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(54) **METHOD FOR PRODUCING A WOUND CONDUCTOR AND WOUND CONDUCTOR ARRANGEMENT**

(57) It is proposed a method for producing an insulated wound conductor (200) for an electrical machine. The method includes providing one or more shrinkable tubes (101; 102) including a tube wall (103) and an inner hollow space (104) being surrounded by the tube wall (103). The tube wall includes at least an insulation layer of insulation material for insulating the wound conductor (200). The method further includes forming a wound con-

ductor (200) by guiding at least one wire (105) including a conductive material from a wire supply device (110) to the at least one shrinkable tube (101; 102) and driving the wire (105) at least once in and through the inner hollow space (104) of the shrinkable tube (101; 102). The method further includes shrinking the shrinkable tube (101; 102) around the one or more wires (105) within the shrinkable tube.

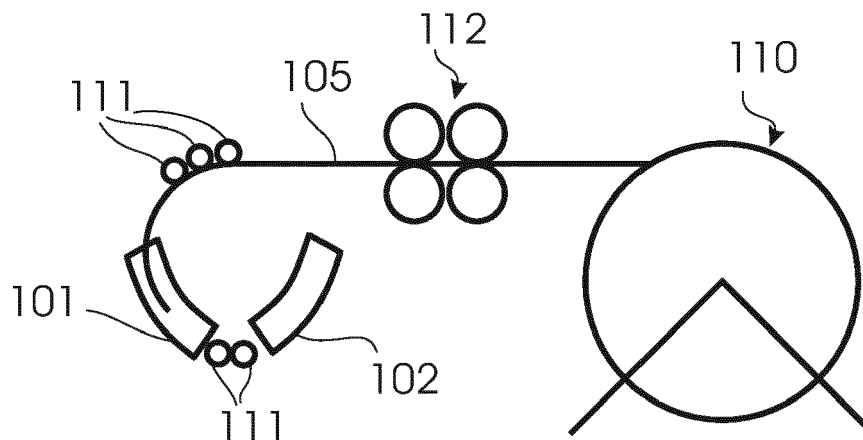


Fig. 1a

Description

Technical Field

[0001] The invention relates to the field of wound conductors for electrical machines, in particular to the insulation of a wound conductor for an electrical machine and to a method for producing an insulated wound conductor. The invention further relates to a wound conductor arrangement for an electrical machine having insulation.

Background Art

[0002] Wound electrical conductors, such as coils or Roebel bars for an electromotor or generator, are insulated for avoiding contact between the single wires or strands of the coils, but also for avoiding a short circuit between the coil and other conductive components of the electromotor, for example the stator core of the electromotor. For instance, the main wall insulation (e.g. mica tape and impregnated resin) is used to insulate a wound conductor on full potential to the stator core on ground potential.

[0003] Nowadays, there are two main insulation technologies for conductor windings (both form-wound coils and Roebel bars) in high voltage electrical machines: "Resin Rich (RR)" and "Vacuum Pressure Impregnation (VPI)". In both technologies, a thermoset resin material is used in combination with mica tape in order to form a highly filled mica composite as mainwall insulation.

[0004] In the RR process, a pre-impregnated "resin rich" mica tape is used where the resin is prepolymerized. This tape is wrapped around the bar, which is then consolidated in a hot-press. In case of the vacuum pressure impregnation (VPI) process, a porous mica tape is first wrapped around the bar / coil which is then impregnated with a low viscous resin. Heat curing of the resin leads to solidification and final consolidation of the bar / coil. Moreover, the global VPI technology is applied on "small" motors and generators (<15 KV). Here, the full stator as such - with placed stator coils and other components - is impregnated in one step and heated up in an oven for final curing of the resin.

[0005] Even though processes employed to create a finished stator coil have been improved in the past 50 years with the widespread application of robotics for coil forming and insulation taping, they are still time-consuming and require multiple steps. Moreover, dealing with liquid resins in the workshops - usually epoxy-anhydride and polyester-diluent resin systems - causes health and safety issues as well as environmental issues due to evaporating chemical gases. Curing of the impregnated parts is time (numerous hours) and energy (heating of large ovens) consuming while also creating chemical fumes that have to be eliminated.

Brief Summary of the Invention

[0006] In view of the above, a method for producing an insulated wound conductor according to claim 1, and a wound conductor arrangement for an electrical machine according to claim 13 are provided. Further aspects, advantages, and features of the present invention are apparent from the dependent claims, the description, and the accompanying drawings.

[0007] According to an aspect of the invention, a method for producing an insulated wound conductor for an electrical machine is provided. The method includes providing one or more shrinkable tubes, each of which including a tube wall and an inner hollow space being surrounded by the tube wall. The tube wall includes at least one insulation layer of insulation material suitable for insulating the wound conductor. The method further includes forming a wound conductor by guiding a wire or strand including a conductive material from a wire supply device to the at least one shrinkable tube. The wire is further driven (at least once) in and through the inner hollow space of the shrinkable tube. The method further includes shrinking the shrinkable tube around the one or more wires within the shrinkable tube.

[0008] The method for producing an insulated conductor according to embodiments described herein offers an advantageous alternative to the traditional VPI technology for the mica-resin main wall insulation and the RR technology. With the method for insulating a wound conductor according to embodiments described herein, the production process can be simplified. Moreover, the time for the production process of an isolated wound conductor can be reduced, which spares production costs. Also, less energy is used for the method according to embodiments described herein than for known production methods, which, in turn, helps further reducing the costs for production and helps to protect the environment. According to embodiments described herein, the method allows for avoiding or at least reducing safety and environmental risks due to the use of a tube and a simplified production process. In particular, the reduction of production time and of production risks (such as risks arising from chemicals used in the known production methods) becomes possible keeping the insulation properties of the wound conductor constant, or even improving the insulation properties, such as improving the resistance against partial discharge in the wound conductor.

[0009] According to a further aspect of the invention, a wound conductor arrangement for an electrical machine is provided. The wound conductor arrangement includes an electrically conductive conductor winding forming a loop, wherein the loop includes several consecutively aligned sections, especially along the circumference of the loop. The wound conductor arrangement further includes a first shrinkable tube, especially a heat shrinkable tube, extending along a first section of the loop and surrounding the conductor winding along the first section of the loop. The shrinkable tube includes an in-

sulation layer for the conductor winding.

[0010] The wound conductor arrangement according to embodiments described herein offers several advantages such as better electrical performance due to much lower partial discharge (PD) in the pre-manufactured insulation, reduced processing time, simplified processing steps, increased performance with higher fields and/or higher voltages as well as less environmental, health and safety issues. Further, the wound conductor arrangement according to embodiments described herein allows for simplifying the production process for the wound conductor arrangement, especially compared to the VPI technology. A simplified process results in decreased production costs, which in turn influence the costs for the end product.

