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# (54) Dry transformer with heat pipe inside the high voltage winding

(57) The present invention relates to a method of manufacturing a dry type transformer (1000). In particular a method of manufacturing a dry type transformer (1000) with a heat pipe evaporator (101) is provided with the steps of providing (801) a hollow cylindrical heat pipe evaporator (101), winding (802) at least one high voltage coil (112, 120) onto the heat pipe evaporator (101) around a longitudinal axis (110) of the heat pipe evaporator (101), and placing (803) an at least one low voltage coil (113) such that the heat pipe evaporator (101) is positioned between the at least one high voltage coil (112, 120) and the at least one low voltage coil (113). The heat pipe evaporator (101) is adapted to remove heat from the at least one high voltage coil (112, 120) and from the at least one low voltage coil (113), and is adapted to dielectrically insulate the at least one high voltage coil (112, 120) from the at least one low voltage coil (113).

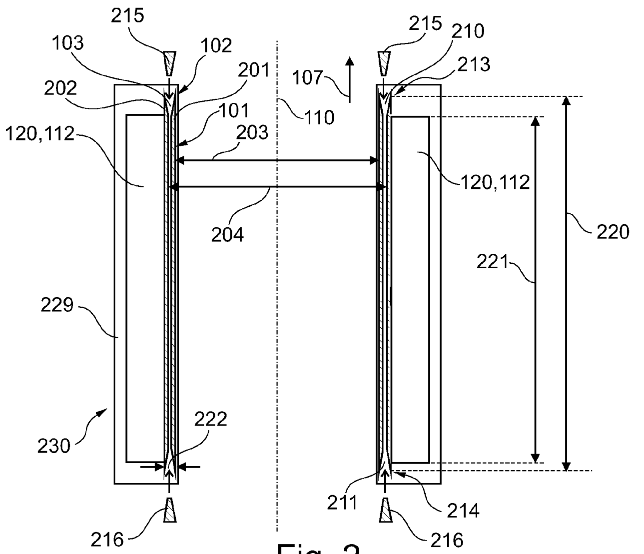


Fig. 2

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## Description

### FIELD OF THE INVENTION

**[0001]** The invention relates to a method of manufacturing a dry type transformer. In particular, the invention relates to a method of manufacturing a dry type transformer with a heat pipe evaporator. Furthermore, the invention relates to a dry type transformer manufactured by the method and to the use of a dry type transformer manufactured by the method for a wind energy plant.

### BACKGROUND OF THE INVENTION

**[0002]** Thermal issues may be an important limitation when attempting to improve the design of dry type transformers towards size reduction and increased power rating. Thermal losses due to the resistance of the conductors of transformer windings as well as transformer core losses may cause the transformer to heat up. The maximum power of the transformer is thus limited by the allowed maximum temperature of the transformer. If cooling of the transformer can be improved, the same transformer may be operated with higher power rating, or a smaller transformer may be used for a certain required power. Both options may result in material and cost saving. Active cooling with fans or dedicated air circulation channels may be used for cooling dry type transformers as well as cooling the dry type transformers utilizing heat pipes.

**[0003]** DE 602 09 574 T2 describes cooling channels for an epoxy casted transformer coil. The cooling channels are permanently installed within the casted epoxy to move heat from the coil of the transformer.

**[0004]** Manufacturing dry type transformers with cooling devices may be complex and costly.

### SUMMARY OF THE INVENTION

**[0005]** It may therefore be seen as objects of the invention to provide a simple and efficient method of manufacturing a transformer with a heat pipe evaporator, to provide an efficient transformer manufactured by the method, and to provide an efficient use of the transformer.

**[0006]** These objects are achieved by the subject-matter of the independent claims. Further exemplary embodiments are evident from the dependent claims and the following description of aspects and embodiments of the invention.

**[0007]** According to a first aspect of the invention, a method of manufacturing a dry type transformer with a heat pipe evaporator, at least one high voltage coil, at least one low voltage coil, and a core with at least one limb is provided. The method comprises the steps of providing a hollow cylindrical heat pipe evaporator, winding the at least one high voltage coil onto the heat pipe evaporator around a longitudinal axis of the heat pipe evaporator, and placing the at least one low voltage coil such that the heat pipe evaporator is positioned between the at least one high voltage coil and the at least one low voltage coil. The heat pipe evaporator is designed to remove heat from the at least one high voltage coil and from the at least one low voltage coil, and is adapted to dielectrically insulate the at least one high voltage coil from the at least one low voltage coil. An air gap may be provided between the at least one high voltage coil and the at least one low voltage coil, the air gap being adapted to dielectrically insulate the at least one high voltage coil from the at least one low voltage coil.

**[0008]** In other words, a high voltage transformer coil is wound around a cylindrical hollow heat pipe evaporator comprising two concentric tubes forming a cavity, and the low voltage coil of the transformer is placed within an inner wall of the hollow cylindrical heat pipe evaporator such that the heat pipe evaporator is separating the high voltage coil from the low voltage coil.

