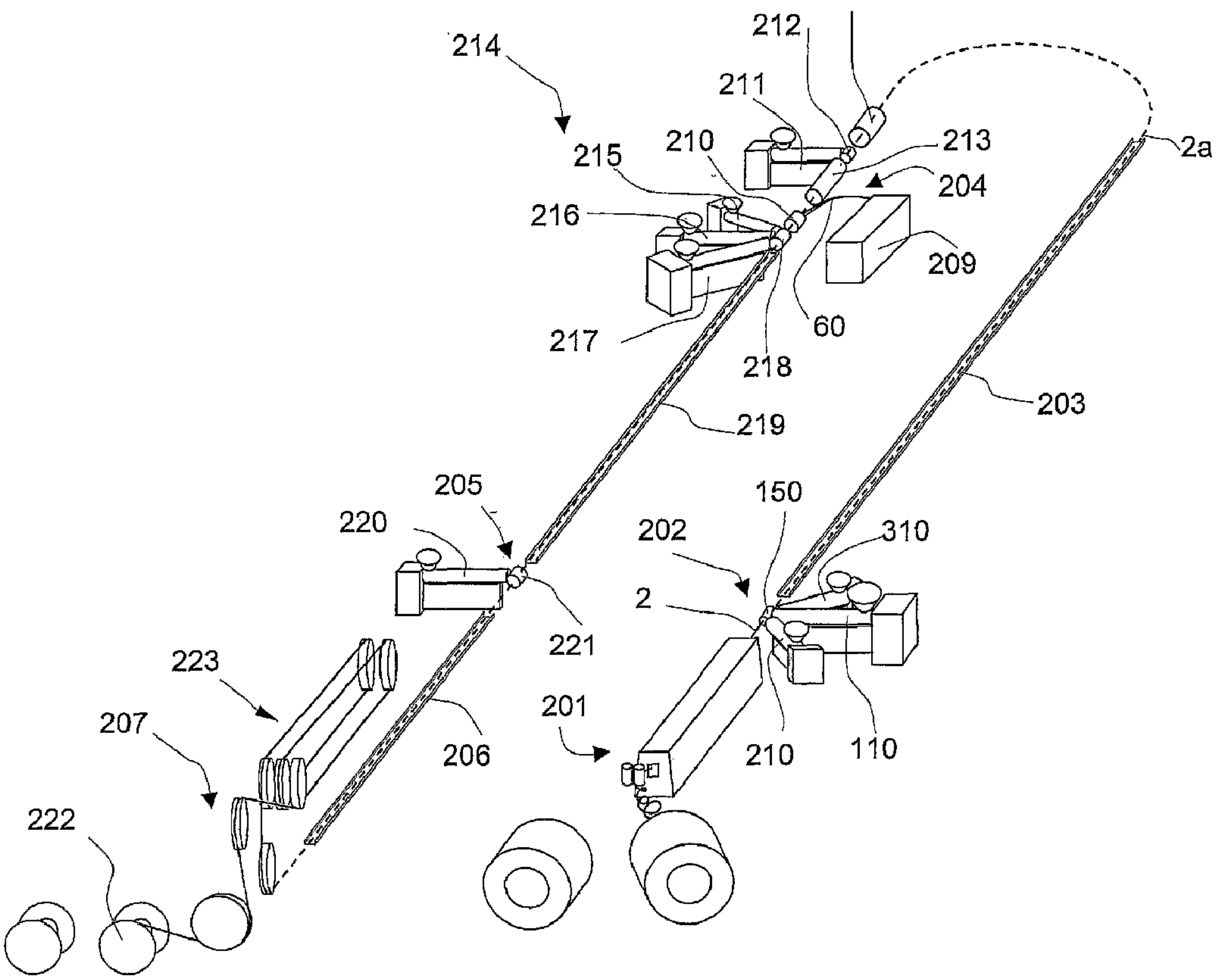
(54) Titre : PROCEDE CONTINU SERVANT A FABRIQUER DES CABLES ELECTRIQUES
(54) Title: CONTINUOUS PROCESS FOR MANUFACTURING ELECTRICAL CABLES



(57) **Abrégé/Abstract:**
The present invention concerns a process for manufacturing an electric cable. In particular, the process comprises the steps of: a) feeding a conductor at a predetermined feeding speed; b) extruding a thermoplastic insulating layer in a radially outer position with

(57) Abrégé(suite)/Abstract(continued):
respect to the conductor; c) cooling the extruded insulating layer at a temperature not higher than 70°C, and d) forming a circumferentially closed metallic screen around said extruded insulating layer. The process according to the invention is carried out continuously, i.e. the time occurring between the end of the cooling step and the beginning of the screen forming step is inversely proportional to the feeding speed of the conductor.

CA 02542986 2006-01-23

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
17 February 2005 (17.02.2005)

PCT

(10) International Publication Number
WO 2005/015576 A1

(51) International Patent Classification[7]: H01B 13/00, 13/14, 13/26

(21) International Application Number: PCT/EP2003/014782

(22) International Filing Date: 18 December 2003 (18.12.2003)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
PCT/EP03/08194 25 July 2003 (25.07.2003) EP

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(81) Designated States (*national*): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States (*regional*): ARIPO patent (BW, GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IT, LU, MC, NL, PT, RO, SE, SI, SK, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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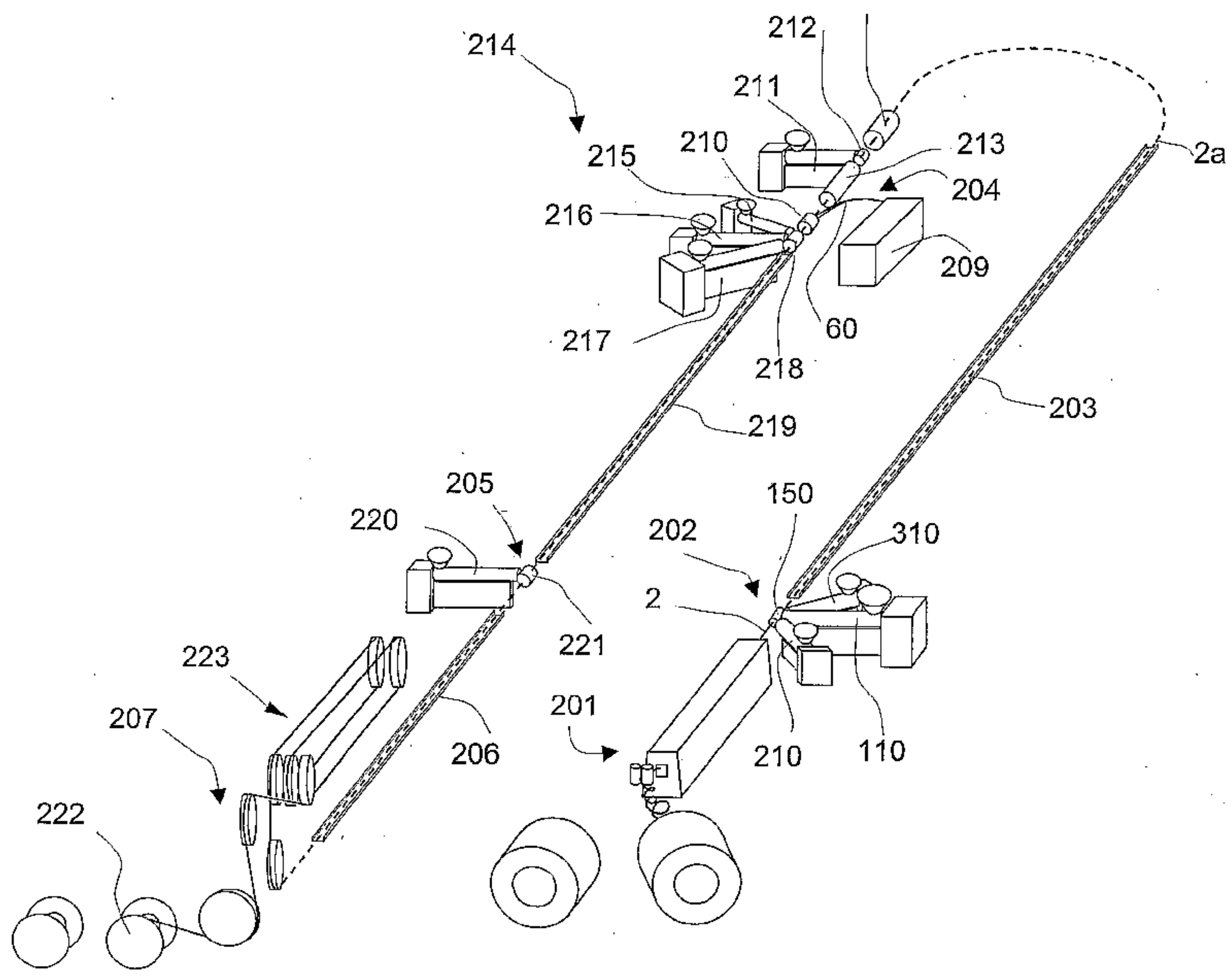
(54) Title: CONTINUOUS PROCESS FOR MANUFACTURING ELECTRICAL CABLES



(57) Abstract: The present invention concerns a process for manufacturing an electric cable. In particular, the process comprises the steps of: a) feeding a conductor at a predetermined feeding speed; b) extruding a thermoplastic insulating layer in a radially outer position with respect to the conductor; c) cooling the extruded insulating layer at a temperature not higher than 70°C, and d) forming a circumferentially closed metallic screen around said extruded insulating layer. The process according to the invention is carried out continuously, i.e. the time occurring between the end of the cooling step and the beginning of the screen forming step is inversely proportional to the feeding speed of the conductor.

WO 2005/015576 A1

WO 2005/015576 A1

Declaration under Rule 4.17:

— *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii)) for all designations*

Published:

— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

Title: Continuous process for manufacturing electrical cables

DESCRIPTION

Field of the invention

The present invention relates to a process for manufacturing electrical cables, in particular electrical cables for power transmission or distribution at medium or high voltage.

In the present description, the term medium voltage is used to refer to a tension typically from about 1 kV to about 30 kV and the term high voltage refers to a tension above 30 kV. The term very high voltage is also used in the art to define voltages greater than about 150 kV or 220 kV, up to 500 kV or more.

The cables the invention relates to may be used for both direct current (DC) or alternating current (AC) transmission or distribution.

Prior art

Cables for power transmission or distribution at medium or high voltage generally are provided with a metal conductor which is surrounded - from the radially innermost layer to the radially outermost layer - with a first inner semiconductive layer, an insulating layer and an outer semiconductive layer respectively. In the following of the present description, said group of elements will be indicated with the term of "cable core".

In a radially outer position with respect to said core, the cable is provided with a metallic screen (or metal shield), usually made of aluminum, lead or copper.

The metallic screen may consist of a number of metal wires or tapes, helically wound around the core, or of a circumferentially continuous tube, such as a metallic sheet which is formed longitudinally into a tubular shape by welding or sealing, e.g. by gluing, the lateral edges thereof in order to provide a barrier to moisture or to water ingress into the cable core.

The metallic screen mainly performs an electrical function by creating, inside the cable, as a result of direct contact between the metallic screen and the outer semiconductive layer of the cable core, a uniform electrical field of the radial type, at the same time canceling the external electrical field of the cable. A further function is that of withstanding short-circuit currents.

When made in circumferentially continuous tubular form, the metallic screen also provides hermeticity against water penetration in the radial direction.

An example of metallic screen is described, for instance, in US Re36307.

In a configuration of the unipolar type, the electrical cable further comprises a polymeric oversheath in a radially outer position with respect to the metallic screen.

Moreover, cables for power transmission or distribution are generally provided with one or more layers for protecting said cables from accidental impacts which may occur on the outer surface thereof.

Accidental impacts on a cable may occur, for example, during transport thereof or during the laying step of the cable in a trench dug into the soil. Said accidental impacts may cause a series of structural damages to the cable, including deformation of the insulating layer and detachment of the insulating layer from the semiconductive layers, damages which may cause variations in the electrical voltage stress of the insulating layer with a consequent decrease in the insulating capacity of said layer.

Cross-linked insulation cables are known and the manufacturing process thereof is described, for example, in EP1288218, EP426073, US2002/0143114, and US4469539.

The cross-linking of the cable insulation can be made either by using the so-called silane cross-linking or by using peroxides.

In the first case, the cable core, comprising the extruded insulating layer surrounding the conductor, is maintained for a relatively long period of time (hours or days) in a water-containing ambient (either liquid or vapor, such as ambient humidity), so that the water can diffuse through the insulating layer to cause the cross-linking to take place. This requires the cable core to be coiled on spools of fixed length, fact which inherently prevents a continuous process to be carried out.

In the second case, the cross-linking is caused by the decomposition of a peroxide, at relatively high temperature and pressure. The chemical reactions which take place generate gaseous by-products which must be allowed to diffuse through the insulating layer not only during the curing time but also after the curing. Therefore a degassing step has to be provided during which the cable core is stored for a period of time sufficient to eliminate such gaseous by-products before further layers can be applied over the cable core (in particular in case such layers are gas-tight or substantially gas-tight, such as in the case a longitudinally folded metal layer is applied).

In the practical experience of the Applicant, in the absence of a degassing step prior to further layers application, it may happen that under particular environmental conditions (e.g. remarkable solar irradiation of the cable core) said by-products expand, thus causing undesired deformations of the metallic screen and/or of the polymeric oversheath.