Brief Description of the Drawings

[0011] The subject matter of the invention will be explained in more detail in the following text with reference to preferred exemplary embodiments which are illustrated in the drawings, in which:

Figure 1a is a schematic drawing of a first feature of a method for forming a wound conductor according to embodiments described herein;

Figure 1b is a schematic drawing of a shrinkable tube for a wound conductor arrangement and for producing an insulated wound conductor according to embodiments described herein,

Figure 1c is a schematic drawing of a second feature of a method for forming a wound conductor according to embodiments described herein;

Figure 1d is a schematic drawing of a third feature of a method for forming a wound conductor according to embodiments described herein;

Figures 2a to 2g show a schematic view of further features of a method for producing an insulated wound conductor arrangement according to embodiments described herein;

Figure 3a shows a schematic view of a wire in a shrinkable tube for forming a wound conductor arrangement according to embodiments described herein;

Figures 3b and 3c show schematic views of a multi-wire configuration in a shrinkable tube for forming a wound conductor arrangement according to embodiments described herein; and

Figure 3d shows a schematic cross-sectional view of a multi-wire configuration in a shrinkable tube for forming a wound conductor arrangement according

to embodiments described herein.

[0012] The reference symbols used in the drawings, and their meanings, are listed in summary form in the list of reference symbols. In principle, identical parts are provided with the same reference symbols in the figures.

Preferred Embodiments of the Invention

[0013] According to embodiments described herein, a method for producing an insulated wound conductor and a wound conductor arrangement is provided, which in particular is used in electric machines. For instance, the wound conductor according to embodiments described herein may be used in electrical motors, generators, and/or transformers.

[0014] Embodiments described herein relate to a method for manufacturing of insulated form wound conductors or wound coils with shrinkable tubes, especially as mainwall insulation. According to embodiments described herein and as will be shown in detail in the following, the wound conductor is made basically by firstly lacing or winding at least one wire or strand through one or more heat shrinkable tubes. Further, the (initially) round wound conductor may then be stretched in an oval shape. The latter is spread into a desired diamond shape. The shrinkable tubes are then shrunk resulting into the mainwall insulation.

[0015] Figure 1a shows a first feature of a method for forming an insulated wound conductor according to embodiments described herein. In Figure 1a, two shrinkable tubes 101 and 102 are provided. The skilled person may understand that the number of the shrinkable tubes shown in the figures is an example only. The number of shrinkable tubes may vary, in particular may vary from typically one shrinkable tube up to ten shrinkable tubes, more typically from one to five shrinkable tubes, and even more typically from one to three shrinkable tubes. Figure 1a further shows a wire supply device 110, which may for instance be a wire spool or the like, allowing delivering a wire comprising conductive material for forming the wound conductor. For instance, the wire may include a material being suitable for being used in a respective electrical machine, such as copper, iron or the like.

[0016] According to embodiments described herein, the wire 105 is pulled from the wire supply device 110, e.g. by drive units 112. In some examples, the drive units 112 may include one or more driven rollers, pulleys or cylinders for pulling the wire 105 from the wire supply device 110. The wire 105 is driven and guided to the first shrinkable tube 101 and guided into the shrinkable tube 101. In some embodiments, guidance units 111 (e.g. guidance rollers) may be provided for guiding the wire 105 into the desired direction after having pulled the wire from the wire supply device. For instance, the wire 105 may be guided on a bent path, e.g. along a round path, so that the wire 105 is bent when being guided. In some embodiments, the bending of the wire may be performed

for forming a wound conductor and giving a loop-like shape to the wire for the wound conductor.

[0017] Figure 1b shows a schematic view of an example of a shrinkable tube 101. The shrinkable tube according to embodiments described herein includes a tube wall 103 and an inner hollow space 104 being surrounded by the tube wall 103. Typically, the tube wall contains an insulation material for insulating the wound conductor, e.g. in the form of one or more insulation layers. According to some embodiments, the shrinkable tube may include several layers, in particular several layers having each different insulation properties. However, the material and the composition of the shrinkable tube will be referred to in detail below. As can be seen in Figure 1b, the shrinkable tube 101 is exemplarily shown with a substantially circular cross-section. However, the shape of the cross-section of the shrinkable tube according to embodiments described herein may be different and may be any shape suitable for the described purpose. For instance, the shape of the cross-section of the shrinkable tube may have a substantially circular shape, an oval shape, a rectangular shape, a quadratic shape, and/or a triangular shape. According to some embodiments, the shape of the cross-section of the shrinkable tubes may be chosen according to the intended application, the intended wire to be used, the number of turns in the wound conductor arrangement, the size of the wire and/ or the wound conductor, the material of the shrinkable tube, the layer composition of the shrinkable tube and the like. In some embodiments, the shape of the cross-section of the tube may be chosen according to the intended coil shape, for which the wound conductor is produced. For instance, a rectangular cross-section of the shrinkable tube may be chosen for fitting with a rectangular cross-section shape of the coil. The skilled person may understand that also the second shrinkable tube 102 or any other shrinkable tube may be formed as described with respect to the shrinkable tube 101 shown in Figure 1b.

[0018] In some embodiments (for instance the embodiments shown in Fig. 1a to 1d), one or more shrinkable tube may be provided in a bent shape to correspond to the loop-like path of the wire. For instance, the bending of the shrinkable tube may be provided by a pre-shaping of the tube before introducing the wire into the shrinkable tube. According to some embodiments, bending the shrinkable tube corresponding to the loop-like path of the wire may simplify the process and reduce the error rate of the production process.

[0019] According to some embodiments, the shrinkable tubes may be pre-manufactured before the winding process. The shrinkable tube suitable for the respective application can for instance be chosen from a stock of shrinkable tubes. Additionally or alternatively, the shrinkable tube desired for a specific application, may be adapted (e.g. by adding additional layers to the tube, such as by coating or spraying or the like) to the process. Using pre-manufactured shrinkable tubes helps accelerating the production of the wound conductor and spares costs.

[0020] In Figure 1c, the wire 105 is guided in and through the shrinkable tubes 101 and 102, in particular through the inner hollow space of the shrinkable tubes 101 and 102. The wire 105 is bended and wound through the shrinkable tubes 101, 102, e.g. with the help of guidance units 111, such as guidance rollers or another suitable tools. Depending on the desired coil size, different diameters can be obtained by adjusting the guidance units. According to some embodiments described herein, the wire 105 is guided sequentially to, into and through the two shrinkable tubes, e.g. the wire is guided through one shrinkable tube after the other.

[0021] The skilled person may understand that the wound conductor or wound conductor arrangement as referred to herein may be used as a coil in an electric machine. The wound conductor or wound conductor arrangement may be understood as a preform of a coil ready to be used, wherein the coil may include the wound conductor either as a constructional part or as a precursor form. According to some embodiments, the coil may have a substantially round shape, or may include substantially straight portions and bent portions (such as a diamond shape coil).