**[0009]** Such a method may provide for an efficient and simple manufacturing of the dry type transformer with an effective connection of the heat pipe evaporator to the transformer high voltage coil, wherein the connection of the heat pipe evaporator may be easily integrated in the manufacturing process of the dry type transformer. The manufactured dry type transformer may require less space than a transformer with a cooling system utilizing fans or dedicated air circulation channels and may be more efficiently manufactured than dry type transformers with such cooling systems. The contact area of the high voltage coil and the heat pipe evaporator may be provided along the whole length of the wound high voltage coil to efficiently remove heat from the high voltage coil to the heat pipe evaporator. The heat pipe evaporator may be attached to the coil such that an optimal thermal contact with the high voltage coil is established to efficiently exchange or remove heat from the coil to the heat pipe evaporator. Dry type transformers manufactured by winding the high voltage coil directly onto such a heat pipe evaporator may be realized in a compact, roomsaving way enabling an optimal size performance ratio. By providing a cavity in the evaporator the heat may be moved from the high voltage coil via a coolant in the cavity to a condenser of a heat pipe. The hollow cylindrical heat pipe evaporator is comparably easy to seal at a top and bottom end of the evaporator, which is important for longterm operation of the heat pipe. Since a high voltage coil of a transformer produces most of the heat of a transformer, the cooling of the high voltage coil may advantageously provide for an efficient removing of heat from the transformer from the place where most of the heat of the transformer is produced during operation.

**[0010]** The heat pipe evaporator may be pre-fabricated or manufactured in a further step of the method. The heat pipe evaporator may also be readily manufactured and provided for the method.

**[0011]** The heat pipe evaporator may have the form of a hollow cylinder and may be made of a material selected from the group consisting of a glass fibre reinforced epoxy, an epoxy, or any insulating material with a thermal expansion similar to the thermal expansion of epoxy or differing from the thermal expansion of epoxy within a range of up to 20%. The dry type transformer may be a dry type transformer with a voltage in a range from 1 kV - 75 kV.

**[0012]** According to another embodiment of the invention the heat pipe evaporator length in a direction of the longitudinal axis of the heat pipe evaporator equals a high voltage coil length in this direction. By providing a heat pipe evaporator with a hollow cylinder length similar to the high voltage coil length the contact area between the high voltage coil and the the evaporator may be enlarged and optimized concerning the heat removal from the high voltage coil to the evaporator.

**[0013]** The cavity of the heat pipe evaporator may have a radial thickness of at least 2 mm, thus enabling an optimal heat removal from the high voltage coil and the low voltage coil by the heat pipe evaporator. Such a cavity with a small thickness of a few millimetres may provide for a small volume of the evaporator while at the same time providing enough volume for the working fluid or coolant of the evaporator to efficiently remove heat from the high voltage coil and the low voltage coil via the heat pipe evaporator. Since the evaporator is arranged between high voltage coil(s) and low voltage coil(s) such a cavity thickness of the evaporator of a few millimetres may provide for the necessary dielectric requirements.

**[0014]** According to a further embodiment of the invention, the radial thickness of the cavity is proportional to the amount of heat needed to be moved from the high voltage coil and the low voltage coil of the transformer to the heat pipe. Thus the thickness of the cavity may be adapted according to the performance of the transformer or the required power of the transformer which causes the heat of the transformer during operation.

**[0015]** According to another embodiment of the invention, the heat pipe evaporator is thermally coupled to the at least one high voltage coil by removing heat from the at least one high voltage coil and the heat pipe evaporator is simultaneously adapted to remove heat which is emitted by the at least one low voltage coil from the at least one low voltage coil.

**[0016]** According to further embodiment of the invention the method further comprises arranging the heat pipe evaporator over a winding mandrel before the winding of the at least one high voltage coil.

**[0017]** Thus, the winding process may be optimized since the cylindrical hollow heat pipe evaporator may be adapted to the size of the mandrel which is used for winding the at least one high voltage coil around the mandrel during the manufacturing process of the dry type transformer.

**[0018]** According to another embodiment of the invention, the method further comprises the step of arranging the at least one low voltage coil on an inner concentric tube of the heat pipe evaporator, wherein the at least one high voltage coil is wound to an outer concentric tube of the heat pipe evaporator. According to another embodiment of the invention an air gap may be provided between the at least one high voltage coil and the at least one low voltage coil, the air gap being adapted to dielectrically insulate the at least one high voltage coil from the at least one low voltage coil.

**[0019]** By arranging the high voltage and low voltage coils on the outer and inner concentric tubes of the hollow cylindrical or in other words ring cylindrical shaped heat pipe evaporator an optimal heat removal from the high voltage and low voltage coils may be provided, as the coils are in direct contact with the concentric tubes forming the cavity of the heat pipe evaporator.

**[0020]** According to another embodiment of the invention, the at least one low voltage coil and the at least one high voltage coil with the heat pipe evaporator are arranged around the at least one limb of the transformer.

**[0021]** Thus, the coils may be arranged efficiently and easily over the limb of the core of the transformer. The low voltage coil may be arranged to the limb separately and then the heat pipe evaporator with the thereto wound high voltage coil may be placed around the limb or the limb with the thereto arranged low voltage coil may be inserted within the evaporator.

**[0022]** According to another embodiment of the invention the method further comprises the step of pre-fabricating the heat pipe evaporator, wherein the pre-fabricating comprises: manufacturing an inner concentric tube with spacers which are attached to the inner concentric tube and spaced apart from each other, manufacturing an outer concentric tube, attaching the outer concentric tube onto the spacers of the inner concentric tube such that the cavity is provided between the outer concentric tube and the inner concentric tube, the cavity acting as the heat pipe evaporator.

**[0023]** Such a pre-fabricating of the heat pipe evaporator may improve the efficiency of manufacturing the dry type transformer since the production of the heat pipe evaporator may be easily integrated in the dry type transformer manufacturing process and may result in cost savings also for manufacturing the heat pipe evaporator since only at least two spacers may be needed between the inner and outer concentric tubes by providing inner and outer concentric tubes with rigid material such as glass fibre reinforced epoxy or any rigid and insulating material with thermal expansion coefficient close to the one of epoxy.