Furthermore, in the case a degassing step is not provided, the gaseous by-products (e.g. methane, acetophenone, cuminic alcohol) remain trapped within the cable core due to the presence of the further layers applied thereto and can exit the cable only from the ends thereof. This is particularly dangerous since some of said by-products (e.g. methane) are inflammable and thus explosions may occur, for instance during laying or joining of said cables in the trench dug into the soil.

Furthermore, in the absence of a degassing step prior to further layers application, it may happen that porosity in the insulation is found which can deteriorate the electric properties of the insulating layer.

A process for producing a cable having thermoplastic insulation is described in WO 02/47092, in the name of the same Applicant, where a cable is produced by extruding and passing through a static mixer a thermoplastic material, comprising a thermoplastic polymer mixed with a dielectric liquid, such thermoplastic material being applied around a conductor by means of an extrusion head. After a cooling and a drying step, the cable core is stored on a reel and then a metallic screen is applied by helically placing thin strips of copper or copper wires onto the cable core. An outer polymeric sheath then completes the cable.

The continuous supply of the cable core to the screen application unit was not contemplated. In fact the screen was of a type only suitable for a non-continuous application process since it required the use of spools mounted on a rotating apparatus, as further explained in the following of the present description.

Summary of the invention

The Applicant has perceived that the presence of a rest step during the cable production, for example for curing or degassing purposes, is undesirable because it limits the length of each cable piece (a collecting step on cable reels being required), it introduces space and logistic problems in the factory, it extends the cable manufacturing time and, finally, it increases the cost of the cable production.

Therefore, the Applicant has provided a continuous process for manufacturing a cable, i.e. a process without intermediate resting or collecting steps, by using a thermoplastic insulation material in combination with a longitudinally folded, circumferentially continuous metallic screen.

In setting up a continuous process for manufacturing a cable, the Applicant has perceived that a criticity may arise if, when carrying out the step of forming the circumferentially closed metallic screen around the extruded insulating layer, the temperature of the extruded insulating layer exceeds a predetermined threshold value.

In particular, the Applicant has perceived that, in a continuous process for manufacturing a cable, the maximum temperature of the extruded insulating layer, at the time of forming the circumferentially closed metallic screen thereupon, is a critical parameter for a correct working of the finished cable, the maximum temperature of the extruded insulating layer needing to be lower than a predetermined threshold value.

In fact, in case such a condition is not satisfied, the Applicant has noted that voids can be formed between the metallic screen and the insulating layer of the finished cable.

In details, since the thermal expansion/shrinkage coefficient of a plastic material is higher than that of a metallic material, if the circumferentially closed metallic screen is formed over the insulating layer when the maximum temperature of the latter - which has been extruded in a previous step of the continuous process - is higher than a predetermined threshold value, when the cable cools down the insulating layer shrinks of a greater amount than the metallic screen. Moreover, due to its tubular shape obtained by longitudinally folding a metallic sheet, the metallic screen is unable to follow the thermal contraction and shrinkage extent of the insulating layer.

Therefore, since the resulting contraction of the insulating layer is greater than that of the metallic screen, voids can originate between the insulating layer and the metallic screen. The presence of voids inside of the cable is particularly critical since they may cause the formation of partial electrical discharges during operation of the cable and thus the breakdown thereof.

Furthermore, the presence of voids in the space between the insulating layer and the metallic screen, negatively affects the cable not only from an electrical point of view, but also from a mechanical point of view since kinks may occur due to the buckling of the metallic screen under remarkable or successive bending actions occurring on the cable, e.g. during the winding of the finished cable on a collecting reel or on a storage unit.

The formation of permanent kinks in the metallic screen has to be avoided since it negatively affects the mechanical resistance of the screen, e.g. the fatigue failure of the metallic screen remarkably decreases in the presence of kinks.

Moreover, since a polymeric layer is generally extruded over the metallic screen, the formation of kinks in the metallic screen may cause localized detachments of the polymeric layer from the screen. This aspect negatively affects the cable life since water may penetrate into the cable and reach said localized detachments, thereby giving rise to corrosion phenomena of the metallic screen.

Moreover, the Applicant has perceived that the temperature of the insulating layer further influences the temperature of the metallic screen which is folded over the insulating layer. In more details, the Applicant has perceived that, in case the maximum temperature of the insulating layer is higher than a predetermined threshold value, the temperature of the metallic screen remarkably increases and, when the finished cable is wound on a collecting reel, kinks can be formed in the metallic screen due to its buckling.

It has to be pointed out that in conventional cable manufacturing processes - according to which the process is not continuously carried out as in the present invention - said drawbacks do not arise since the metallic screen is applied over the insulating layer when the latter is in a cold state since the cable core is obtained in a first step of the manufacturing process and successively stored on a collecting reel.

The Applicant has found that, before the step of forming the circumferentially closed metallic screen around the extruded insulating layer is carried out, the extruded insulating layer has to be cooled down to a temperature not higher than 70°C.

In other words, in order that the drawbacks mentioned above do not arise, the Applicant has found that it is not necessary to cool down the extruded insulating layer to the environmental temperature (20 - 25 °C) - e.g. to a temperature which is typical of a discontinuous process according to which the cable core is produced and successively stored on a collecting reel - since a cooling of the extruded insulating layer to a temperature not higher than 70°C ensures that a finished cable with good electrical/mechanical properties can be obtained.

Furthermore, the Applicant has perceived that, in a continuous cable manufacturing process, the fact of cooling the extruded insulating layer to a temperature not higher than 70°C allows to advantageously optimize the layout of the plant. In fact, as mentioned above, since there is no need to remarkably cooling down the extruded insulating layer, the cooling section can be designed to have a limited length and there is no need to make it complex - e.g. by increasing the number of passages of the cable core within suitable cooling channels.

Moreover, the Applicant has noticed that it is particularly advantageous that the extruded insulating layer is not in a cold state when the metallic screen is going to be formed thereon. In fact, in the case the extruded insulating layer is in a cold state when the metallic screen is formed in a radially outer position with respect to the insulating layer and successively a polymeric sheath - e.g. a protective element - is formed in a radially outer position with respect to the metallic screen, the material of the polymeric sheath which is closest to the metallic screen, and thus to the insulating layer, cools down very quickly with respect to the remaining material of the polymeric sheath.

As a consequence of such a quick cooling, the polymeric sheath layer closest to the insulating layer solidifies - i.e. it becomes rigid - while the remaining material of the polymeric sheath is still in a soft state. This aspect is particularly disadvantageous for the reason that the presence of said rigid layer prevents the polymeric sheath to suitably shrink onto the metallic screen and thus a good tightening of the metallic screen and of the polymeric sheath onto the insulating layer can not be performed.

On the contrary, in the case the extruded insulating layer is cooled down to a temperature not higher than 70°C in accordance with the present invention, the polymeric sheath - which is formed onto the metallic screen - is not caused to quickly cool down and the formation of a rigid polymeric sheath layer is prevented. As a result, the polymeric sheath suitably shrinks onto the metallic screen and thus a good tightening of the metallic screen and of the polymeric sheath onto the insulating layer can be performed.

Preferably, the extruded insulating layer has to be cooled down to a temperature in the range from about 30°C to about 70°C.

Preferably, the extruded insulating layer has to be cooled down to a temperature in the range from about 40°C to about 60°C.

In a first aspect, the present invention refers to a continuous process for manufacturing an electric cable, said process comprising the steps of:

- feeding a conductor at a predetermined feeding speed;

- extruding a thermoplastic insulating layer in a radially outer position with respect to the conductor;

- cooling the extruded insulating layer to a temperature not higher than 70°C;

- forming a circumferentially closed metallic screen around said extruded insulating layer.

In particular, the circumferentially closed metallic screen around the extruded insulating layer is formed by longitudinally folding a metal sheet, either having overlapping edges or edge-bonded edges.

Preferably, the step of forming the metallic screen according to the process of the present invention comprises the step of overlapping the edges of a metal sheet. Alternatively, said forming step comprises the step of bonding, e.g. by welding, the edges of said metal sheet.

Preferably, the process comprises the step of supplying the conductor in the form of a metal rod.

Generally the process of the invention further comprises the step of applying an oversheath around the metallic screen. Preferably, the oversheath is applied by extrusion.

Furthermore, preferably the process of the present invention comprises the step of applying an impact protecting element around the metallic screen. Preferably, said impact protecting element is applied by extrusion. Preferably, said impact protecting element comprises a non-expanded polymeric layer and an expanded polymeric layer. Preferably, the expanded polymeric layer is in a outer radially position with respect to the non-expanded polymeric layer. Preferably, the non-expanded polymeric layer and the expanded polymeric layer are applied by co-extrusion.

Preferably, the impact protecting element is applied between the closed metallic screen and the oversheath.

Preferably, the thermoplastic polymer material of the insulating layer includes a dielectric liquid.

Furthermore, the Applicant has found that the cable obtained by the continuous process of the present invention is surprisingly provided with high mechanical resistance to accidental impacts which may occur on the cable.

In particular, the Applicant has found that a high impact protection is advantageously conferred to the cable by combining a circumferentially closed metallic screen with an impact protecting element comprising at least one expanded polymeric layer, the latter being located in a radially outer position with respect to the metallic screen.

Furthermore, the Applicant has noticed that, in case a deformation of the screen occurs due to a relevant impact on the cable, the presence of a circumferentially closed metallic screen is particularly advantageous since the screen deforms continuously and smoothly, thereby avoiding any local increases of the electric field in the insulating layer.

Moreover, the Applicant has found that a cable provided with a thermoplastic insulating layer, a circumferentially closed metallic screen and an impact protecting element comprising at least one expanded polymeric layer can be advantageously obtained by means of a continuous manufacturing process.

Furthermore, the Applicant has found that the mechanical resistance to accidental impacts can be advantageously increased by providing the cable with a further expanded polymeric layer in a radially inner position with respect to the metallic screen.

Moreover, the Applicant has found that said further expanded polymeric layer - in a radially inner position with respect to the metallic screen - contributes in favoring the expansion/shrinkage of the metallic screen (during the cable manufacturing process as well as in the thermal cycles of the cable during use). In fact, said expanded layer acts as an elastic cushion and favors the adhesion between the metallic screen and the cable core.

Preferably, said further expanded polymeric layer is a water-blocking layer.

Brief description of the drawings

Further details will be illustrated in the description which follows, with reference to the appended drawings, in which:

- Fig. 1 is a perspective view of an electrical cable which can be obtained by the process of the present invention;

- Fig. 2 is a perspective view of a further electrical cable which can be obtained by the process of the present invention;

- Fig. 3 schematically represents a plant for the production of cables according to the process of the present invention;

- Fig. 4 schematically represents an alternative plant for the production of cables according to the process of the present invention;

- Figs. 5 to 7 are exemplary thermal profiles of the process of the present invention;

- Fig. 8 is a cross-sectional view of a traditional electrical cable provided with a screen made of wires, damaged by an impact;

- Fig. 9 is a cross-sectional view of an electrical cable damaged by an impact and made according to the process of the present invention, and

- Fig. 10 is a photograph of the metallic screen of a cable obtained by the process of the present invention.

Detailed description of the preferred embodiments

Figures 1 and 2 show a perspective view, partially in cross-section, of an electrical cable 1, typically designed for use in medium or high voltage range, which is made by the process according to the present invention.

The cable 1 comprises: a conductor 2; an inner semiconductive layer 3; an insulating layer 4; an outer semiconductive layer 5; a metallic screen 6 and a protective element 20.

Preferably, the conductor 2 is a metal rod. Preferably, the conductor is made of copper or aluminum.

Alternatively, the conductor 2 comprises at least two metal wires, preferably of copper or aluminum, which are stranded together according to conventional techniques.

The cross-sectional area of the conductor 2 is determined as a function of the power to be transported at the selected voltage. Preferred cross-sectional areas for cables according to the present invention range from 16 mm^2 to 1,600 mm^2.

In the present description, the term "insulating material" is used to indicate a material having a dielectric strength of at least 5 kV/mm, preferably greater than 10 kV/mm. For medium-high voltage power transmission cables (i.e. voltage greater than about 1 kV), preferably the insulating material has a dielectric strength greater than 40 kV/mm.

Typically, the insulating layer of power transmission cables has a dielectric constant greater than 2.

The inner semiconductive layer 3 and the outer semiconductive layer 5 are generally obtained by extrusion.

The base polymeric materials of the semiconductive layers 3 and 5, which are conveniently selected from those mentioned in the following of the present description with reference to the expanded polymeric layer, are additivated with an electroconductive carbon black, for example electroconductive furnace black or acetylene black, so as to confer semiconductive properties to the polymer material. Generally, the surface area of the carbon black is greater than 20 m^2/g, usually between 40 and 500 m^2/g. Advantageously, a highly conducting carbon black may be used, having a surface area of at least 900 m^2/g, such as, for example, the furnace carbon black known commercially under the tradename Ketjenblack® EC (Akzo Chemie NV). The amount of carbon black to be added to the polymer matrix can vary depending on the type of polymer and of carbon black used, the degree of expansion which it is intended to obtain, the expanding agent, etc. The amount of carbon black thus has to be such as to give the expanded material sufficient semiconductive properties, in particular such as to obtain a volumetric resistivity value for the expanded material, at room temperature, of less than 500 $\Omega \cdot m$, preferably less than 20 $\Omega \cdot m$. Typically, the amount of carbon black may range between 1 and 50% by weight, preferably between 3 and 30% by weight, with respect to the weight of the polymer.

In a preferred embodiment of the present invention, the inner and outer semiconductive layers 3 and 5 comprise a non-cross-linked polymeric material, more preferably a polypropylene material.