[0022] Figure 1c shows how the wire 105 is placed within the two shrinkable tubes 101, 102 after being guided through the shrinkable tubes 101 and 102. The wire 105 after being guided through and placed within the shrinkable tubes 101, 102 forms a round shape, comparable to a loop-like shape, e.g. a substantially circular loop shape.

[0023] The term "substantially" as used herein may mean that there may be a certain deviation from the characteristic denoted with "substantially." For instance, the term "substantially circular" refers to a shape which may have certain deviations from the exact circular shape, such as a deviation of about 1 to 10% of the general extension in one direction. In another example, the term "substantially straight" refers to an arrangement of an element which may have certain deviations from the exact straight arrangement, such as a deviation from the straight arrangement along about 1% to about 15% of the total length of the straight element.

[0024] According to some embodiments, the loop formed by the wire 105 in Figure 1c may be described as having consecutively aligned sections, which are in particular aligned along the circumferential direction of the loop. Two of the consecutively aligned sections are surrounded by the shrinkable tubes 101 and 102. For instance, one shrinkable tube can be described as surrounding the whole cross-section of one section of the consecutively aligned sections (especially aligned in circumferential direction of the loop). In one example, all sections being put together along a round shape form the loop.

[0025] According to some embodiments described herein, the wire 105 is repeatable guided to, in and through the shrinkable tubes 101 and 102, e.g. by further unwinding the wire 105 from the wire supply device 110,

by driving the wire 105 by the drive units 112 and by guiding the wire 105 by the guidance units 111. The shrinkable tubes may be fixed at defined locations for allowing a reliable and fast winding of the wire 105 to a loop-like shape. In some embodiments, the wire 105 is guided in a circle-like closed-loop path.

[0026] Figure 1d shows the result of a repetition of guiding the wire to, in and through the shrinkable tubes 101 and 102. A strand of multiple wire loops 106, 107, and 108 is formed within the inner hollow space 104 of the shrinkable tubes 101 and 102. The strand, or some sections of the strand being consecutively aligned along the circumferential direction of the strand, is surrounded by the walls 103 of each of the shrinkable tubes 101, 102. The example shown in Figure 1d shows only three wire loops forming the strand for the sake of simplicity. The skilled person may understand that the number of wire loops is not limited to the shown example, but that the number of wire loops within the shrinkable tubes may be chosen according to the intended application of the wound conductor, the size of the shrinkable tubes and the like.

[0027] The skilled person may understand that the method and the wound conductor according to embodiments described herein are produced by not fitting a wound conductor into the shrinkable tube. Rather, a wire, which will form a wound conductor after the method for producing an insulated wound conductor is finished, is inserted into the shrinkable tube.

[0028] Figure 2a shows an example of a formed wound conductor 200 or wound conductor arrangement according to embodiments described herein. The wound conductor 200 or conductor arrangement includes four wire windings or wire loops 106 to 109. In the shown example, the wire windings or wire loops 106 to 109 form a substantially circular loop.

[0029] Other shapes of the loop are also possible, such as generally a round shape or an oval shape. In some embodiments, the loop may be provided as a spiral like structure or a helix like structure, where the single wire loops 106 to 109 are connected to each other, e.g. by being formed from the same wire 105. For instance, the spiral-like structure of the wound conductor 200 may allow a current to consecutively flow through the single wire windings or wire loops 106 to 109. According to some embodiments, the wound conductor 200 shown in Figure 2a may be used as a coil for an electrical machine. In some embodiments, the wound conductor may be configured for being connected to a power supply, e.g. so that current can flow through the single wire windings or wire loops 106 to 109.

[0030] Typically, the loop of the wound conductor 200 includes consecutively aligned sections. In Figure 2a, two of the consecutively aligned sections 203 and 204 (first section 203 and second section 204) are shown. The consecutively aligned sections of the loop are in particular aligned along the circumferential direction of the loop. Typically, a shrinkable tube surrounds the whole

cross-section of one section, as for instance shown in Figure 2b.

[0031] Figure 2b shows a sectional view of the first section 203 of the wound conductor 200 along line A-A (as indicated in Figure 2a). In Figure 2b, the four windings 106 to 109 as well as the shrinkable tube 101 are shown in a cross-sectional view. The four windings 106 to 109 are placed within the shrinkable tube 101, in particular in the inner hollow space 104 of the shrinkable tube 101.

[0032] According to some embodiments, a shrinkable tube surrounding a section of the loop may be understood as covering the section of the loop at the inner side 202 of the loop and the outer side 201 of the loop, as exemplarily shown in Figures 2a and 2b. Typically, the inner side 202 of the loop is a space surrounded by the loop, and the outer side 201 of the loop is the space outside of the loop. According to some embodiments described herein, one shrinkable tube only surrounds one of the consecutively aligned sections (e.g.: a first shrinkable tube covers the first section). Further, in some embodiments, one section of the consecutively aligned sections may run continuously over a part of the loop along the circumferential direction and may especially not be allowed to skip or jump over other sections of the loop (i.e. a section including different, separated parts of the loop in circumferential direction may not be included in the term "a section of several consecutively aligned sections" as used herein). The skilled person may understand that two consecutively aligned sections may have a distance between each other, such as exemplarily shown in Figure 2a with the first section 203 and the second section 204.

[0033] In Figure 2c, the shrinkable tubes 101 and 102 are placed in an appropriate position along the loop. For instance, the location of the tubes during the winding process (as exemplarily shown in Figures 1a to 1d) may be chosen arbitrarily and/or suitable for the winding process. In one example, the tubes may be placed near to each other or directly adjacent to each other during the winding process, e.g. for simplifying the winding process. Typically after the winding of the loop is finished, the position of the tubes may be varied, e.g. for placing the tubes in the "future straight parts" of the coil. In the example of Figure 2c, the tubes are placed substantially opposite to each other in the loop.

[0034] Figure 2d shows the use of a stretching machine 300. For instance, a stretching machine may include a hydraulic or electrical motor or may be provided by any suitable apparatus. Starting from Figure 2d and going to Figure 2e, the substantially circular loop of the wound conductor 200 is stretched to a substantially oval shape. According to some embodiments, the substantially oval shape may be known as racetrack coil in the manufacturing process. As can be seen in Figure 2e, the tubes are now placed at the substantially straight or lengthy portions of the wound conductor. In some embodiments, adhesive tapes may be taped around the wound conductor strand or around the wires for pre-consolidation.

[0035] Figure 2f shows the further shaping of the

wound conductor 200. According to some embodiments described herein, the racetrack coil may be spread to a diamond shaped coil. For instance, today's existing spreading machines may be used. Using known spreading machines may also contribute to a simple and reliable production process of the wound conductor.