**[0024]** According to another embodiment of the invention, the heat pipe evaporator comprises an inner concentric tube with a first diameter and comprises an outer concentric tube with a second diameter, wherein the inner concentric tube features a surface structure to strengthen the heat pipe evaporator and to reduce working fluid volume. The inner concentric tube may comprise spacers spaced apart from each other to create the cavity of the heat pipe evaporator when the outer concentric tube is attached to such spacers. The spacers may be spaced apart from each other by a first distance in a circumferential direction of the inner concentric tube.

**[0025]** According to another embodiment of the invention the step of pre-fabricating the heat pipe evaporator comprises the step of attaching a liquid return tube to the cavity of the heat pipe evaporator, the liquid return tube being adapted to enable a separate liquid return flow of a coolant in a direction from an condensor to a bottom part of the cavity.

**[0026]** The liquid may flow from any part within the tube to a lower located part within the tube. The liquid return tube may be adapted to enable a separate liquid return flow of a coolant from the heat pipe condenser to a bottom part of the cavity, wherein the tube inlet is at the condenser and the tube outlet is at the bottom part of the cavity. The heat pipe evaporator may be pre-fabricated including a polytetrafluorethylene (PTFE) liquid return tubing attached to the inner cavity of the hollow cylinder. The PTFE tubing enables a separate liquid return flow of the coolant from the heat pipe condenser, while the coolant vapour ascends through a second pipe attached to the evaporator top outlet after manufacturing of the high voltage coil. The PTFE tube is attached to the inner cavity of the hollow cylinder such that the tube outlet is at the bottom of the cavity, enabling the liquid to flow to the very bottom of the cavity.

**[0027]** Such a flow separation of coolant liquid and vapour may improve the performance of the heat pipe by preventing the two phases from blocking each other which is the case when they flow through the same tube.

**[0028]** According to another embodiment of the invention the method further comprises the step of closing a top gap and a bottom gap of the heat pipe evaporator at a top end and at a bottom end of the heat pipe evaporator by arranging a top sealing ring in the top gap and by arranging a bottom sealing ring in the bottom gap.

**[0029]** By closing the top gap and the bottom gap between the outer and the inner tube of the heat pipe evaporator a tight and sealed heat pipe evaporator may be provided enabling an optimal heat exchange from the high voltage coil and the low voltage coil of the transformer to the evaporator and thus to a heat pipe since no liquid or vapour of the working fluid of the evaporator may escape the heat pipe evaporator within a heat pipe cycle.

**[0030]** According to another embodiment of the invention, the step of closing the top and bottom gaps by the top and bottom sealing rings may happen before the placement of the at least one low voltage coil.

**[0031]** According to a further embodiment of the invention, the top and bottom sealing rings have a wedge-like cross-sectional shape to facilitate attaching (gluing) the sealing rings in the gaps between the two tubes of the heat pipe evaporator. This may ensure more efficiently the tightness and the sealing of the heat pipe evaporator, since the contact area between the sealing rings and the gaps may be enlarged.

**[0032]** According to another embodiment of the invention, the top gap and the bottom gap may have a form matching the form of the top and bottom sealing rings in order to provide a large contact area with the sealing rings.

**[0033]** The top and bottom gaps may have a radial distance smaller than the radial thickness of the cavity.

**[0034]** According to another embodiment of the invention, the inner concentric tube may have a circumferential protrusion in a radial direction at the top end and at the bottom end of the evaporator with a protrusion length in the radial direction which equals the thickness of the cavity such that no sealing rings are needed to tighten or to seal the heat pipe evaporator since the outer concentric tube may be attached to the inner concentric tube and to these protrusions and thus effectively seal the cavity.

**[0035]** The spacers may be glued to the inner concentric tube or may be integrated in the manufacturing of the inner concentric tube, such as by removing cavities between the spacers from a one piece inner concentric tube during the manufacturing process of the inner concentric tube.

**[0036]** According to another embodiment of the invention, the method further comprises the step of adding a reinforcement material to the wound at least one high voltage coil.

**[0037]** By adding such a reinforcement material the wound high voltage coil may be mechanically stabilized. A sealed evaporator may be provided enabling an optimal heat exchange from the coil and the transformer within the heat pipe since no liquid or vapour may escape the heat pipe evaporator within the heat pipe cycle.

**[0038]** According to another embodiment of the invention, the reinforcement material is selected from the group consisting of glass fibre nets or rigid foils,

**[0039]** According to another embodiment of the invention, the method further comprises the step of casting the at least one high voltage coil and the heat pipe evaporator such that a casted high voltage coil evaporator unit is formed.

**[0040]** The heat pipe evaporator and the wound high voltage coil may gain mechanical stability by the casting, an effective electrical insulation may be provided between the high voltage coil and the low voltage coil, and the heat pipe evaporator may be sealed since no vapour or fluid may escape the heat pipe evaporator.

**[0041]** According to another embodiment of the invention, the casting material is selected from the group of epoxies.

**[0042]** According to another embodiment of the invention, the method further comprises the step of attaching a heat pipe condenser to the heat pipe evaporator to form a dry type transformer with a heat pipe.

**[0043]** Such a method may provide for an easy and efficient manufacturing and installation of a heat pipe to a dry type transformer, wherein the heat pipe may efficiently cool the transformer since the heat of the high voltage and low voltage coils of the transformer may be removed in an optimized way to the evaporator since at least the surface of the high voltage coil is in direct contact with the heat pipe evaporator.

**[0044]** According to another embodiment of the invention the heat pipe condenser is detachably attached to the heat pipe evaporator via a flange or flanges such as KF-type flanges.

**[0045]** Such a detachable connection for the heat pipe condenser to the heat pipe evaporator via flanges may provide for a simple and efficient attachment and de-attachment of the heat pipe condenser to the heat pipe evaporator, for example when the heat pipe condenser needs to be exchanged.