Preferably the insulating layer 4 is made of a thermoplastic material which comprises a thermoplastic polymer material including a predetermined amount of a dielectric liquid.

Preferably the thermoplastic polymer material is selected from the group comprising: polyolefins, copolymers of different olefins, copolymers of an olefin with an ethylenically unsaturated ester, polyesters, polyacetates, cellulose polymers, polycarbonates, polysulphones, phenol resins, urea resins, polyketones, polyacrylates, polyamides, polyamines, and mixtures thereof. Examples of suitable polymers are: polyethylene (PE), in particular low density PE (LDPE), medium density PE (MDPE), high density PE (HDPE), linear low density PE (LLDPE), ultra-low density polyethylene (ULDPE); polypropylene (PP); ethylene/vinyl ester copolymers, for example ethylene/vinyl acetate (EVA); ethylene/acrylate copolymers, in particular ethylene/methyl acrylate (EMA), ethylene/ethyl acrylate (EEA) and ethylene/butyl acrylate (EBA); ethylene/α-olefin thermoplastic copolymers; polystyrene; acrylonitrile/butadiene/styrene (ABS) resins; halogenated polymers, in particular polyvinyl chloride (PVC); polyurethane (PUR); polyamides; aromatic polyesters such as polyethylene terephthalate (PET) or polybutylene terephthalate (PBT); and copolymers thereof or mechanical mixtures thereof.

Preferably, the dielectric liquid may be selected from the group comprising: mineral oils such as, for example, naphthenic oils, aromatic oils, paraffinic oils, polyaromatic oils, said mineral oils optionally containing at least one heteroatom selected from the group comprising: oxygen, nitrogen or sulphur; liquid paraffins; vegetable oils such as, for example, soybean oil, linseed oil, castor oil; oligomeric aromatic polyolefins; paraffinic waxes such as, for example, polyethylene waxes, polypropylene waxes; synthetic oils such as, for example, silicone oils, alkyl benzenes (such as, for example, dibenzyltoluene, dodecylbenzene, di(octylbenzyl)toluene), aliphatic esters (such as, for example, tetraesters of pentaerythritol, esters of sebacic acid, phthalic esters), olefin oligomers (such as, for example, optionally hydrogenated polybutenes or polyisobutenes); or mixtures thereof. Aromatic, paraffinic and naphthenic oils are particularly preferred.

In the preferred embodiments shown in Figures 1 and 2, the metallic screen 6 is made of a continuous metal sheet, preferably of aluminum or copper, which is shaped as a tube.

The metal sheet forming the metallic screen 6 is folded lengthwise around the outer semiconductive layer 5 with overlapping edges.

Conveniently, a sealing and bonding material is interposed between the overlapping edges, so as to make the metallic screen watertight. Alternatively, the metal sheet edges may be welded.

As shown in Figures 1 and 2, the metallic screen 6 is surrounded by an oversheath 23 preferably made of a non-cross-linked polymer material, for example polyvinyl chloride (PVC) or polyethylene (PE); the thickness of such oversheath can be selected to provide the cable with a certain degree of resistance to mechanical stresses and impacts, however without excessively increasing the cable diameter and rigidity. Such solution is convenient, for example, for cables intended for use in protected areas, where limited impacts are expected or protection is otherwise provided.

According to a preferred embodiment, shown in Fig. 1, which is particularly convenient when an enhanced impact protection is desired, the cable 1 is provided with a protective element 20, located in a radially outer position with respect to said metallic screen 6. According to said embodiment, the protective element 20 comprises a non-expanded polymeric layer 21 (in a radially inner position) and an expanded polymeric layer 22 (in a radially outer position). According to the embodiment of Figure 1, the non-expanded polymeric layer 21 is in contact with the metallic screen 6 and the expanded polymeric layer 22 is between the non-expanded polymeric layer 21 and the polymeric oversheath 23.

The thickness of the non-expanded polymeric layer 21 is in the range of from 0.5 mm to 5 mm.

The thickness of the expanded polymeric layer 22 is in the range of from 0.5 mm to 6 mm.

Preferably, the thickness of the expanded polymeric layer 22 is from one to two times the thickness of the non-expanded polymeric layer 21.

The protective element 20 has the function of providing enhanced protection to the cable from external impacts, by at least partially absorbing the impact energy.

The expandable polymeric material which is suitable for being used in the expanded polymeric layer 22 may be selected from the group comprising: polyolefins, copolymers of different olefins, copolymers of an olefin with an ethylenically unsaturated ester, polyesters, polycarbonates, polysulphones, phenol resins, urea resins, and mixtures thereof. Examples of suitable polymers are: polyethylene (PE), in particular low density PE (LDPE), medium density PE (MDPE), high density PE (HDPE), linear low density PE (LLDPE), ultra-low density polyethylene (ULDPE); polypropylene (PP); elastomeric ethylene/propylene copolymers (EPR) or ethylene/propylene/diene terpolymers (EPDM); natural rubber; butyl rubber; ethylene/vinyl ester copolymers, for example ethylene/vinyl acetate (EVA); ethylene/acrylate copolymers, in particular ethylene/methyl acrylate (EMA), ethylene/ethyl acrylate (EEA) and ethylene/butyl acrylate (EBA); ethylene/α-olefin thermoplastic copolymers; polystyrene; acrylonitrile/butadiene/styrene (ABS) resins; halogenated polymers, in particular polyvinyl chloride (PVC); polyurethane (PUR); polyamides; aromatic polyesters such as polyethylene terephthalate (PET) or polybutylene terephthalate (PBT); and copolymers thereof or mechanical mixtures thereof.

Preferably, the polymeric material forming the expanded polymeric layer 22 is a polyolefin polymer or copolymer based on ethylene and/or propylene, and is selected in particular from:

(a) copolymers of ethylene with an ethylenically unsaturated ester, for example vinyl acetate or butyl acetate, in which the amount of unsaturated ester is generally between 5% by weight and 80% by weight, preferably between 10% by weight and 50% by weight;

(b) elastomeric copolymers of ethylene with at least one C_3-C_{12} α-olefin, and optionally a diene, preferably ethylene/propylene (EPR) or ethylene/propylene/diene (EPDM) copolymers, generally having the following composition: 35%-90% mole of ethylene, 10%-65% mole of α-olefin, 0%-10% mole of diene (for example 1,4-hexadiene or 5-ethylidene-2-norbornene);

(c) copolymers of ethylene with at least one C_4-C_{12} α-olefin, preferably 1-hexene, 1-octene and the like, and optionally a diene, generally having a density of between 0.86 g/cm^3 and 0.90 g/cm^3 and the following composition: 75%-97% by mole of ethylene; 3%-25% by mole of α-olefin; 0%-5% by mole of a diene;

(d) polypropylene modified with ethylene/C_3-C_{12} α-olefin copolymers, wherein the weight ratio between polypropylene and ethylene/C_3-C_{12} α-olefin copolymer is between 90/10 and 10/90, preferably between 80/20 and 20/80.

For example, the commercial products Elvax® (DuPont), Levapren® (Bayer) and Lotryl® (Elf-Atochem) are in class (a), products Dutral® (Enichem) or Nordel® (Dow-DuPont) are in class (b), products belonging to class (c) are Engage® (Dow-DuPont) or Exact® (Exxon), while polypropylene modified with ethylene/α-olefin copolymers (d) are commercially available under the brand names Moplen® or Hifax® (Basell), or also Fina-Pro® (Fina), and the like.

Within class (d), particularly preferred are thermoplastic elastomers comprising a continuous matrix of a thermoplastic polymer, e.g. polypropylene, and fine particles (generally having a diameter of the order of 1 μm - 10 μm) of a cured elastomeric polymer, e.g. cross-linked EPR o EPDM, dispersed in the thermoplastic matrix.

The elastomeric polymer may be incorporated in the thermoplastic matrix in the uncured state and then dynamically cross-linked during processing by addition of a suitable amount of a cross-linking agent.

Alternatively, the elastomeric polymer may be cured separately and then dispersed into the thermoplastic matrix in the form of fine particles.

Thermoplastic elastomers of this type are described, e.g. in US patent 4,104,210 or in European Patent Application EP-A 0 324 430. These thermoplastic elastomers are preferred since they proved to be particularly effective in elastically absorb radial forces during the cable thermal cycles in the whole range of working temperatures.

For the purposes of the present description, the term "expanded" polymer is understood to refer to a polymer within the structure of which the percentage of "void" volume (that is to say the space not occupied by the polymer but by a gas or air) is typically greater than 10% of the total volume of said polymer.

In general, the percentage of free space in an expanded polymer is expressed in terms of the degree of expansion (G). In the present description, the term "degree of expansion of the polymer" is understood to refer to the expansion of the polymer determined in the following way:

$$G \text{ (degree of expansion)} = (d_0/d_e - 1) \times 100$$

where d_0 indicates the density of the non-expanded polymer (that is to say the polymer with a structure which is essentially free of void volume) and d_e indicates the apparent density measured for the expanded polymer.

Preferably, the degree of expansion of the expanded polymeric layer 22 is chosen in the range of from 20% to 200%, more preferably from 25% to 130%.

Preferably, the non-expanded polymeric layer 21 and the oversheath 23 are made of polyolefin materials, usually polyvinyl chloride or polyethylene.

As shown in Figures 1 and 2, the cable 1 is further provided with a water-blocking layer 8 placed between the outer semiconductive layer 5 and the metallic screen 6.

Preferably, the water-blocking layer 8 is an expanded, water swellable, semiconductive layer.

An example of an expanded, water swellable, semiconductive layer is described in International Patent Application WO 01/46965 in the name of the Applicant.

Preferably, the expandable polymer of the water-blocking layer 8 is chosen from the polymeric materials mentioned above for use in the expanded layer 22.

Preferably, the thickness of the water-blocking layer 8 is in the range of from 0.2 mm and 1.5 mm.

Said water-blocking layer 8 aims at providing an effective barrier against the longitudinal water penetration towards the interior of the cable.

The water swellable material is generally in a subdivided form, particularly in the form of powder. The particles constituting the water-swellable powder have preferably a diameter not greater than 250 μm and an average diameter of from 10 μm to 100 μm. More preferably, the amount of particles having a diameter of from 10 μm to 50 μm are at least 50% by weight with respect to the total weight of the powder.

The water-swellable material generally consists of a homopolymer or copolymer having hydrophilic groups along the polymeric chain, for example: cross-linked and at least partially salified polyacrylic acid (for example, the products Cabloc® from C. F. Stockhausen GmbH or Waterlock® from Grain Processing Co.); starch or derivatives thereof mixed with copolymers between acrylamide and sodium acrylate (for example, products SGP Absorbent Polymer® from Henkel AG); sodium carboxymethylcellulose (for example, the products Blanose® from Hercules Inc.).

The amount of water-swellable material to be included in the expanded polymeric layer is generally of from 5 phr to 120 phr, preferably of from 15 phr to 80 phr (phr = parts by weight with respect to 100 parts by weight of base polymer).

In addition, the expanded polymeric material of the water-blocking layer 8 is modified to be semiconductive by adding a suitable electroconductive carbon black as mentioned above with reference to the semiconductive layers 3, 5.

Furthermore, by providing the cable of Figure 1 with an expanded polymer material having semiconductive properties and including a water-swellable material (i.e. the semiconductive water-blocking layer 8), a layer is formed which is capable of elastically and uniformly absorbing the radial forces of expansion and contraction due to the thermal cycles to which the cable is subjected during use, while ensuring the necessary electrical continuity between the cable and the metallic screen.

Moreover, the presence of the water-swellable material dispersed into the expanded layer is able to effectively block moisture and/or water, thus avoiding the use of water-swellable tapes or of free water-swellable powders.

Furthermore, by providing the cable of Figure 1 with the semiconductive water-blocking layer 8, the thickness of the outer semiconductive layer 5 may be advantageously reduced since the electrical property of the outer semiconductive layer 5 is partially performed by said water-blocking semiconductive layer. Therefore, said aspect advantageously contributes to the reduction of the outer semiconductive layer thickness and thus of the overall cable weight.

Manufacturing process and plant

As shown in Figure 3, a plant for the production of cables according to the present invention comprises: a conductor supply unit 201, a first extrusion section 202 for obtaining the insulating layer 4 and the semiconductive layers 3 and 5, a cooling section 203, a metallic screen application section 204, a second extrusion section 214 for applying the protective element 20, an oversheath extrusion section 205, a further cooling section 206 and a take up section 207.

Conveniently, the conductor supply unit 201 comprises an apparatus for rolling a metal rod to the desired diameter for the cable conductor (providing the required surface finishing).

In case connection of metal rod lengths is required to produce in continuous the final cable length as required by the application (or by other customer's requirements), the conductor supply unit 201 conveniently comprises apparatus for welding and thermally treating the conductor, as well as accumulating units suitable to provide sufficient time for the welding operation without affecting the continuous, constant speed delivery of the conductor itself.

The first extrusion section 202 comprises a first extruder apparatus 110, suitable to extrude the insulating layer 4 on the conductor 2 supplied by the conductor supply unit 201; the first extruder apparatus 110 is preceded, along the direction of advancement of the conductor 2, by a second extruder apparatus 210, suitable to extrude the inner semiconductive layer 3 on the outer surface of the conductor 2 (and beneath the insulating layer 4), and followed by a third extruder apparatus 310, suitable to extrude the outer semiconductive layer 5 around the insulating layer 4, to obtain the cable core 2a.

The first, second and third extruder apparatus may be arranged in succession, each with its own extrusion head, or, preferably, they are all connected to a common triple extrusion head 150 to obtain the co-extrusion of said three layers.