[0036] In Figure 2g, the end-winding regions (e.g. the regions or sections of the wound conductor not covered by the shrinkable tubes) may be lapped with end insulations 114, e.g. resin rich tapes. In some embodiments, spray coating or paint can be also used to apply the end insulation 114 in the overhang region of the wound conductor. Typically, the shrinkable tubes are then shrunk to provide good and adjusted isolation for the wound conductor. In some embodiments, a field grading tape or painting is added and the final consolidation is carried out. According to some embodiments, a final layering may include providing a conductive layer, a semiconductive layer, a field grading layer and/or a mechanical fixation layer.

[0037] According to some embodiments, which may be combined with other embodiments described herein, the shrinkable tubes may be shrunk by a heat treatment. The heat treatment may be applied by radiation, infrared light, laser light, warm gas, in an oven, by a flame gun or the like.

[0038] Typically, the shrinkable tube can be any suitable type of heat or cold shrinkable polymeric material and composite. For instance, the shrinkable tube may include at least one material chosen from the group consisting of: a polymeric material, a polymeric composite, polyolefin, fluoropolymer, polyester based materials, PVC, neoprene, polyesterimide, and silicones. According to some embodiments, the insulation material is chosen as a material being resistant against partial discharge.

[0039] In some embodiments, which may be combined with other embodiments described herein, the shrinkable tube may change material properties during shrinkage, such as size, material composition, stiffness, shape, and the like. According to some embodiments, the shrinkable tube comprises a shrinkage ratio of about 2:1 to 6:1 under thermal treatment, such as a treatment including heating the shrinkable tube and/or cooling the shrinkable tube. According to some embodiments, the shrinkage ratio of the shrinkable tube may even be higher than 6:1 under thermal treatment. According to some embodiments, the shrinkable tube may have a certain level of moisture before being shrunk. In other alternative or additional embodiments, the shrinkable tube may have a temperature dependent elasticity. For instance, the shrinkage temperature for materials used in embodiments described herein, such as polyolefin based materials, may be between about 100°C and about 120 °C, or higher. According to other embodiments, the shrinkage temperature for materials used in embodiments described herein, such as fluoropolymer based materials may be between about 150°C and about 175 °C, or higher.

[0040] In some embodiments, the shrinkable tube may be a cold shrinkable tube, which in particular shrinks without the application of heat. For instance, the shrinkable tube may be provided with a supplying strap, which is removed for inducing the shrinking process. The skilled person will understand that the term "thermal treatment" may include a treatment at a temperature, at which the shrinking tube shrinks.

[0041] According to some embodiments described herein, the shrinkable tube may be adapted, e.g. by being adapted in size and material, so as to provide a tight fitting around the respective section of the wound conductor after the shrinkage process. In one embodiment, tight fitting may include a contact between the shrank tube and the respective section of the wound conductor provided with the shrinkable tube, in particular a contact between the shrank tube and the respective section of the wound conductor over typically at least 85% of the area of the shrank tube, more typically at least 90% of the area of the shrank tube, and even more typically at least 95% of the area of the shrank tube. According to some embodiments, at least 60% of the surface of the wound conductor to be isolated may be covered by one or more shrank tubes, more typically at least 70% of the surface of the wound conductor to be isolated may be covered by one or more shrank tubes, and even more typically at least 80% of the surface of the wound conductor to be isolated may be covered by one or more shrank tubes. According to some embodiments, the wound conductor may include a substantially straight portion (e.g. within a stator slot) and a substantially bent portion (e.g. the overhang of the stator). Typically, more than 85%, more typically more than 90%, and even more typically more than 95% of the substantially straight portion of the wound conductor may be covered by one or more shrank tubes. In some embodiments, the substantially straight portion of the wound conductor in the stator slot may fully be covered by one or more shrank tubes.

[0042] According to some embodiments, which may be combined with other embodiments described herein, the shrinkable tube may include an insulation layer comprising an insulation material for the wound conductor. In some embodiments, the shrinkable tube may include more than one layer, e.g. several layers. For instance, the shrinkable tube may include an insulation layer and an intermediate layer having an electrical conductivity between the electrical conductivity of the conductor material of the wound conductor and the electrical conductivity of the insulation layer. In particular, the shrinkable tube includes an intermediate layer being a semiconductive layer between insulation and conductor to reduce high field stresses.

[0043] According to some embodiments, the intermediate layer may have a conductivity value greater than the conductivity value of the insulation layer, and in particular a conductivity value less than the conductivity value of the conductive material of the conductive material of the wound conductor. In some embodiments described

herein, the intermediate layer may include a semiconductor material. Typically, the term "semiconductor" as used in this context should be understood as a material, which has electrical conductivity between that of a conductor (such as copper) and that of an insulator (such as glass). According to some embodiments, the intermediate layer may have a conductivity value between typically about 10^{-5} S/m and about 10^3 S/m at 20°C , and more typically a conductivity value of between about 10 to about 10^2 S/m at 20°C . Compared thereto, a conductor as referred to herein may be understood as a material having the property of transmitting electricity. Typically, a conductor or conductive material as referred to herein may have a conductivity value equal to or greater than 10^3 S/m at 20°C . The insulator, or insulation material as used herein, may be understood as a material that resists electricity. The conductivity of the insulation material may typically be of from about $1 \cdot 10^{-8}$ to about $1 \cdot 10^{-20}$ S/m at 20°C , and more typically from $1 \cdot 10^{-9}$ to $1 \cdot 10^{-16}$. For example, the conductivity of Al_2O_3 is from 10^{-10} to 10^{-12} S/m.

[0044] The semiconductor material may be composed of a conductive polymeric material or composite. In the latter case, the polymeric material may be filled with conductive particles such as carbon black. In some embodiments, the semiconductive material may be formed from an insulation material filled with any organic additive (e.g. antioxidants) or inorganic filler (e.g. alumina or mica). According to some embodiments, the intermediate layer may include at least one material from the group consisting of: a conductive polymeric material (e.g. a polymer as described above with respect to the insulation layer), a conductive composite, carbon black filled silicone, epoxy, mastic, a material including fillers like TiO_2 , V_2O_5 , Cr_2O_3 , MnO , Fe_2O_3 , CoO , NiO , Cu_2O , ZnO , ZnS , Ta_2O_5 , Y_2O_3 , ZrO_2 , Nb_2O_5 , MoO_3 , In_2O_3 , SnO_2 , La_2O_3 , Ta_2O_5 , WO_3 , SiC , B_4C , WC , W_2C , TiC , ZrC , HfC , NbC , TaC , Cr_3C_2 , Mo_2C , $\text{Sn}_x\text{Sb}_y\text{O}_z$, a metal layer of aluminum, a noble metal, epoxy, silicone, polyester resin, polyester-imide resin, PU, acryl resin, and Novolac resin.

[0045] According to embodiments described herein, the shrinkable tube configured for providing an electrical insulation for the wound conductor according to embodiments described herein, may be used as the main electrical insulation layer around the wound conductor or wound conductor arrangement, and may be denoted as main wall insulation. According to some embodiments described herein, the applicability of the insulation to be used as a main electrical insulation for the wound conductor depends inter alia on the AC breakdown strength of the pure material before and after shrinkage and the dielectric properties of the pure material before and after shrinkage.