**[0046]** According to another embodiment of the invention, the method further comprises the step of connecting the heat pipe evaporator to a heat pipe condenser via a heat pipe connector.

**[0047]** The heat pipe connector may be formed as a half-moon shaped connector and may comprise epoxy. The heat pipe evaporator may be attached to the heat pipe connector such that the working fluid of the evaporator may easily exit the evaporator and move towards the connector and from there to a condenser of the heat pipe.

**[0048]** By connecting the heat pipe evaporator to a heat pipe condenser via a heat pipe connector, different sized heat pipe evaporators and condensers may be easily connected via the interface of the heat pipe connector which may be adapted to different size connections of the heat pipe evaporator and the heat pipe condenser.

**[0049]** According to another embodiment of the invention, the step of connecting the heat pipe evaporator to the heat pipe connector comprises attaching a connector base of the condenser connected to a top gap or a bottom gap of the heat pipe evaporator, wherein the connector base comprises a connector gap matching the top and the bottom gaps, attaching a connector cap with a through-hole to the connector base, and attaching a connector insulating tube to the connector cap through the through-hole.

**[0050]** Alternatively, the connector consists of one single piece attached to the hollow cylinder before or after casting.

**[0051]** A silicon cap may be provided between the connector and the casting mould in order to prevent the epoxy from flowing into the cavity during casting.

**[0052]** By connecting the heat pipe evaporator to the heat pipe connector by the above-mentioned steps, a quick and efficient attaching of the heat pipe evaporator to a condenser may be achieved with a sealed connection of the heat pipe evaporator and the heat pipe condenser as well as an adaptive method of connecting different sized heat pipe evaporators with different sized heat pipe condensers.

**[0053]** According to another embodiment of the invention, the at least one high voltage coil comprises disk windings.

**[0054]** Such disks winding may be easily and efficiently wound onto the heat pipe evaporator. Since a high voltage coil of a transformer produces most of the heat of a transformer, the winding of the high voltage coil by winding discs to the heat pipe evaporator may advantageously provide for an efficient removing of heat from the transformer from the place where most of the heat of the transformer is produced during operation.

**[0055]** By providing disk windings instead of wire, the contact area between the wound high voltage disks and the heat pipe evaporator may be enlarged, thus providing for a larger contact area and thus for a better heat removal from the high voltage coil by the heat pipe evaporator.

**[0056]** According to another embodiment of the invention, the heat pipe evaporator comprises an evaporator material similar to the high voltage coil material and with a similar thermal conductivity and thermal expansion coefficient, wherein the evaporator material is selected from the group comprising an epoxy, glass fibres, and a glass reinforced plastic or any other insulation material with similar thermal properties.

**[0057]** The thermal conductivity of the evaporator material and the coil material may range from 0,1-2,0 W/K/m.

**[0058]** By providing a high voltage coil material and an evaporator material with similar thermal expansion coefficients the stresses due to thermal expansions during the operation of the dry type transformer may be minimized. The evaporator material may be similar to the low voltage coil material with respect to the thermal expansion.

**[0059]** The evaporator material is electrically insulating, and thus providing for an optimal direct dielectric insulation of the high voltage coil from the low voltage coil.

**[0060]** According to another aspect of the invention, a dry type transformer manufactured by the method of any of the preceding aspects or exemplary embodiments of the invention is provided.

**[0061]** Such a dry type transformer may be operated with a higher power rating as dry type transformer without a heat pipe evaporator, or a small transformer may be used for a certain required power. Both options result in material and cost saving. Such a dry type transformer with heat pipe evaporators may increase the transformer loading capacity, may reduce the size of a transformer, and may improve the fire safety of the dry type transformer.

**[0062]** According to another aspect of the invention, the use of a dry type transformer manufactured by the method of any of the preceding aspects or exemplary embodiments for a wind energy plant with a housing comprising the dry type transformer is provided. A heat pipe of the dry type transformer may comprise a condenser placed outside the housing which is cooled by wind.

**[0063]** By utilizing such a heat pipe cooled dry type transformer for a wind energy plant, the fire protection regulations of such a wind energy plant may be fulfilled, since such heat pipe cooled dry type transformer may have a high fire protection level compared to other transformers of comparable power density without such type of cooling. Such a dry type transformer with a heat pipe evaporator providing for a high fire protection level may be manufactured in a small and compact size fitting in the limited space of the housing of the wind energy plant.

**[0064]** According to another aspect of the invention, the use of a dry type transformer manufactured by the method of any of the preceding aspects or exemplary embodiments for any application in which space is limited or material cost should be reduced, is provided. The application may be an application selected from the group comprising a transportation means, a ship, a train, an aircraft, a vehicle, and a truck.

**[0065]** The step of attaching in the above and the below mentioned aspects and embodiments of the invention may comprise gluing, milling, smoothing with sandpaper, cleaning or other mechanical steps.

**[0066]** These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0067]** Below, embodiments of the present invention are described in more detail with reference to the attached drawings.

Fig. 1 schematically shows a perspective view of part of a dry type transformer with a heat pipe evaporator according to an embodiment of the invention.

Fig. 2 schematically shows a cross-sectional view of part of a dry type transformer coil with a heat pipe evaporator according to another embodiment of the invention.

Fig. 3 schematically shows a perspective view of a heat pipe evaporator with a heat pipe connector according to another embodiment of the invention.

Fig. 4 schematically shows a perspective view of an inner concentric tube of a heat pipe evaporator for a dry type transformer according to another embodiment of the invention.

Fig. 5 schematically shows a perspective view of parts of a heat pipe connector and a part of the heat pipe evaporator for a dry type transformer according to another embodiment of the invention.

Fig. 6 schematically shows a cross-sectional side view of part of a transformer coil with a heat pipe evaporator according to another embodiment of the invention.