An example of structure suitable for the extruder apparatus 110 is described in WO 02/47092 in the name of the same Applicant.

Conveniently, the second and third extruder apparatus have a structure similar to the structure of the first extruder apparatus 110 (unless different arrangements are required by the specific materials to be applied).

The cooling section 203, through which the cable core 2a is passed, may consist of an elongated open duct, along which a cooling fluid is caused to flow. Water is a preferred example of such cooling fluid. The length of such cooling section, as well as the nature, temperature and flow rate of the cooling fluid, are determined to provide a final temperature suitable for the subsequent steps of the process.

A drier 208 is conveniently inserted prior to entering into the subsequent section, said drier being effective to remove residuals of the cooling fluid, such as humidity or water droplets, particularly in case such residuals turn out to be detrimental to the overall cable performance.

The metallic screen application section 204 includes a metallic sheet delivery apparatus 209 which is suitable to supply a metallic sheet 60 to an application unit 210.

In a preferred embodiment, the application unit 210 includes a former (not shown) by which the metallic sheet 60 is folded lengthwise into a tubular form so as to surround the cable core 2a advancing therethrough, and to form the circumferentially closed metallic screen 6.

A suitable sealing and bonding agent may be supplied in the overlapping area of the edges of the sheet 60 so as to form the circumferentially closed metallic screen 6.

Alternatively, a suitable sealing and bonding agent may be supplied at the edges of the sheet 60 so as to form the circumferentially closed metallic screen 6.

The use of a longitudinally folded metallic screen is particularly convenient in that it contributes to enable to produce the cable with a continuous process, without requiring the use of complex spool rotating machines, which would otherwise be needed in case of a multi-wire (or tape) spirally wound metallic screen.

If convenient for the specific cable design, a further extruder 211, equipped with an extrusion head 212, is located upstream of the application unit 210, together with a cooler 213, to apply the expanded semiconductive layer 8 around the cable core 2a, beneath the metallic screen 6.

Preferably, the cooler 213 is a forced air cooler.

If no additional impact protection is required, the cable is finished by passing the same through the oversheath extrusion section 205, which includes an oversheath extruder 220 and the extrusion head 221 thereof.

Downstream of the final cooling section 206, the plant includes the take-up section 207 by which the finished cable is coiled on a spool 222.

Preferably, the take-up section 207 includes an accumulation section 223 which allows to replace a completed spool with an empty spool without interruption of the cable manufacturing process.

In case an enhanced impact protection is desired, a further extrusion section 214 is located downstream of the application unit 210.

In the embodiment shown in Figure 3, the extrusion section 214 comprises three extruders 215, 216, 217 equipped with a common triple extrusion head 218.

In more details, the extrusion section 214 is suitable for applying a protective element 20 comprising an expanded polymeric layer 22 and a non-expanded polymeric layer 21. The non-expanded polymeric layer 21 is applied by the extruder 216 while the expanded polymeric layer 22 is applied by the extruder 217.

Furthermore, the extrusion section 214 comprises a further extruder 215 which is provided for applying a primer layer which is suitable for improving the bonding between the metallic screen 6 and the protective element 20 (i.e. the non-expanded polymeric layer 21).

A cooling section 219 is conveniently provided downstream of the further extrusion section 214.

Figure 4 shows a plant similar to the plant of Figure 3, according to which the extruders 215, 216, 217 are separate from each other and three distinct independent extrusion heads 215a, 216a, 217a are provided.

Separate cooling channels or ducts 219a and 219b are provided downstream of the extruder 215 and 216 respectively, while the cooling channel 219 is located downstream of the extruder 217.

According to a further embodiment (not shown), the primer layer and the non-expanded polymeric layer 21 are applied together by co-extrusion and, successively, the extrusion of the expanded polymeric layer 22 is performed.

According to a further embodiment (not shown) the primer layer and the non-expanded polymeric layer 21 are applied together by co-extrusion and, successively, the expanded polymeric layer 22 and the oversheath 23 are applied together by co-extrusion. Alternatively, the primer layer and the non-expanded polymeric layer 21 are applied separately by using two distinct extrusions heads 215a, 216a, while the expanded polymeric layer 22 and the oversheath 23 are applied together by co-extrusion.

In Figures 3 and 4 the layout of the manufacturing plant is U-shaped in order to reduce the longitudinal size of the factory. In the figures, the advancement of the cable is reversed at the end of the cooling section 203 by means of any suitable device known in the art, e.g. by means of rollers.

Alternatively, the layout of the manufacturing plant extends longitudinally and there is no reversing of the cable feeding direction.

Continuous manufacturing process

With the plant described above, a cable can be produced by means of a continuous process.

In the present description, by "continuous process" it is meant a process in which the time required to manufacture a given cable length is inversely proportional to the advancement speed of the cable in the line, so that there are no intermediate rest steps between the conductor supply and the finished cable take-up.

According to the present invention, the conductor is continuously supplied from the supply unit 201.

The supply unit 201 is arranged so as to allow a continuous delivery of the conductor.

The conductor is conveniently made of a single metal rod (typically aluminum or copper). In this case, the continuous delivery of the conductor is enabled by connecting the available length of the metal rod (typically loaded on a spool or the like) to a further length of the metal rod.

Such connection may be made, for example, by welding the rod ends.

According to the continuous process of the present invention, the maximum length of the produced cable, such as the length of the line to be laid (between two intermediate stations), the maximum size of the shipping spool to be used (with the relevant transport limitations), the maximum installable length and the like, is determined by the customer's or installer's requirements and not by the available raw material or semi-finished product length or machinery capacity. In this way it is possible to install electrical lines with a minimum number of joints between cable lengths, so as to increase the line reliability since cable joints are known to be points of discontinuity which are prone to electrical problems during the use of the line.

In case a stranded conductor is desired, rotating machines are required for stranding and the conductor is conveniently prepared off-line in the required length and the splicing operation is difficult. In such case, the length of the manufactured cables is determined by the available stranded conductor length (which can be predetermined on the basis of the customer's requirements) and/or by the capacity of the shipping spools, while the process remains otherwise continuous from the conductor supply up to the end.

The extrusion of the insulating layer 4, the semiconductive layers 3 and 5, the oversheath 23, the protective element 20 (if any) and the water blocking layer 8 (if any) can be carried out continuously since the various materials and compounds to be extruded are supplied to the relevant extruders inlets without interruption.

As no cross-linking step is required, because of the use of thermoplastic, non-cross-linked materials, in particular for the insulating layer, no process interruption is required.

As a matter of fact, conventional, cross-linked insulation cables production processes include a "rest" step, in which the insulated conductor is maintained off-line for a certain period of time (hours or even days) to allow: a) the cross-linking reactions to take place, in case silane-cross-linking is used or b) the emission of gases resulting as cross-linking reactions by-products, in case of peroxide cross-linking.

The rest step of case a) may be carried out by introducing the cable (wound on a supporting reel) into an oven or by immersing the same in water at a temperature of about 80 °C so as to improve the cross-linking reaction speed.

The rest step of case b), i.e. the degassing step, may be carried out by introducing the cable (wound on a supporting reel) into an oven so as to decrease the degassing time.

This "rest" step is typically carried out by coiling the semi-finished element on spools at the end of the extrusion of the relevant layers. After that, the cross-linked, semi-finished element is supplied to another, independent line, where the cable is completed.

According to the process of the present invention, the metallic screen 6 is formed by a longitudinally folded metal sheet which is conveniently unwound from a spool which is mounted on a stationary apparatus while being free to rotate about its rotating axis so that the sheet can be unwound from the spool. Accordingly, in the process of the present invention the metal sheet can be supplied with no interruptions since the rear end of the sheet of the spool in use can be easily connected (e.g. by welding) to the front end of the sheet which is loaded on a new spool.

Generally, an appropriate sheet accumulation apparatus is further provided. This would not be possible in case a helical type screen is used (either formed by helically wound wires or tapes) because in such case the spools carrying the wires or tapes would be loaded in a rotating apparatus, revolving around the cable, and the replacement of empty spools with new spools would require an interruption in the cable advancement.

However, it is possible to provide the cable with a metallic screen made of wire or tapes while keeping the manufacturing process continuous, by using an apparatus according to which said wires/tapes are applied onto the cable according to S and Z stranding operations to be carried out alternatively. In such a case, the reels supporting said wire/tapes are not constrained to be rotatably moved around the cable.

However, the use of a longitudinally folded metallic screen has been found particularly convenient in connection with the use of thermoplastic insulating and semiconductive layers.

As a matter of fact, as mentioned above, in case a cross-linked material is used, after the cross-linking reaction is completed, it is necessary that a certain period of time is provided in order to allow the gaseous by-products to be emitted. Conventionally, this is obtained by allowing the semi-finished product (i.e. the cable core) to rest for a certain period of time after the cross-linking reaction has occurred. In case a circumferentially non-continuous metallic screen is used (as in case of wires or tapes helically wound around the cable core), the gas emission may take place also by diffusion through the metallic screen (e.g. through the wires or the tape overlapping areas) and through the extruded layers located in a radially outer position with respect to the metallic screen.

However, in case a longitudinally folded metallic screen is used, the latter extends circumferentially around the whole perimeter of the cable core, thereby forming a substantially impervious envelope, which substantially prevents further evacuation of the gaseous by-products. Accordingly, when a longitudinally folded metallic screen is used in combination with cross-linked insulating layers, the degassing of this material should be substantially completed before the metallic screen is applied.

On the contrary, the use for the cable insulating layer of thermoplastic, non-cross-linked materials, which do not emit cross-linking gaseous by-products (and, accordingly, do not require any degassing step), in combination with a longitudinally folded metal sheet as cable metallic screen enables the cable manufacturing process to be continuous since no “rest” step is needed off-line.

Preferably, the line speed of the process according to the present invention is of about 60 m/min, more preferably of about 80-100 m/min, while in a discontinuous traditional manufacturing process the line speed is set at about 10-15 m/min.

For further description of the invention, illustrative examples are given below.

EXAMPLE 1

The following example describes in detail the main steps of the continuous production process of a 150 mm^2, 20 kV cable as shown in Fig. 1. The line speed was set at 60 m/min.

a) cable core extrusion

The cable insulating layer was obtained by feeding directly into the hopper of the extruder 110 a propylene heterophase copolymer having melting point 165°C, melting enthalpy 30 J/g, MFI 0.8 dg/min and flexural modulus 150 MPa (Adflex® Q 200 F - commercial product of Basell).

Subsequently, the dielectric oil Jarylec® Exp3 (commercial product of Elf Atochem - dibenzyltoluene), previously mixed with the antioxidants, was injected at high pressure into the extruder.

The extruder 110 had a diameter of 80 mm and a L/D ratio of 25.

The injection of the dielectric oil was performed - during the extrusion - at about 20 D from the beginning of the screw of the extruder 110 by means of three injections point on the same cross-section at 120° from each other. The dielectric oil was injected at a temperature of 70°C and a pressure of 250 bar.

Corresponding extruders were used for the inner and the outer semiconductive layers.

A rod-shaped aluminum conductor 2 (cross-section 150 mm^2) was fed through the triple extruder head 150.

The cable core 2a leaving the extrusion head 150 was cooled by passing through the channel shaped cooling section 203 where cold water was made to flow.

The resulting cable core 2a had an inner semiconductive layer of about 0.2 mm thickness, an insulating layer of about 4.5 mm thickness and an outer semiconductive layer of about 0.2 mm thickness.

b) cable water blocking semiconductive expanded layer

The water blocking semiconductive expanded layer 8, having a thickness of about 0.5 mm and a degree of expansion of 20%, was applied on the cable core 2a by the extruder 211 which had a diameter of 60 mm and a L/D ratio of 20.

The material for said expanded layer 8 is given in Table 1 below. The material was chemically expanded by adding about 2% of the expanding agent Hydrocerol® CF 70 (carboxylic acid + sodium bicarbonate) into the extruder hopper.

TABLE 1

COMPOUNDS	QUANTITY (phr)
Elvax® 470	100
Ketjenblack® EC 300	20
Irganox® 1010	0.5
Waterloock® J 550	40
Hydrocerol® CF 70	2

wherein:

- Elvax® 470: ethylene/vinyl acetate (EVA) copolymer (commercial product of DuPont);
- Ketjenblack® EC 300: high-conductive furnace carbon black (commercial product of Akzo Chemie);
- Irganox® 1010: pentaerythryl-tetrakis[3-(3,5-di-t-butyl-4-hydroxyphenyl) propionate] (commercial product of Ciba Specialty Chemicals);

- Waterloock® J 550: grounded cross-linked polyacrylic acid (partially salified) (commercial product of Grain Processing);

- Hydrocerol® CF 70: carboxylic acid/sodium bicarbonate expanding agent (commercial product of Boeheringer Ingelheim).

Downstream of the extrusion head 212 of the extruder 211, cooling was provided by the forced air cooler 213.

c) cable metallic screen application

The cable core 2a, provided with the expanded semiconductive layer 8, was then covered - by means of the application unit 210 - by a longitudinally folded lacquered aluminum sheet of about 0.2 mm thickness, using an adhesive to bond the overlapping edges thereof. The adhesive was applied by means of the extruder 215.

d) cable protective element application

Subsequently, the inner polymeric layer 21, made of polyethylene, of about 1.0 mm thickness, was extruded over the aluminum screen by means of the extruder 216 having a diameter of 120 mm and a L/D ratio of 25.