[0046] In one embodiment, the semiconductive layer is applied between conductor and insulation before the winding process and may act as adhesive (e.g. in the shrinking process). In another embodiment, the semiconductive layer is part of or integrated inside the shrinkable

tube - e.g. by providing a multi-layer shrinkable tube with an inner semiconductive and outer insulation layer. According to some embodiments, a multi-layer shrinkable tube as referred to herein may include a shrinkable cross-linked or cross-linkable semiconductor (as intermediate layer as referred to herein) and a shrinkable cross-linked or cross-linkable insulation layer.

[0047] According to some embodiments described herein, the shrinkable tube may have a multiple layer (> 2) structure. In one embodiment, an outer slot corona protection layer may be applied via coating, painting or spraying of a semiconductive material. Another option would be the use of a 3-layer shrinkable tube. In another embodiment a field grading material is applied on one of the outer layers for end corona protection. The field grading layer may be used when a field peak appears, in particular where the windings exit the stator core. Field peaks may cause damages to the insulation of the wound conductor. For avoiding such field peaks, field grading tapes or end corona protection tapes may be applied, which may minimize the field peak. In one example, a field grading layer may be applied by a SiC filled tape or a ZnO containing tape.

[0048] In some embodiments, the shrinkable tube (which may be a multi-layer tube including the insulation layer as well as the intermediate layer according to embodiments described herein) may be a co-extruded tube or a tube being coated inside. In one example, the shrinkable tube is a multi-layer tube provided by a two-layer extrudate. According to some embodiments, the two-layer extrudate may include an adhesive material and carbon black for providing the semiconductive function of the intermediate layer.

[0049] The insulation provided by the shrinkable tube according to embodiments described herein is a promising alternative compared to the mica-resin main wall insulation obtained by traditional VPI (Vacuum Pressure Impregnation) technology. It offers many benefits such as better electrical performance due to much lower partial discharge (PD), reduced processing time, simplified processing steps as well as less environmental, health and safety issues.

[0050] Figure 3a shows a partial view of a wound conductor arrangement 200 according to embodiments described herein. In Figure 3a, one section of several consecutively aligned sections of a loop is shown (as explained in detail above). The example of Figure 3a shows a wound conductor arrangement 200 including a shrinkable tube 101 with an insulation layer 115 and an intermediate layer 113. Within the shrinkable tube 101, a wire 105 is provided, e.g. by guiding the wire from a wire supply device to, into and through the shrinkable tube 101 (as for instance explained in detail above). The wire 105 may form a closed loop in a substantially circular or round shape, a spiral-like structure, or diamond shape for providing a wound conductor. Figure 3a shows the wound conductor arrangement 200 before shrinking the shrinkable tube 101.

[0051] Figure 3b shows several windings of the wire 105 within the shrinkable tube 101 before the shrinking process. As can be seen in Figure 3b, there is a space between the shrinkable tube 101 with the layers 115 and 113 and the strand of wires 105.

[0052] According to some embodiments, a strand as referred to herein may be understood as a bundle of wires 105. According to some embodiments, the wires 105 forming the strand may be made from one wire being provided in a spiral-like structure so that the same wire 105 forms a strand including several adjacently arranged parts of the wire 105.

[0053] Figure 3c shows the strand of the wire 105 and the shrinkable tube 101 after the shrinking process, which may - according to some embodiments - be performed by a heat treatment. According to the example shown in Figure 3c, the intermediate layer 113 is in contact with the bundle of the wire 105 and isolates the conductive material of the wound conductor arrangement.

[0054] Figure 3d shows a cross-sectional view of a wound conductor arrangement according to embodiments described herein. The wound conductor arrangement 200 includes two rows 205 and 206 of wires 105 within a shrinkable tube 101. According to some embodiments, which may be combined with other embodiments described herein, the wire 105 of a wound conductor arrangement may be provided in any suitable shape and number within the shrinkable tube. For instance, the wire 105 may be provided in one block as shown in Figures 3b and 3c, in defined rows or packages, in a single manner or as a plurality forming a strand of wires or the like. The skilled person may understand that the arrangement of the one or more wires in any number and shape within the shrinkable tube may be chosen according to the intended application of the coil, the size of the coil, the performance of the coil, the costs of the coil and the like.

[0055] According to some embodiments, a wound conductor or wound conductor arrangement being provided with a shrinkable tube may include a wound conductor with a shrunk tube, e.g. a shrinkable tube after a shrinking process. The term "shrinkable tube" may be understood as including a tube in an expanded form and a tube in a shrunk form.

[0056] As an example, a prototype of a racetrack coil has been manufactured to show that mainwall insulation can be applied on the straight sections of an "actually closed" form. In the following, an example of the prototype of the wound conductor arrangement according to embodiments described herein is described. The dimensions of the prototype example are reasonably oriented according to typical coils. A standard conductor (having e.g. a 10 mm width and a 3.3 mm height) from a conductor supply device, such as a drum, is wound eight times through two shrinkable tubes. In the given example, the shrinkable tubes are about 40 cm long. The arrangement results in a final wound conductor bundle of eight conductors or wires. The tubes are placed on the "future straight" parts (as for instance shown in Figure 2c). The

round coil is then spread manually by force to an oval shape and consolidated by tapes. Afterwards, the tubes were shrunk at 140°C for 45 min into an oven.

[0057] For the prototype test, an accelerated voltage endurance tests has been performed on straight bars (on a simplified concept). As an example, two sets (each two replicates) of insulated racetrack coils were manufactured, one set without (set 1) and one with (set 2) semiconductive layer in the shrinkable tube. Scotch-Weld™ 5313 from 3M was used as carbon black filled semiconductive mastic. A polyolefin based heat shrinkable tube was obtained from R.E.P.L international (RIRT 65/21, with recovered wall thickness of about 2 mm). The copper bars of set 2 were covered by a semiconductive layer. The shrinkable tubes were then placed over the bars and heated in an oven for shrinkage. In order to test the bars, an electrode semiconductive layer (mastic tape) was applied in the middle of the bar. Furthermore, the field grading tape (Krempel Akasic 4b) was then applied and cured (140°C for 1 h). The samples were tested under voltage endurance at 20 kV (average stress level: 10 kV/mm) with an insulation thickness of about 2 mm and at room temperature until breakdown. The time to breakdown for set 1 (without semiconductive layer) was about five times less than for set 2 (with semiconductive layer). The test showed that the insulation according to some embodiments described herein is at least equal or even better than the known systems, and facilitate at the same time the production process.