Fig. 7 schematically shows a cross-sectional top view of the dry type transformer coil inside the casting mold with the heat pipe evaporator of Fig. 6.

Fig. 8 schematically shows a perspective view of part of a dry type transformer coil according to another embodiment of the invention.

Fig. 9 schematically shows a perspective view of part of a dry type transformer coil according to another embodiment of the invention.

Fig. 10 schematically shows a flow chart of a method of manufacturing a dry type transformer with a heat pipe evaporator.

Fig. 11 schematically shows a flow chart of a method of connecting a heat pipe evaporator of a transformer to a heat pipe connector according to another embodiment of the invention.

Fig. 12 schematically shows a cross-sectional view of a dry type transformer manufactured by the method of the invention according to another embodiment of the invention.

Fig. 13 schematically shows a cross-sectional view of a wind energy plant with the dry type transformer of Fig. 12 according to another embodiment of the invention.

Fig. 14 schematically shows a cross-sectional view of a ship with the dry type transformer of Fig. 12 according to another embodiment of the invention.

Fig. 15 schematically shows a cross-sectional view of a train with the dry type transformer of Fig. 12 according to another embodiment of the invention.

**[0068]** The reference symbols used in the drawings, and their meanings, are listed in summary form in a list of reference symbols. In principle, identical parts are provided with the same reference symbols in the figures.

## DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

**[0069]** Fig. 1 shows a part of a dry type transformer with a limb 114, a low voltage coil 113 arranged around the limb 114, a hollow cylindrical heat pipe evaporator 101 arranged around the low voltage coil 113, and a high voltage coil 112, 120 wound onto the heat pipe evaporator 101 around a longitudinal axis 110 of the heat pipe evaporator 101. The heat pipe evaporator 101 has the form of a hollow ring shaped cylinder 102 with a cavity 103 which has a radial thickness 222 which may be proportional to the amount of heat needed to be removed from the high voltage coil 112, 120 of the dry type transformer to a heat pipe. The cavity 103 of the heat pipe evaporator 101 may have a radial thickness 222 of at least 2 mm.

**[0070]** The low voltage coil 113 is placed such that the heat pipe evaporator 101 is positioned between the high voltage coil 112, 120 and the low voltage coil 113. The heat pipe evaporator 101 is arranged such in a thermally conducting contact with the high voltage coil 112, 120 to remove heat from the high voltage coil 112, 120 and from the low voltage coil 113, and is made of dielectric material to dielectrically insulate the high voltage coil 112, 120 from the low voltage coil 113. The dry type transformer may be a dry type transformer with a voltage ranging from 1 kV - 75 kV.

**[0071]** Fig. 2 schematically shows a cross-sectional view of a high voltage coil 112, 120 wound onto a heat pipe evaporator 101 of a dry type transformer. The heat pipe evaporator length 220 in a direction 107 of the rotational axis 110 of the heat pipe evaporator equals a high voltage coil length 221 in this direction 107. The high voltage coil 112, 120 may comprise disk windings. As shown in Fig. 1 the cavity 103 of the heat pipe evaporator 101 has a determined radial thickness 222 of at least 2 mm which may be proportional to the amount of heat needed to be removed from the high voltage coil 112, 120 of the dry type transformer to a condenser of a heat pipe. The heat pipe evaporator 101 comprises an inner concentric tube 201 with a first diameter 203 and comprises an outer concentric tube 202 with a second diameter 204 which is larger than the first diameter 203. The inner concentric tube 201 features a surface structure to strengthen the heat pipe evaporator 101 and to reduce the working fluid volume of the heat pipe evaporator 101. The inner concentric tube 201 may comprise spacers spaced apart from each other to create the cavity 103 of the heat pipe evaporator. The high voltage coil 112, 120 is wound onto the outer concentric tube 202, wherein a low voltage coil may be arranged on the inner concentric tube 201.

**[0072]** A top gap 210 and a bottom gap 211 of the heat pipe evaporator 101 at a top end 213 and at a bottom end 214 of the heat pipe evaporator 101 may be closed by arranging a top sealing ring 215 in the top gap 210 and by arranging a bottom sealing ring 216 in the bottom gap 211. The top and bottom sealing rings 215, 216 have a wedge-like cross-sectional shape to facilitate attaching or gluing the rings 215, 216 in between the two tubes 201, 202 of the heat pipe evaporator 101 which is required in order to ensure the tightness and the sealing of the heat pipe evaporator by providing a large contact area of the gaps 210, 211 with the sealing rings 215, 216. According to another embodiment of the invention, the top and bottom gaps 210, 211 may have a radial distance smaller than a radial thickness 222 of the cavity 103. The sealing rings 215, 216 may be omitted by providing the inner concentric tube 201 with protrusions extending radially towards the longitudinal axis 110 at the top and bottom ends 213, 214 of the heat pipe evaporator 101 with a radial length similar to the radial thickness 222 such that the heat pipe evaporator 101 may be sealed tight when the outer concentric tube 202 is attached to the inner concentric tube 201. The high voltage coil 112, 120 and the heat pipe evaporator 101 are casted by an epoxy, such that a casted high voltage coil evaporator unit 230 is formed. A low voltage coil which may be arranged within the inner concentric tube 201 of the heat pipe evaporator may also be casted such that a casted high voltage coil and low voltage coil evaporator unit may be formed.