According to the process plant of Fig. 3, the expanded polymeric layer 22, having a thickness of about 1.5 mm and a degree of expansion of 70%, was co-extruded with the non-expanded inner polymeric layer 21.

The expanded polymeric layer 22 was applied by means of the extruder 217 which had a diameter of 120 mm and a L/D ratio of 25.

The material for the expanded polymeric layer 22 is given in Table 2 below.

TABLE 2

COMPOUNDS	QUANTITY (phr)
Hifax® SD 817	100
Hydrocerol® BiH40	1.2

wherein:

- Hifax® SD 817: propylene modified with ethylene/propylene copolymer, commercially available by Basell;
- Hydrocerol® BiH40: carboxylic acid + sodium bicarbonate expanding agent, commercially available by Boeheringer Ingelheim.

The polymeric material was chemically expanded by adding the expanding agent (Hydrocerol® BiH40) into the extruder hopper.

At a distance of about 500 mm from the extrusion head 218 a cooling section 219, in the form of a pipe or channel through which cold water was flown, stopped the expansion and cooled the extruded material before extruding the outer non-expanded polymeric layer 23.

e) cable oversheath extrusion

Subsequently, the oversheath 23, made of polyethylene, of about 1.0 mm thickness, was extruded using the extruder 220 having a diameter of 120 mm and a L/D ratio of 25.

The cable leaving the extrusion head 221 was finally cooled in a cooling section 206 through which cold water was flown.

The cooling of the finished cable can be carried out by using a multi-passage cooling channel which advantageously reduces the longitudinal size of the cooling section.

Thermal profiles of the continuous process

Fig. 5 shows the thermal profile of the constitutive components of a 150 mm^2, 20 kV cable (shown in Fig. 1) obtained by a continuous process according to the present invention. The line speed was set at a value of 60 m/min.

In details, Fig. 5 plots in abscissae the length (m) of the process plant and in ordinates the temperature (°C). The curves of Fig. 5 show how the temperature of each constitutive element of the cable varies with respect to the process plant length.

In more details, the curve designated with reference "a" indicates the environment temperature variation; the curve designated with reference "b" indicates the temperature variation of the conductor 2; the curve designated with reference "c" indicates the temperature variation of the cable element comprising the inner semiconductive layer 3, the insulating layer 4 and the outer semiconductive layer 5; the curve designated with reference "d" indicates the temperature variation of the water-blocking layer 8; the curve designated with reference "e" indicates the temperature variation of the metallic screen 6; the curve designated with reference "f" indicates the temperature variation of the cable element comprising a primer layer and the non-expanded polymeric layer 21; the curve designated with reference "g" indicates the temperature variation of the expanded polymeric layer 22; the curve designated with reference "h" indicates the temperature variation of the outer sheath 23.

As shown in Fig. 5, the metallic screen was applied to the cable when the temperature of the insulating layer was of about 40°C.

Impact and load resistance

In the presence of a mechanical stress applied to the cable, such as an impact applied on the outer surface of the cable or a significant local load, suitable to cause a deformation of the cable itself, it has been observed that, even in case the deformation involves also the insulation, for example because the impact energy exceeds the admissible value capable of being supported by the impact protection layer, or in case the protective element is selected with relatively small thickness, the deformation profile of the metallic screen follows a continuous, smooth line, thereby avoiding local increases of the electric field.

Generally, the materials used for the insulating layer and the oversheath of the cable elastically recover only part of their original size and shape after the impact, so that after the impact, even if the same has taken place before the cable is energized, the insulating layer thickness withstanding the electric stress is reduced.

However, the Applicant has observed that, when a metallic screen is used outside the cable insulating layer, the material of such screen is permanently deformed by the impact, further limiting the elastic recover of the deformation, so that the insulating layer is restrained from elastically recovering its original shape and size.

Consequently, the deformation caused by the impact, or at least a significant part thereof, is maintained after the impact, even if the cause of the impact itself has been removed.

Said deformation results in that the insulating layer thickness changes from the original value t_0 to a “damaged” value t_d (see Fig. 8).

Accordingly, when the cable is being energized, the real insulating layer thickness which is bearing the electric voltage stress (Γ) in the impact area is no more t_0, but rather t_d.

In addition, when an impact is made against a cable having a metallic screen of "discontinuous" type, e.g. made of helically wound wires or tapes, either in case an impact protecting layer is absent (as shown in Fig. 8) or even in the presence of an impact protecting layer (of compact or expanded type), the uneven resistance of the metallic screen wires structure causes the wire located closer to the impact area to be significantly deformed and transmits such deformation to the underlying layers as a "local" deformation, with minimal involvement of the neighboring areas.

In the insulating layer, this results in a "spike" effect, which causes a deformation of the otherwise circular equipotential lines of the electric field in the impact area, as shown in Fig. 8, where the original circular equipotential lines are drawn with dotted lines and the deformed lines are drawn with continuous lines.

The deformation of the equipotential lines of the electric field causes the same to get closer in the impact area, which means that the electric gradient in this area becomes significantly higher. This local increase of the electric gradient is likely to cause electrical discharges to take place, determining the (impacted) cable failure in a partial discharge electric test, even in case of impacts of relatively low energy.

In case the metallic screen is made of a longitudinally folded metal sheet, particularly when combined with an expanded protective element, however, the Applicant has found that the local deformation of the screen and of the underlying insulating layer is significantly reduced.

As a matter of fact, the expanded protecting element, continuously supported by the underlying metallic screen, is capable to distribute the impact energy on a relatively large area around the impact position, as shown in Fig. 9.

Accordingly, the deformation of the equipotential lines of the electric field is reduced (and associated with a larger area as well), so that the same get less close than in the case of the helical wires described above, with an impact of the same energy.

As a result, the local electric gradient increase caused by the impact is minimized and the cable ability to withstand partial discharge tests is significantly increased.

EXAMPLE 2

A continuous process for producing a 50 mm^2, 10 kV cable according to Fig. 1 was carried out as described in Example 1. The process line speed was set at 70 m/min.

The materials used for the constitutive elements of the cable were the same as those disclosed in Example 1.

The thickness of the insulating layer was of about 2.5 mm, while the thickness of the inner and the outer semiconductive layers was of about 0.2 mm.

The thickness of the metallic screen was of about 0.2 mm.

The water blocking semiconductive expanded layer had a thickness of about 0.5 mm and a degree of expansion of 20%.

The inner polymeric layer 21 was of about 1.0 mm in thickness, while the expanded polymeric layer 22 had a thickness of about 1.5 mm and a degree of expansion of 70%.

The oversheath 23 was of a thickness of about 0.5 mm.

Thermal profiles of the continuous process

Fig. 6 shows the thermal profile of the constitutive components of the cable mentioned above and obtained by a continuous process according to the present invention.

As shown in Fig. 6, the metallic screen was applied to the cable when the temperature of the insulating layer was of about 30°C.

EXAMPLE 3

A continuous process for producing a 240 mm^2, 30 kV cable according to Fig. 1 was carried out as described in Example 1. The process line speed was set at 50 m/min.

The materials used for the constitutive elements of the cable were the same as those disclosed in Example 1.

The thickness of the insulating layer was of about 5.5 mm, while the thickness of the inner and the outer semiconductive layers was of about 0.2 mm.

The thickness of the metallic screen was of about 0.2 mm.

The water blocking semiconductive expanded layer had a thickness of about 0.5 mm and a degree of expansion of 20%.

The inner polymeric layer 21 was of about 1.0 mm in thickness, while the expanded polymeric layer 22 had a thickness of about 1.5 mm and a degree of expansion of 70%.

The oversheath 23 was of a thickness of about 1.0 mm.

Thermal profiles of the continuous process

Fig. 7 shows the thermal profile of the constitutive components of the cable mentioned above and obtained by a continuous process according to the present invention.

As shown in Fig. 7, the metallic screen was applied to the cable when the temperature of the insulating layer was of about 45°C.

EXAMPLE 4 (comparative)

A continuous process as described in Example 1 was carried out. The only difference - with respect to the process of the Example 1 - was the fact that the metallic screen was applied to the cable at a temperature value of the insulating layer of 75°C.

A cable sample (of a length of about 1 m) was subjected to a bending test so as to simulate the bending actions which a cable needs to withstand, e.g. during its collecting on a reel or its laying in a trench.

The text consisted in bending the cable sample eight times. Each time the sample was bent on one side for 30 seconds and successively on the opposite side (at 180° with respect to the first bending side) for further 30 seconds.

Then the cable was longitudinally cut into two halves and the cable core as well as the water-blocking layer were removed so that the metallic screen was made accessible for inspection thereof.

Fig. 10 shows a photograph (1:1 enlargement) of the cable after the cutting thereof and the removal of the cable elements mentioned above.

In more details, Fig. 10 shows a plant view of the two halves of the cable.

By carrying out a visual analysis, it was noticed that in the cable metallic screen a plurality of kinks had occurred (some of which are shown in squares in Fig. 10), said kinks having been caused by the bending actions described above.

Claims

1. A continuous process for manufacturing an electric cable, comprising the steps of:

feeding a conductor at a predetermined feeding speed;

extruding a thermoplastic insulating layer in a radially outer position with respect to the conductor;

cooling the extruded insulating layer to a temperature in the range from about 30°C to about 70°C;

forming a circumferentially closed metallic screen around said extruded insulating layer.

2. Process according to claim 1, wherein the extruded insulating layer is cooled down to a temperature in the range from about 40°C to about 60°C.

3. Process according to claim 1, wherein the forming step comprises the step of longitudinally folding a metal sheet around said extruded insulating layer.

4. Process according to claim 3, wherein the forming step comprises the step of overlapping the edges of said metal sheet to form the metallic screen.

5. Process according to claim 3, wherein the forming step comprises the step of bonding the edges of said metal sheet to form the metallic screen.

6. Process according to claim 1, further comprising the step of supplying the conductor in the form of a metal rod.

7. Process according to claim 1, further comprising the step of applying a primer layer around the metallic screen.

8. Process according to claim 7, wherein the step of applying the primer layer is carried out by extrusion.

9. Process according to claim 1, further comprising the step of applying an impact protecting element around said circumferentially closed metallic screen.

10. Process according to claim 9, wherein the step of applying an impact protecting element comprises the step of applying a non-expanded polymeric layer around said metallic screen.

11. Process according to claim 9, wherein the step of applying an impact protecting element comprises the step of applying an expanded polymeric layer.

12. Process according to claim 10 or 11, wherein the expanded polymeric layer is applied around the non-expanded polymeric layer.

13. Process according to claim 1, further comprising the step of applying an oversheath around the metallic screen.

14. Process according to claim 11 or 13, wherein the oversheath is applied around the expanded polymeric layer.

15. Process according to claim 1, wherein the step of cooling the extruded insulating layer is carried out by longitudinally feeding the conductor with the thermoplastic insulating layer through an elongated cooling device.

16. Process according to claim 1, wherein the thermoplastic polymer material of the insulating layer is selected from the group comprising: polyolefins, copolymers of different olefins, copolymers of an olefin with an ethylenically unsaturated ester, polyesters, polyacetates, cellulose polymers, polycarbonates, polysulphones, phenol resins, urea resins, polyketones, polyacrylates, polyamides, polyamines, and mixtures thereof.

17. Process according to claim 16, wherein said thermoplastic polymer material is selected from the group comprising: polyethylene (PE), polypropylene (PP), ethylene/vinyl acetate (EVA), ethylene/methyl acrylate (EMA), ethylene/ethyl acrylate (EeA), ethylene/butyl acrylate (EBA), ethylene/α-olefin thermoplastic copolymers, polystyrene, acrylonitrile/butadiene/styrene (ABS) resins, polyvinyl chloride (PVC), polyurethane, polyamides, polyethylene terephthalate (PET), polybutylene terephthalate (PBT), and copolymers thereof or mechanical mixtures thereof.

18. Process according to claim 1, wherein the thermoplastic polymer material of the insulating layer includes a predetermined amount of a dielectric liquid.