[0058] According to embodiments described herein, a wound conductor arrangement or a method for producing an insulated wound conductor according to embodiments described herein may be used in electrical machines. Generally, an electrical machine as referred to herein may be an electrical machine for high voltages, in particular a high voltage (HV) electrical rotating machine (such as large AC motors and small generators). For instance, the electrical machine and the wound conductor arrangement according to embodiments described herein may be adapted for a rated voltage being typically larger than 1 kV, more typically larger than about 15 kV, and even more typically larger than about 30 kV. In some embodiments, the electrical machine and the wound conductor arrangement according to embodiments described herein may be adapted for an electric machine, such as a motor or a generator working with a frequency of about 50 Hz.

[0059] Furthermore, an electrical machine is provided including an electrical conductor arrangement according to any of the embodiments described herein. Also, an electrical machine is provided having an insulated wound conductor produced by the method according to the embodiments described herein.

[0060] In known insulation systems for wound conductors, early breakdown of the insulation in voltage endurance tests often occurs, especially due to gaps between the insulation and the conductor material and due to high field stresses in the interfaces. The method for producing

an insulated wound conductor and the wound conductor arrangement according to embodiments described herein allows for minimizing the gaps and for reducing the filed stresses at the interfaces, e.g. corners and the like. In particular, an approach using a multi-layer shrinkable tube, such as an insulation outer layer with an inner semiconductive (mastic, painted or co-extruded) layer, is helpful for improving the insulation for wound conductors. For instance, the gaps can be minimized with mastic.

[0061] As mentioned above, such insulated wound conductors may be used for electrical rotating machines such as large AC motors and generators. The method according to embodiments described herein is a promising alternative to traditional VPI (Vacuum Pressure Impregnation) technology and the mica-resin mainwall insulation, which is produced by lapping of mica tape, impregnation with liquid thermosetting resin and heat curing. The method according to embodiments described herein combined with a respective material choice offers many advantages such as better electrical performance due to possibly higher temperature rating and possibly lower partial discharge (PD), reduced processing time, simplified processing steps (increase automated steps) as well as less environmental, health and safety issues.

[0062] In particular, several beneficial effects are achieved by the method for producing an insulated wound conductor and a wound conductor arrangement according to embodiments described herein. For instance, with the embodiments described herein, a dry application of mainwall insulation for wound coils is possible, which in particular reduces the production risks. Especially, no wet chemistry in comparison to today's state of the art with lapping, impregnation and curing is used in the production process. Thus, the overall production costs are lowered with a shorter and automated process and an environmentally friendly process.

[0063] Further, embodiments described herein lead to a wound conductor insulation with no or very low PD of an extruded and pre-manufactured mainwall insulation. The very low PD risk allows for higher temperatures and higher electrical stress level and higher efficiency of the full machine.

[0064] Though the present invention has been described on the basis of some preferred embodiments, those skilled in the art should appreciate that those embodiments should by no way limit the scope of the present invention. Without departing from the spirit and concept of the present invention, any variations and modifications to the embodiments should be within the apprehension of those with ordinary knowledge and skills in the art, and therefore fall in the scope of the present invention which is defined by the accompanied claims.

Reference numerals

[0065]

101, 102 shrinkable tube

103 tube wall
 104 inner hollow space of tube
 105 wire
 106-109 wire loops
 5 110 wire supply device
 111 guidance units
 112 drive units
 113 intermediate layer of shrinkable tube
 114 end insulations
 10 115 insulation layer of shrinkable tube
 200 wound conductor, wound conductor arrangement
 201 outer side of wound conductor
 202 inner side of wound conductor
 15 203, 204 consecutively aligned section
 205, 206 rows of wires
 300 stretching machine

20 Claims

1. Method for producing an insulated wound conductor (200) for an electrical machine, comprising the following steps:

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a) Providing one or more shrinkable tubes (101; 102) comprising a tube wall (103) and an inner hollow space (104) being surrounded by the tube wall (103), the tube wall comprising at least an insulation layer of insulation material for insulating the wound conductor (200);

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b) Forming a wound conductor (200) by guiding at least one wire (105) comprising a conductive material from a wire supply device (110) to the at least one shrinkable tube (101; 102) and driving the wire (105) at least once in and through the inner hollow space (104) of the shrinkable tube (101; 102); and

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c) Shrinking the shrinkable tube (101; 102) around the one or more wires (105) within the shrinkable tube.

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2. The method according to claim 1, wherein guiding the wire (105) comprises bending the wire (105) of conductive material.

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3. The method according to any of the preceding claims, wherein guiding the wire (105) comprises guiding the wire (105) in a circle-like closed-loop path.

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4. The method according to any of the preceding claims, wherein forming the wound conductor further comprises inserting the wire (105) repeatedly in the hollow space (104) of the shrinkable tube (101; 102) and guiding the wire (105) repeatedly through the shrinkable tube (101; 102) until a wound conductor (200) with a strand of multiple wire loops (106; 107;