**[0073]** Fig. 3 schematically shows a heat pipe evaporator 101 in form of a hollow cylinder 102 with an inner concentric tube 201 and an outer concentric tube 202 attached to the inner concentric tube 201 forming a cavity 103 between the inner concentric tube 201 and the outer concentric tube 202. A top gap 210 is closed by arranging a top sealing ring 215 in the top gap 210 at a top end 213 of the heat pipe evaporator and a bottom gap (not shown, see Fig. 2) is closed by arranging a bottom sealing ring 216 at a bottom end 214 of the heat pipe evaporator. A connector 302 may be connected to the heat pipe evaporator 101 by attaching a connector base 304 of the connector 302 to the top gap 210 of the heat pipe evaporator 101. A connector cap 305 with a through-hole (not shown) may be attached to the connector base 304. A connector insulating tube 306 may be connected to the connector cap 305 through the through-hole (not shown, see Fig. 5).

**[0074]** Fig. 4 schematically shows a perspective view of an inner concentric tube 201 of the heat pipe evaporator (see Figs. 1 to 3) with spacers 401 spaced apart from each other by a first distance 402 in a circumferential direction 403 of the inner concentric tube 201 to create the cavity of the heat pipe evaporator, when an outer concentric tube is attached to the inner concentric tube 201.

**[0075]** Fig. 5 schematically shows a perspective view of a connector base 304 and a connector cap 305 of a connector 302 before a connection to a part of the heat pipe evaporator in form of a hollow cylinder 102 with an inner concentric tube 201 and an outer concentric tube 202 forming an upper gap 210 of a heat pipe evaporator cavity. The connector base 304 may be attached to the top gap 210 of the heat pipe evaporator, wherein the connector base 304 comprises the connector gap 501 matching the top gap 210. The connector base 304 may also be connected to a bottom gap of the heat pipe evaporator (not shown). The connector cap 305 with a through-hole 502 may be attached to the connector base 304. A connector insulating tube (not shown) may be attached to the connector cap 305 through the through-hole 502.

**[0076]** Fig. 6 schematically shows a cross-sectional view of a heat pipe evaporator 101 in form of a hollow cylinder of part of a dry type transformer with high voltage disk windings 604 of a high voltage coil wound on an outer concentric tube of the heat pipe evaporator 101. The heat pipe evaporator 101 is closed at its ends at a top and a bottom end by a top sealing ring 215 and by a bottom sealing ring 216, wherein a heat pipe connector 302 is connected to the heat pipe evaporator at the top end. The heat pipe evaporator 101 with thereto wound high voltage disk windings 604 is casted by a casting mould 602. The casting mould 602 may be a metallic material such as steel.

**[0077]** A silicon cap 601 may be provided between the connector 302 and the casting mould 602 in order to prevent the epoxy from flowing into the hollow cylinder cavity during casting. An abutment 603 or a radial space holder is arranged between the casting mould 602 and the bottom sealing ring 216 in order to squeeze the silicon cap 601 at the connector 302 at the top end of the heat pipe evaporator 101. The heat pipe evaporator 101 may be arranged over a winding mandrel 606 before the winding of the high voltage coil in form of a high voltage disk 604 takes place.

**[0078]** Fig. 7 schematically shows a cross-sectional top view of the casted high voltage coil with the heat pipe evaporator of the dry type transformer according to Fig. 6. A casting mould 602 is casted to the heat pipe evaporator 101 and the thereto wound high voltage coil with the high voltage disk windings 604 to a casted high voltage coil evaporator unit 230. The outer diameter 609 of the casted high voltage coil evaporator unit 230 may have a length of 700 mm, depending on the rating of the transformer. The inner diameter 608 of the casted high voltage coil evaporator unit 230 may have a length of 550 mm, depending on the rating of the transformer. The longitudinal axis 110 of the heat pipe evaporator 101 is arranged in the middle of the casted high voltage coil evaporator unit 230 in a direction 107. The casted high voltage coil evaporator unit 230 comprises a horizontal axis 607 and a vertical axis 608 located perpendicular to each other and both located perpendicular to the longitudinal axis 110. The casted mould 602 protrudes over the casted high voltage coil evaporator unit 230 at one side in the direction of the vertical axis 608.

**[0079]** Fig. 8 schematically shows a perspective view of a high voltage coil 120 of a transformer. Spacers 311 are attached onto a coil surface 312 of the dry type transformer or onto a surface of a component (not shown, see component 224 of Fig. 9) such that the spacers 311 are spaced apart from each other. The spacers 311 may be spaced apart by a first distance 313 in a circumferential direction 314 of the high voltage coil 120. The spacers 311 may be attached onto the coil surface 312 in such a way that the spacers 311 are spaced apart from each other at a connection region 318 of a cavity of a heat pipe evaporator formed by the component and the coil surface 312 to be connected to a heat pipe connector by a second distance 316 in an axial direction 107 parallel to the longitudinal axis 110 of the heat pipe evaporator. The spacers 311 may be attached onto the coil surface 312 in such a way that the spacers 311 are spaced apart by the second distance 316 in the axial direction 107 parallel to the longitudinal axis 110 only at the connection region 318 or along the whole longitudinal length of the coil surface 312. The second distance 316 may range from 4-5 cm, and the first distance 313 may range from 4-5 cm. The spacers 311 may have a width of 8 mm - 10 mm in the circumferential direction 314.

**[0080]** The spacers 311 may not be spaced apart in the longitudinal direction 107 but form longitudinal stripes according to an embodiment of the invention.

**[0081]** The component (see Fig. 9) may be attached onto the spacers 311 or the component with thereto attached spacers 311 may be attached onto the coil surface 312 to create a cavity (not shown) adapted to act as the heat pipe evaporator with a first wall formed by the coil surface 312 and a second wall formed by the component such that the evaporator is in direct thermal contact with the coil surface 312.