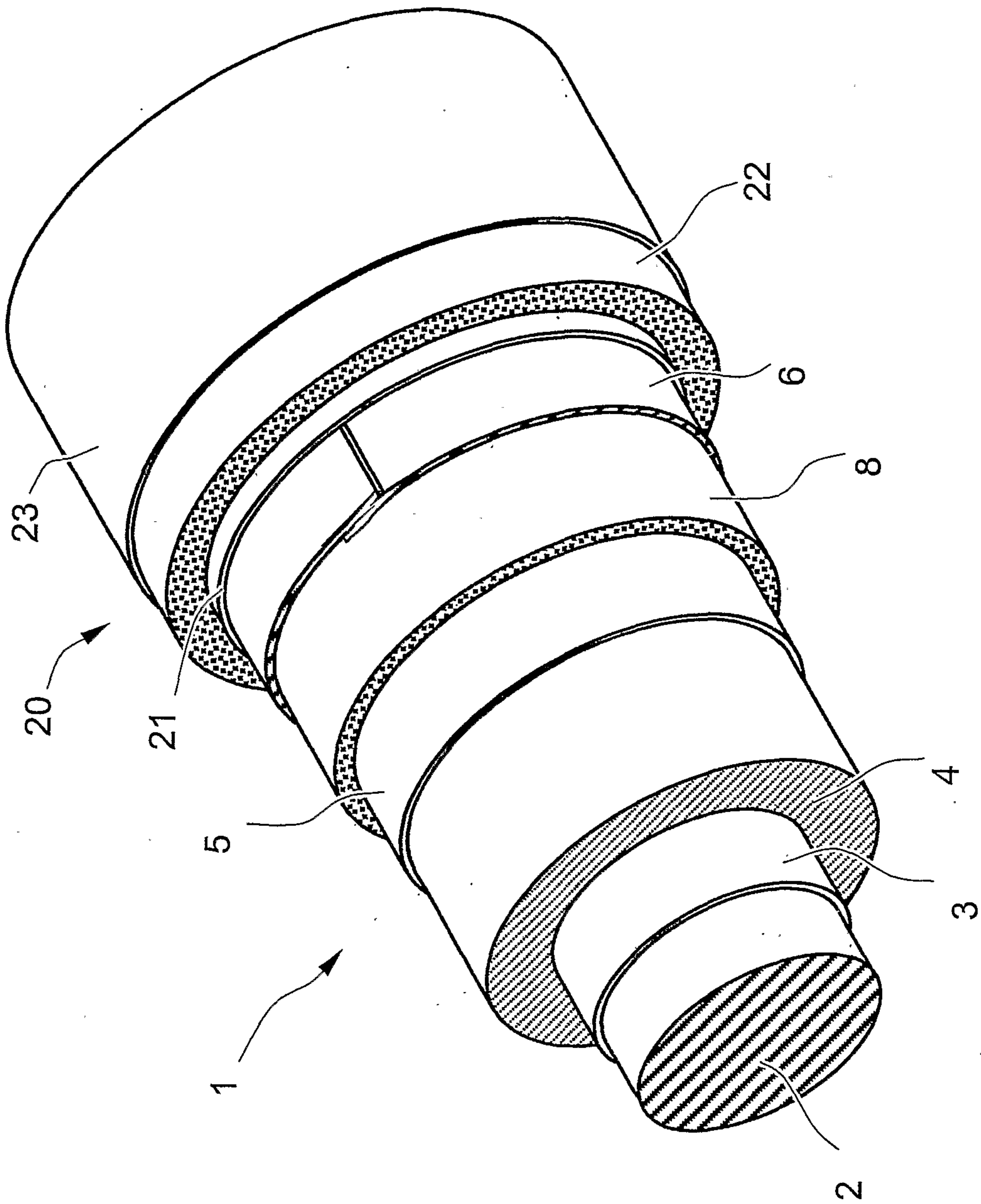
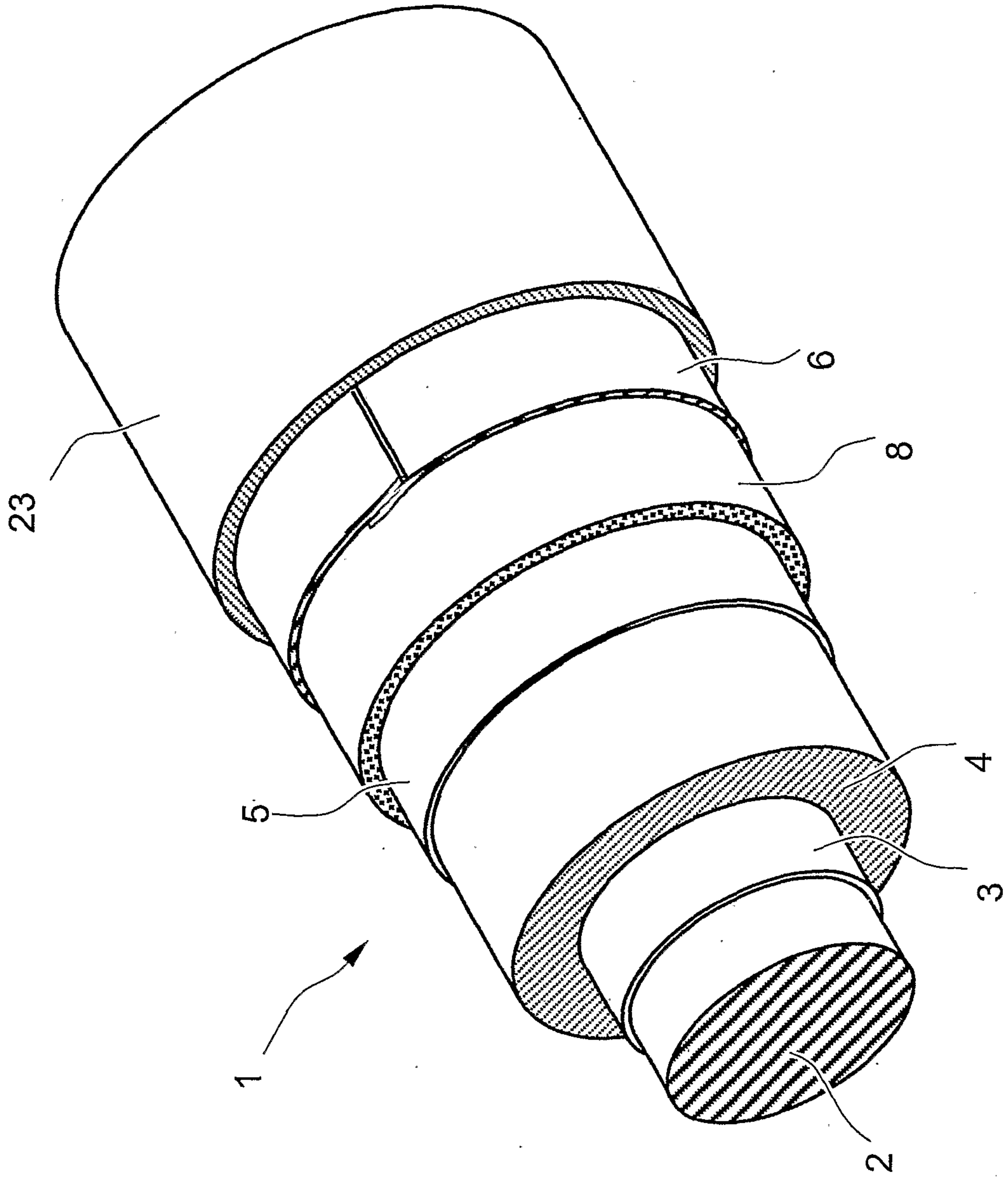


Fig. 1

Fig. 2



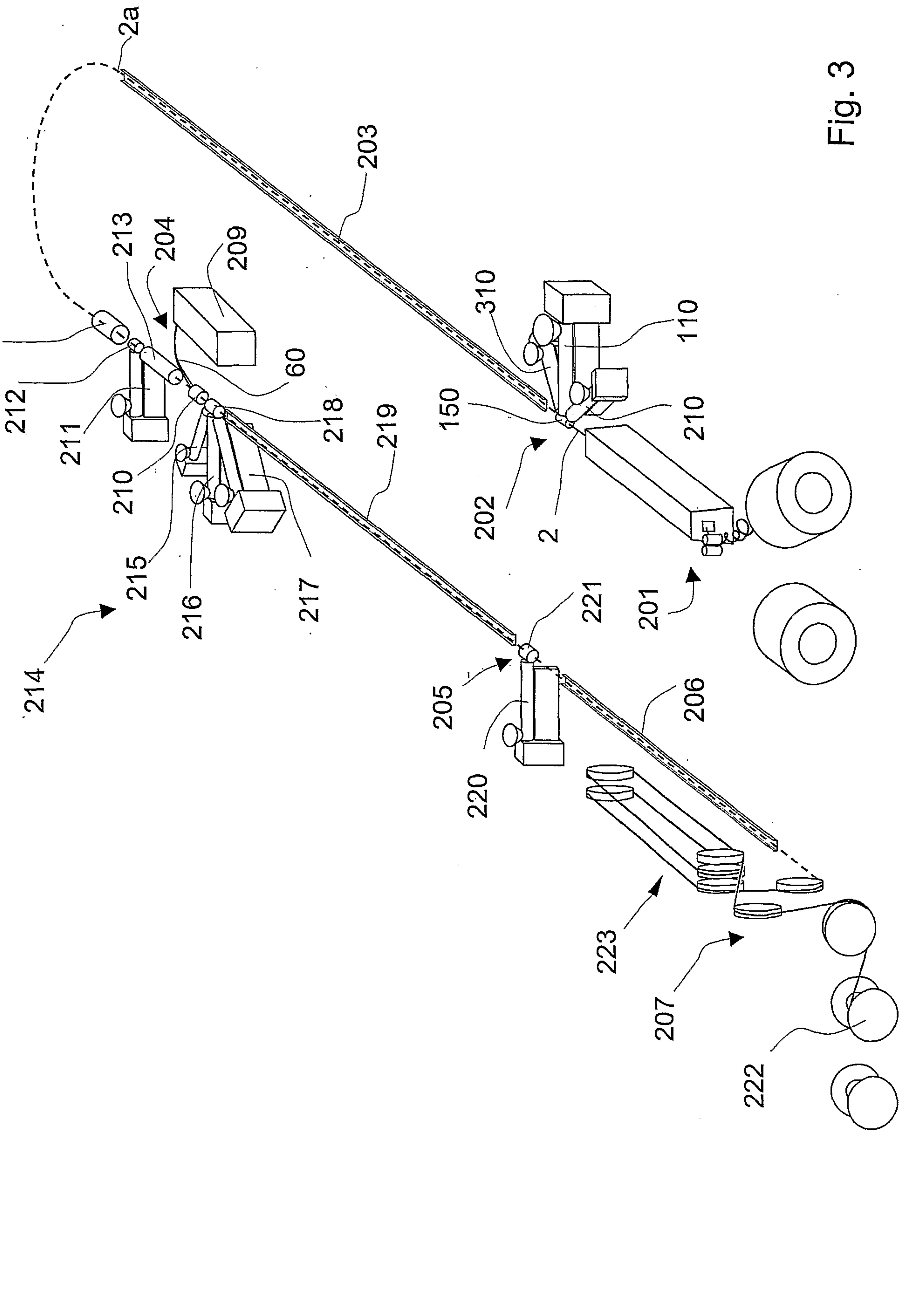

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Fig. 3

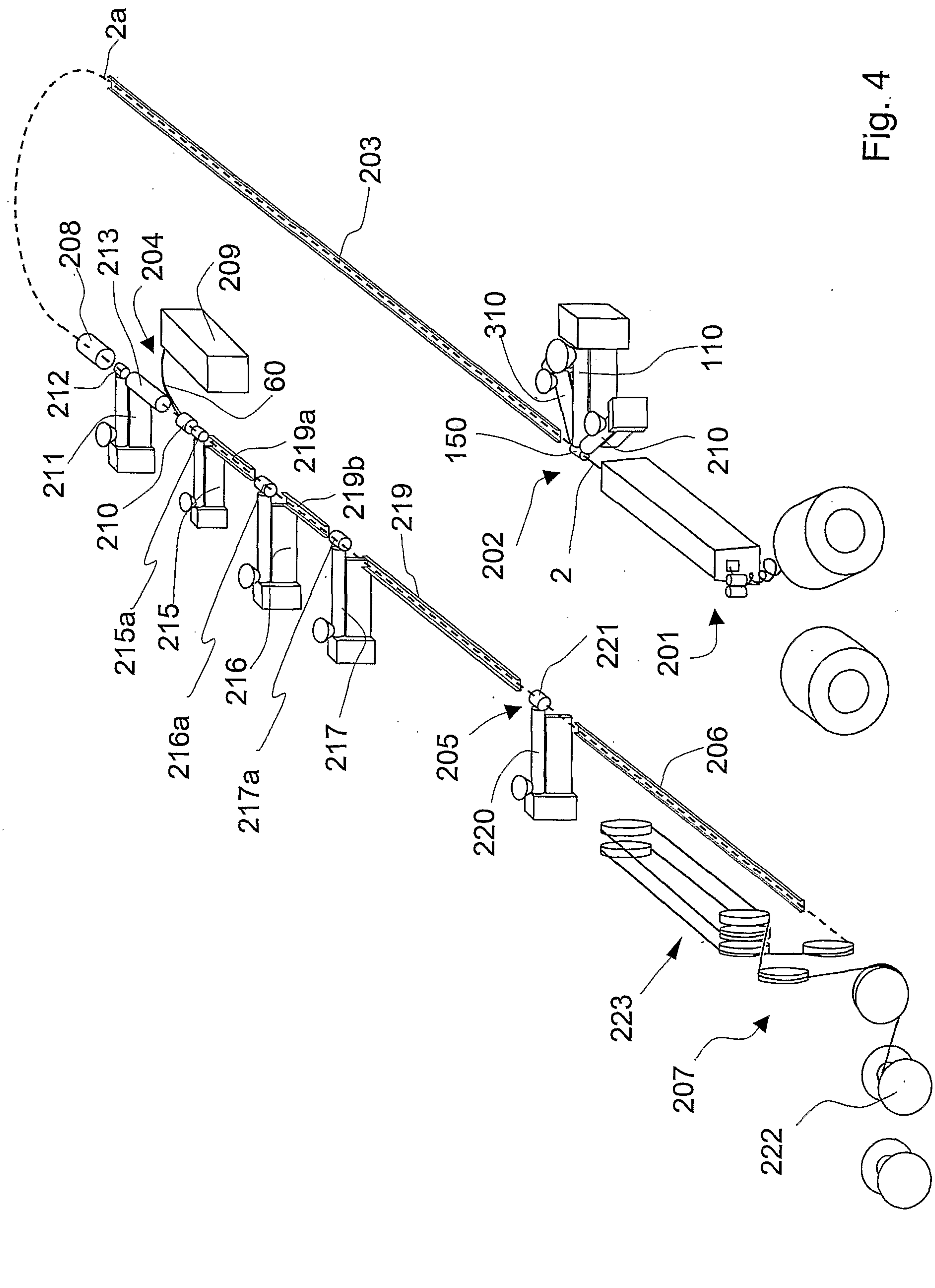
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Fig. 4