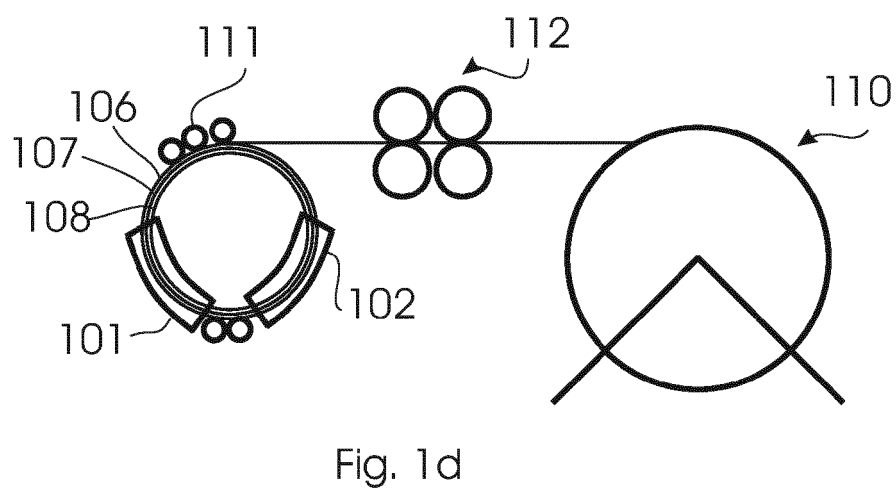
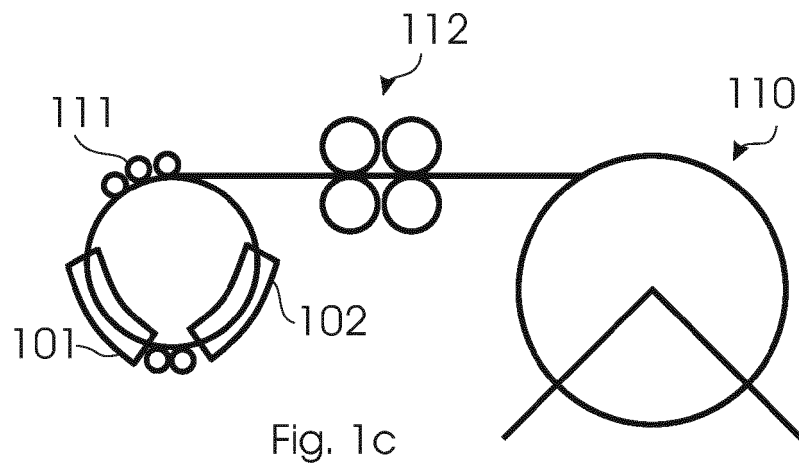
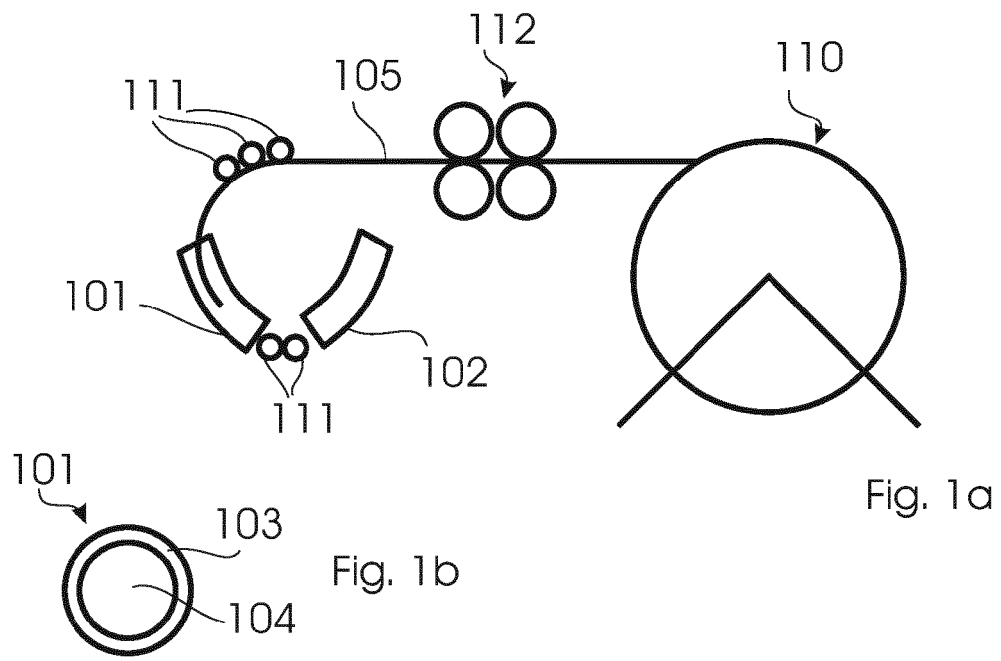
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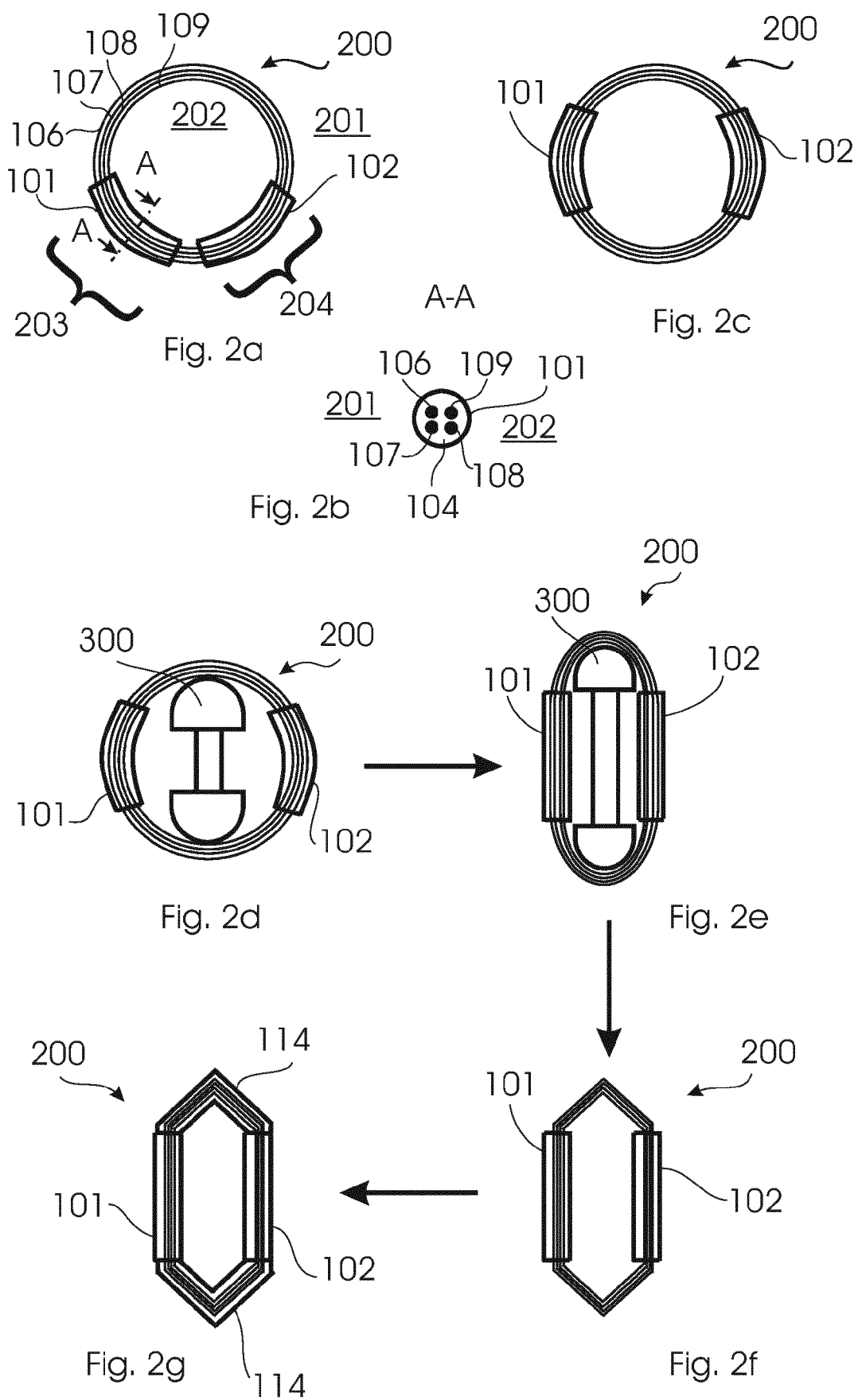
108) is formed.