**[0082]** The term attaching may be designated as gluing. The spacers 311 may be epoxy stripes ensuring the formation of a hollow volume after closing the evaporator. The component 224 may be a rigid epoxy foil attached to the spacers 311 to create a rigid inner wall of the evaporator which is able to withstand the evacuation of the system before operation. The outer wall of the evaporator may be formed by the inner border of the high voltage coil 120 providing for an optimal thermal contact since there is no additional material placed between the inside of the evaporator and the high voltage coil 120. The cavity length in a direction 107 of the longitudinal axis of the coil may equal a coil length in the direction of the longitudinal axis 107.

**[0083]** Fig. 9 schematically shows the high voltage coil 120 for a dry type transformer of Fig. 12 wherein the component 224 is already attached to the spacers of the coil surface, and a lower gap and an upper gap between the component 224 and a coil surface is closed with pre-impregnated fibres (PRE-PREG) which may comprise layers of epoxy soaked glass fibres. The pre-impregnated fibres may take the form of a weave or may be unidirectional and contain an amount of matrix material used to bond them together and to other components during manufacture. By closing the lower and upper gap between the component 224 and the coil an optimal heat exchange may be enabled since a working fluid of the evaporator may be guided to a heat pipe condenser of a heat pipe with no fluid escaping the heat pipe exchange cycle due to the closed lower and upper gap.

**[0084]** The component 224 may be enforced by adding further PRE-PREG to the component 224 such that the component 224 gains mechanical stability and may be sealed by PRE-PREG to hinder the escape of the working fluid of the heat pipe evaporator. The heat pipe evaporator may be connected to a heat pipe connector 302 with an insulating tube 306 leading to a heat pipe condenser where a vapour of the evaporator working fluid may be condensed. A heat resistant sealing material such as araldite may be added to the component and the closed upper and lower gaps for further sealing the heat pipe evaporator. Thus, a sealed evaporator may be provided enabling an optimal heat exchange from the coil of the transformer within the heat pipes since no liquid or vapour may escape the heat pipe evaporator within the heat pipe cycle. The heat pipe evaporator may be located between the high voltage coil and a low voltage coil. The evaporator may be exposed to thermal radiation from the low voltage coil, and may move heat from the high voltage coil and via the component 224 from the low voltage coil of the transformer to the heat pipe.

**[0085]** Referring to Figs. 8 and 9 a method of manufacturing a dry type transformer may be provided, the dry transformer comprising a heat pipe evaporator, with the steps of attaching spacers onto a coil surface of the dry type transformer or onto a surface of a component such that the spacers are spaced apart from each other, attaching the component onto the spacers or attaching the component with thereto attached spacers onto the coil surface to create a cavity adapted to act as the heat pipe evaporator with a first wall formed by the coil surface and a second wall formed by the component such that the evaporator is in direct thermal contact with the coil surface. The method may further comprise the step of closing a lower gap and an upper gap between the component and the coil surface with pre-impregnated fibres. According to an aspect of the invention, the method may further comprise enforcing the component by adding pre-impregnated fibres to the component, and according to a further embodiment of the invention the method may comprise adding a heat resistant sealing material to the component and the closed upper and lower gaps for sealing the heat pipe evaporator. Furthermore, the method may comprise the step of attaching a heat pipe condenser to the heat pipe evaporator forming a heat pipe. The step of attaching may comprise connecting the heat pipe evaporator, and in particular the cavity of the heat pipe evaporator, to a heat pipe connector, and connecting the heat pipe connector to the heat pipe condenser.

**[0086]** Fig. 10 schematically shows a flow-chart of a method 800 of manufacturing a dry type transformer with a heat pipe evaporator, at least one high voltage coil, at least one low voltage coil, and a core with at least one limb, the method comprising: providing 801 a hollow cylindrical heat pipe evaporator, winding 802 a high voltage coil onto the heat pipe evaporator around a longitudinal axis of the heat pipe evaporator, placing 803 a low voltage coil such that the heat pipe evaporator is positioned between the high voltage coil and the low voltage coil, wherein the heat pipe evaporator is designed to remove heat from the high voltage coil and from the low voltage coil, and is designed to dielectrically insulate the high voltage coil from the low voltage coil. The method further comprises the step of arranging 804 the heat pipe evaporator over a winding mandrel before the winding of the high voltage coil, arranging 805 the low voltage coil on an inner concentric tube of the heat pipe evaporator, wherein the high voltage coil is wound to an outer concentric tube of the evaporator, and arranging 806 the low voltage coil and the high voltage coil around the at least one limb. A further step of the method is pre-fabricating 807 the heat pipe evaporator with the steps of manufacturing an inner concentric tube with spacers which are attached to the inner concentric tube and spaced apart from each other, manufacturing an outer concentric tube, and attaching the outer concentric tube onto the spacers of the inner concentric tube such that a cavity is provided between the outer concentric tube and the inner concentric tube, the cavity acting as the heat pipe evaporator. A further step of the method is closing 808 a top gap and a bottom gap of the heat pipe evaporator at a top end and at a bottom end of the heat pipe evaporator by arranging a top sealing ring in the top gap and by arranging a bottom sealing ring in the bottom gap. After that the step of adding 809 a reinforcement material to the wound high voltage coil is performed. Further steps of the method are casting 810 the high voltage coil and the heat pipe evaporator such that a casted high voltage coil evaporate unit is formed, attaching 811 a heat pipe condenser to the heat pipe evaporator to form a dry type transformer with a heat pipe, and connecting 812 the heat pipe evaporator to a heat pipe condenser via a heat pipe connector.

**[0087]** Fig. 11 schematically shows a flow-chart of a method of connecting 812 the heat pipe evaporator to the heat pipe connector, comprising the steps of attaching 901 a connector base of the connector to a top gap or a bottom gap of the heat pipe evaporator, wherein the connector base comprises a connector gap matching the top and the bottom gaps, attaching 902 a connector cap with a through-hole to the connector base, and attaching 903 a connector insulating tube to the connector cap through the through-hole.