Fig. 5

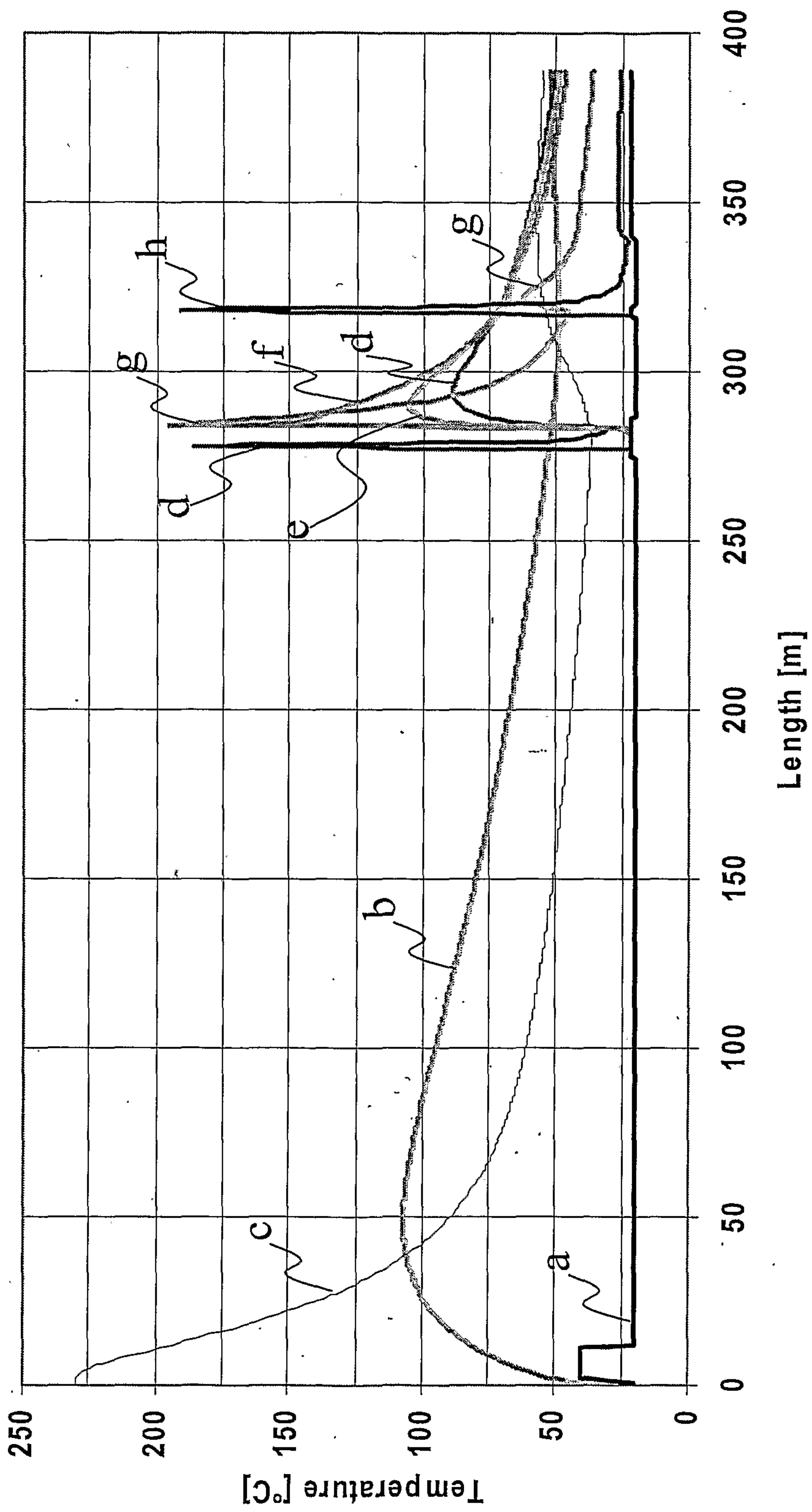
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Fig. 6

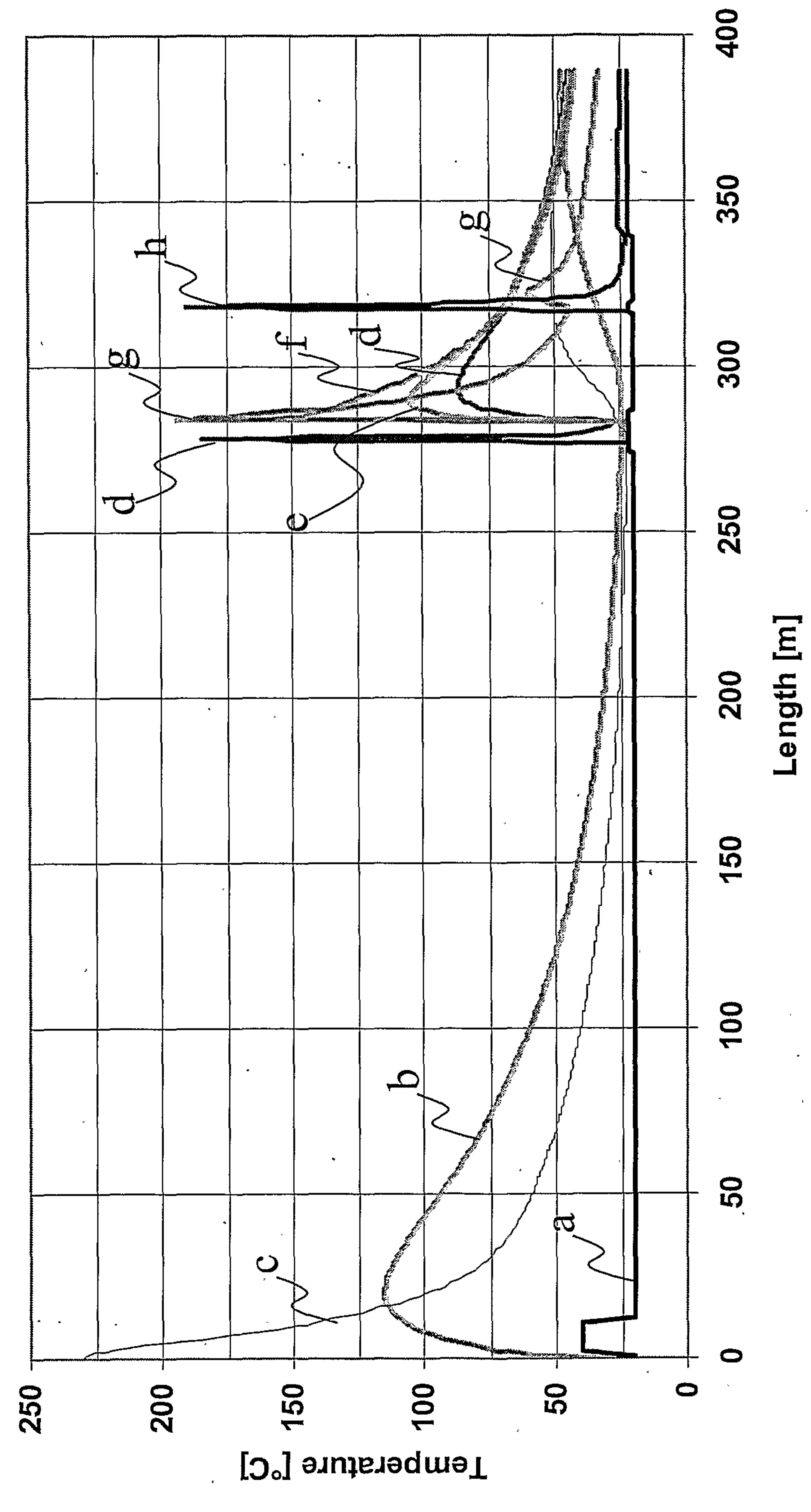
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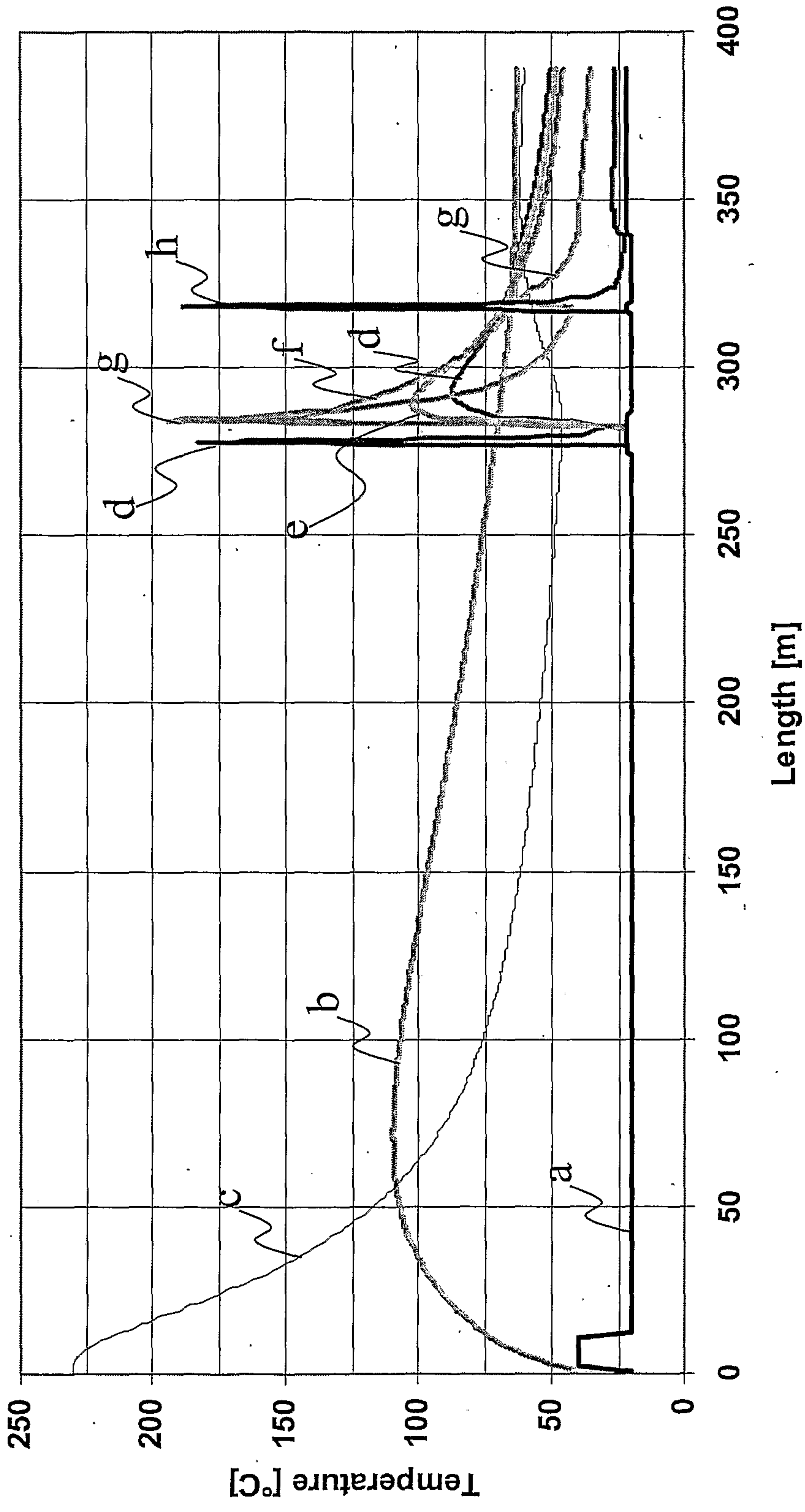
Fig. 7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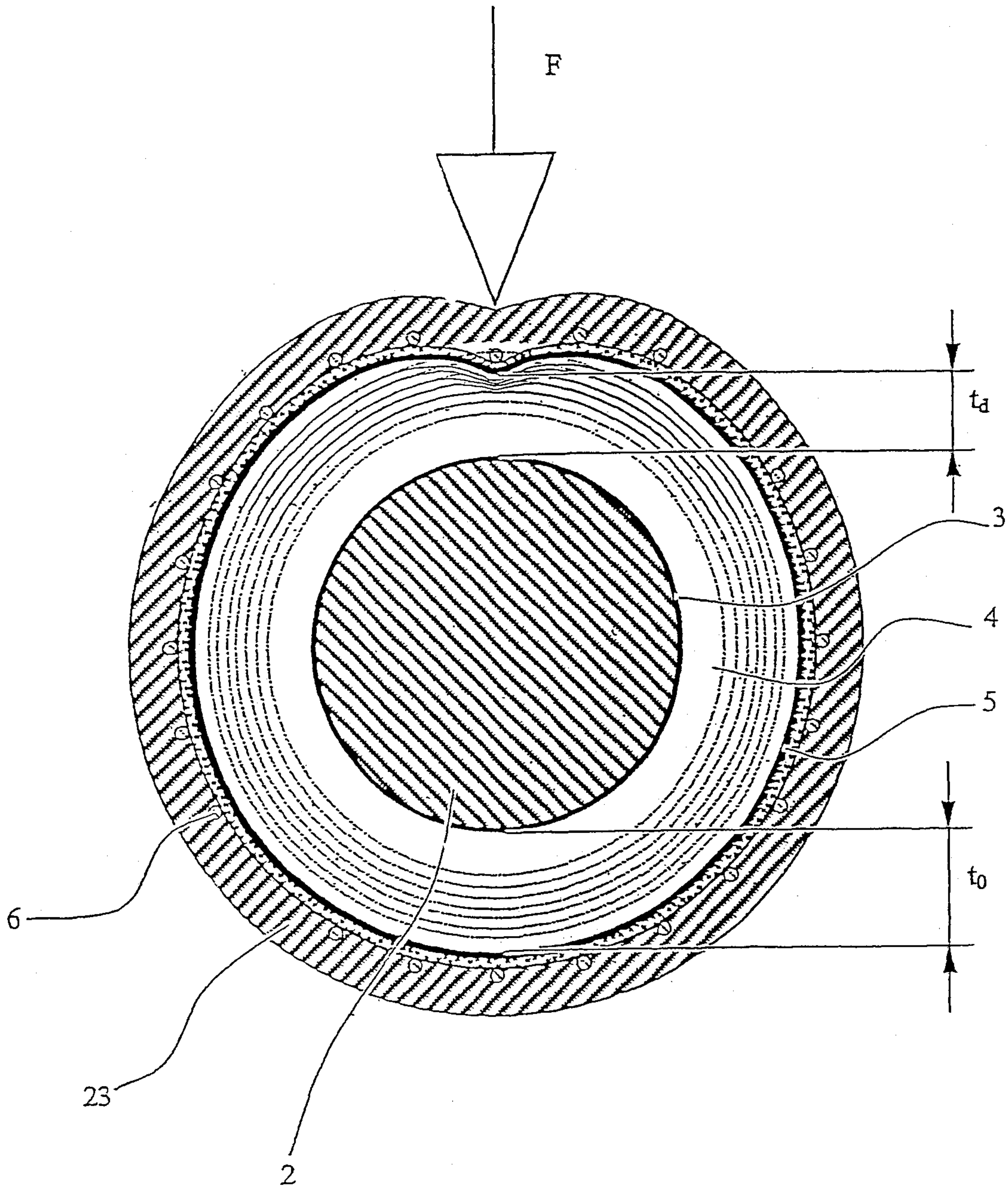