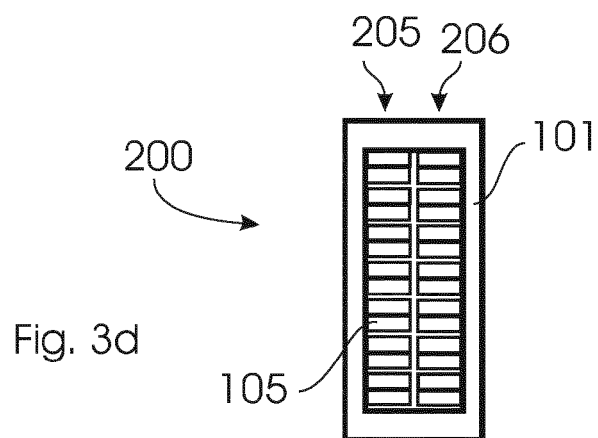
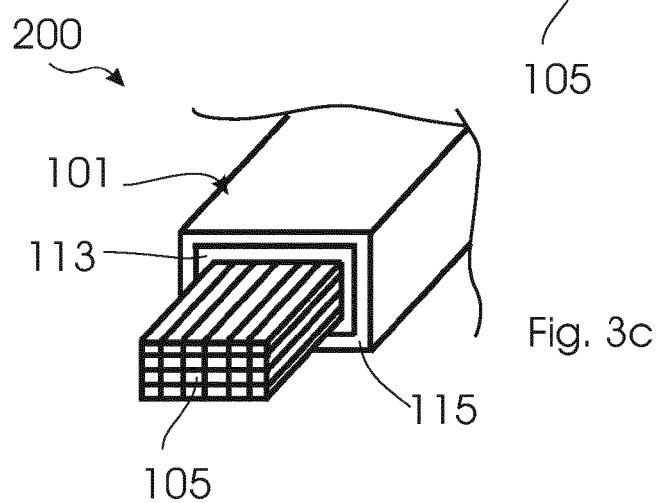
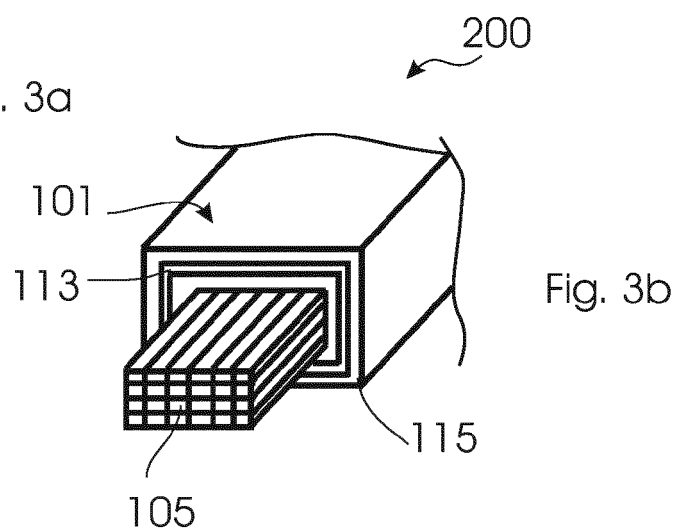
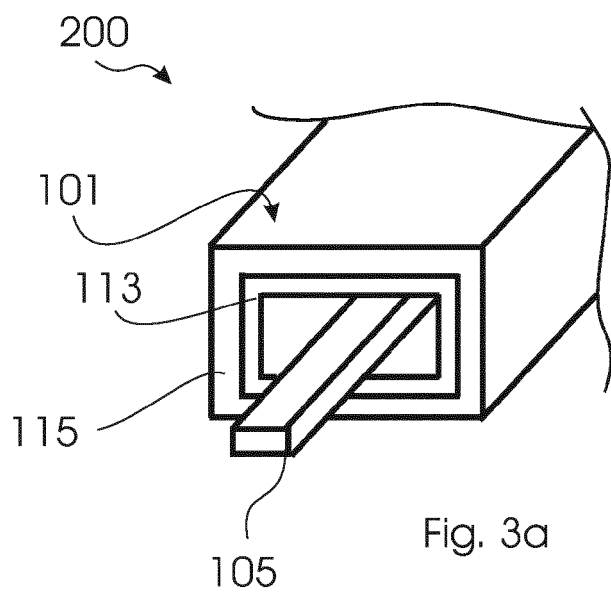
5. The method according to any of the preceding claims, wherein the shrinkable tube is a heat shrinkable tube and wherein shrinking the shrinkable tube (101; 102) around the wire (105) comprising conductive material comprises shrinking the shrinkable tube by thermal treatment. 5
6. The method according to any of the preceding claims, wherein providing the one or more shrinkable tubes comprises providing the shrinkable tubes in a bent shape corresponding to the path of the guided wire (105). 10
7. The method according to any of the preceding claims, further comprising providing an intermediate layer (113) between the wire (105) comprising the conductive material and the insulation layer of the tube wall (103) of the shrinkable tube (101; 102), the intermediate layer (113) having a conductivity less than the conductivity of the wire (105) comprising the conductive material and greater than the insulation layer of the tube wall (103) of the shrinkable tube (101; 102). 15
8. The method according to claim 7, wherein the intermediate layer (113) is provided by being a part of the shrinkable tube (101; 102). 20
9. The method according to any of the preceding claims, wherein at least two shrinkable tubes (101; 102) are provided and the wire (105) comprising conductive material is guided and driven in and through the two shrinkable tubes (101; 102) sequentially. 25
10. The method according to any of the preceding claims, further comprising shaping, in particular spreading, the wound conductor (200) before shrinking the shrinkable tube (101; 102) in a desired shape, in particular in a substantially diamond shaped coil. 30
11. The method according to any of the preceding claims, further comprising at least one of providing end insulations (114) at positions of the wound conductor (200), where the wound conductor (200) is not insulated by the shrinkable tube (101; 102) and providing end insulations (114) at positions overlapping with the shrinkable tube. 35
12. The method according to any of the preceding claims, further comprising providing a final layering comprising at least one of a conductive layer, a semiconductive layer, a field grading layer and a mechanical fixation layer. 40
13. A wound conductor arrangement for an electrical machine, comprising: 45

An electrically conductive conductor winding (200) forming a loop, the loop comprising several consecutively aligned sections (203; 204); A first shrinkable tube (101; 102), especially a heat shrinkable tube, extending along a first section of the loop and surrounding the conductor winding along the first section (203) of the loop; wherein the shrinkable tube (101; 102) comprises an insulation layer for the conductor winding (200). 50

14. The wound conductor arrangement according to claim 13, further comprising an intermediate layer (113) provided between the wound conductor (200) and the insulation layer of the shrinkable tube (101; 102), wherein the intermediate layer (113) has a conductivity value less than the conductivity value of the wound conductor (200). 55
15. The wound conductor arrangement according to any of claims 13 to 14, wherein the intermediate layer (113) is a part of the shrinkable tube (101; 102) providing the insulation layer. 60









EUROPEAN SEARCH REPORT

 Application Number
 EP 16 15 2879

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Munich		2 June 2016	Winkelman, André
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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