Fig. 8
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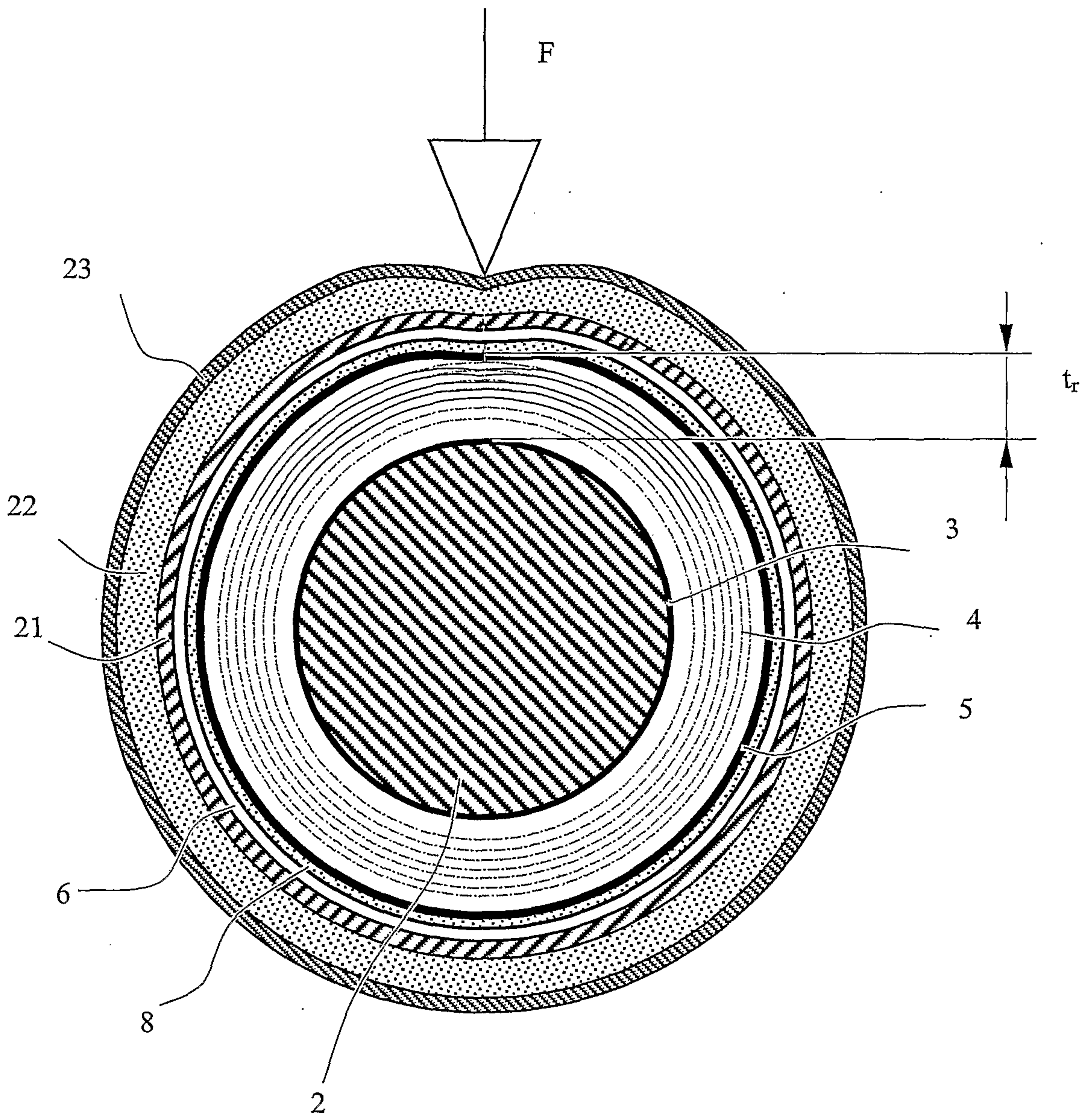


Fig. 9

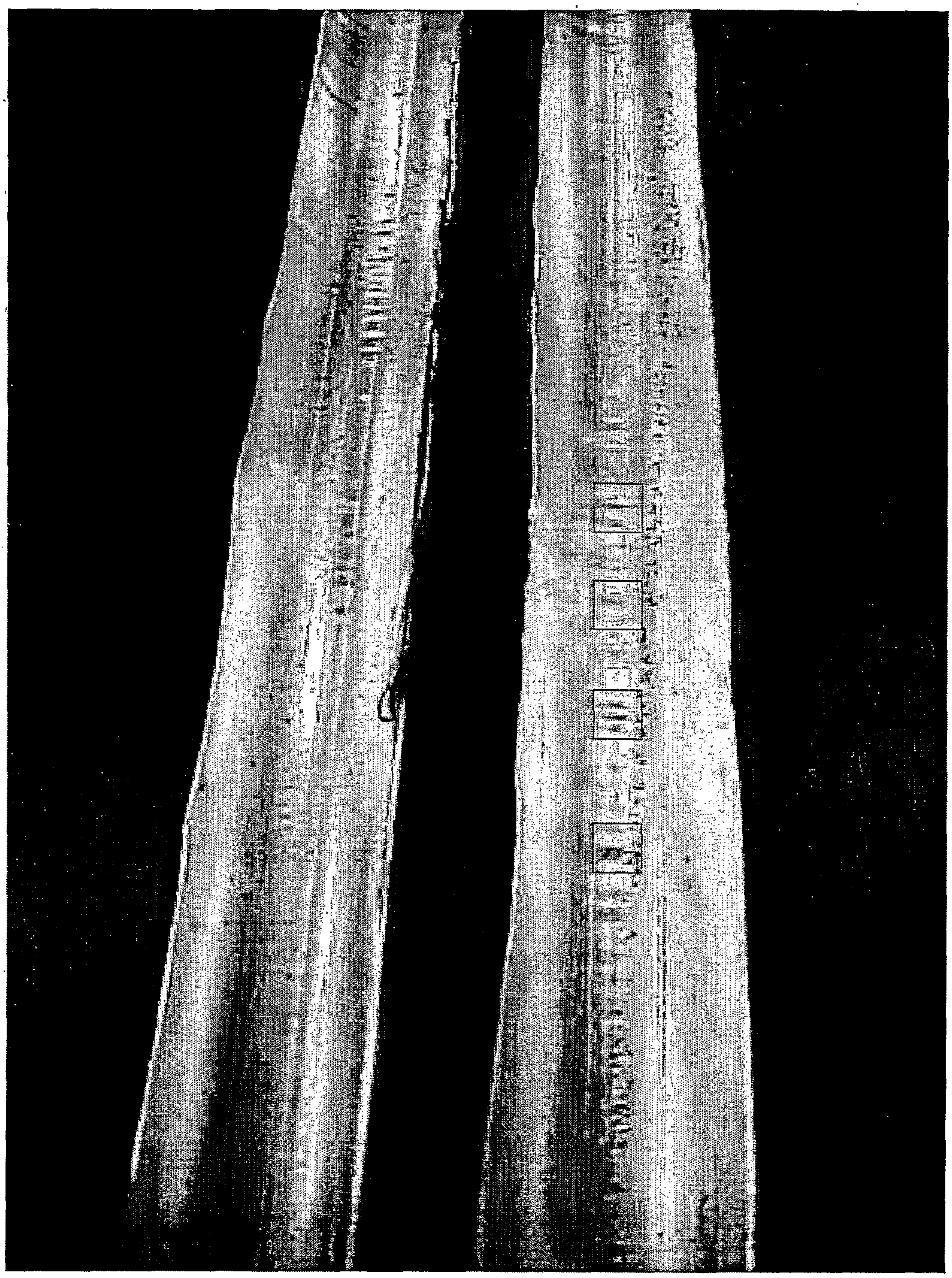
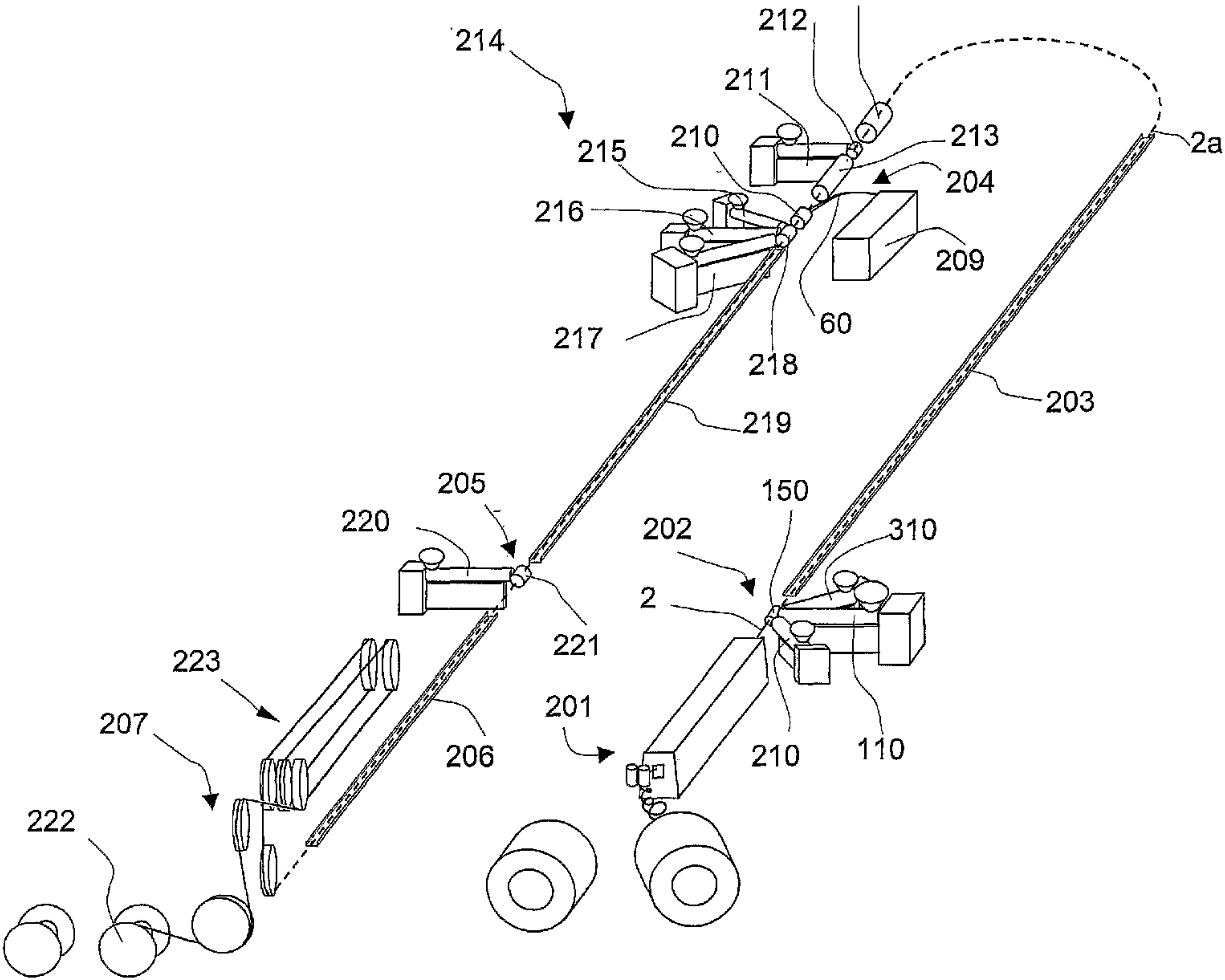


Fig. 10



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