**[0088]** Fig. 12 schematically shows a dry type transformer 1000 with three coils 120, the dry type transformer 1000 comprising a heat pipe evaporator and manufactured by the method of Fig. 10 or by the method of any of the before-mentioned aspects and embodiments of the invention. A condenser which may be mounted on top of the transformer is not shown.

**[0089]** Fig. 13 schematically shows a cross-sectional view of a wind energy plant 1100 with a housing 1101 comprising the dry type transformer 1000 of Fig. 12, wherein the heat pipe of the transformer 1000 comprises a condenser 1102 which is placed outside the housing (1101) and cooled by wind.

**[0090]** Fig. 14 schematically shows a ship 1200 having the dry type transformer 1000 of Fig. 12, wherein a heat pipe of the transformer 1000 comprises a condenser 1102 which is thermally coupled to a wall or a floor of the ship 1200.

**[0091]** Fig. 15 schematically shows a train 1300 having the dry type transformer 1000 of Fig. 12, wherein a heat pipe of the transformer 1000 comprises a condenser 1102 which is arranged at the train 1300 such that a cooling of the condenser 1102 by train airflow is provided.

**[0092]** While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art in practising the claimed invention, from a study of the drawings, the disclosure, and the appended claims.

**[0093]** In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures can not be used to advantage. Any reference symbols in the claims should not be construed as limiting the scope.

LIST OF REFERENCE SYMBOLS

**[0094]**

| | |
|---|---|
| 101 | Heat pipe evaporator |
| 102 | Hollow cylinder |
| 103 | Cavity |
| 107 | direction |
| 110 | Longitudinal axis |
| 112 | High voltage coil |
| 113 | Low voltage coil |
| 114 | Limb |
| 120 | High voltage coil |
| 201 | Inner concentric tube |
| 202 | Outer concentric tube |
| 203 | First distance |
| 204 | Second distance |
| 210 | Top gap |
| 211 | Bottom gap |
| 213 | Top end |
| 214 | Bottom end |
| 215 | Top sealing ring |
| 216 | Bottom sealing ring |
| 220 | Heat pipe evaporator length |
| 221 | High voltage coil length |
| 222 | Radial cavity thickness |
| 224 | Component |
| 302 | Heat pipe connector |
| 304 | Connector base |
| 305 | Connector cap |
| 306 | Connector insulating tube |
| 313 | First distance |
| 316 | Second distance |
| 311 | Spacers |
| 312 | Coil surface |
| 318 | Connection region |
| 401 | Spacers (of inner concentric tube) |
| 402 | First distance (of inner concentric tube) |
| 403 | Circumferential direction (of inner concentric tube) |
| 501 | Connector gap |
| 502 | Through-hole |
| 601 | Silicon cap |
| 602 | Casting mould |
| 603 | Abutment |
| 604 | High voltage disk winding |
| 606 | Mandrel |
| 607 | Horizontal axis |
| 608 | Vertical axis |
| 608 | First diameter |
| 609 | Second diameter |
| 1000 | Dry type transformer |
| 1100 | Wind energy plant |
| 1101 | Housing |
| 1102 | Condenser |
| 1200 | Ship |
| 1300 | Train |

## Claims

1. Method of manufacturing a dry-type transformer (1000), the transformer (1000) comprising a heat pipe evaporator (101), at least one high voltage coil (112, 120), at least one low voltage coil (113), and a core with at least one limb (114), the method comprising:

    Providing (801) a hollow cylindrical heat pipe evaporator (101);
    Winding (802) the at least one high voltage coil (112, 120) onto the heat pipe evaporator (101) around a longitudinal axis (110) of the heat pipe evaporator (101);
    Placing (803) the at least one low voltage coil (113) such that the heat pipe evaporator (101) is positioned between the at least one high voltage coil (112, 120) and the at least one low voltage coil (113);
    wherein the heat pipe evaporator (101) is designed to remove heat from the at least one high voltage coil (112, 120) and from the at least one low voltage coil (113) and
    is adapted to dielectrically insulate the at least one high voltage coil (112, 120) from the at least one low voltage coil (113).

2. The method of claim 1, wherein the hollow cylindrical heat pipe evaporator (101) comprises an inner concentric tube (201) and an outer concentric tube (202) and the method further comprising the step of:

    Arranging (805) the at least one low voltage coil (113) on the inner concentric tube (201), wherein the at least one high voltage coil (112, 120) is wound onto the outer concentric tube (202).

3. The method of any of the preceding claims, further comprising:

    Arranging (806) the at least one low voltage coil (113) and the at least one high voltage coil around the at least one limb (114);

4. The method of any of the preceding claims, further comprising:

    Pre-fabricating (807) the heat pipe evaporator (101) comprising:

        Manufacturing an inner concentric tube (201) with spacers (401) which are attached to the inner concentric tube (201) and spaced apart from each other;
        Manufacturing an outer concentric tube (202);
        Attaching the outer concentric tube (202) onto the spacers (401) of the inner concentric tube (201) such that a cavity (103) is provided between the outer concentric tube (202) and the inner concentric tube (201), the cavity (103) acting as the heat pipe evaporator volume.

5. The method of any of the preceding claims,
Closing (808) a top gap (210) and a bottom gap (211) of the heat pipe evaporator (101) at a top end (213) and at a bottom end (214) of the heat pipe evaporator (101) by arranging a top sealing ring (215) in the top gap (210) and by arranging a bottom sealing ring (216) in the bottom gap (211).

6. The method of claim 1, further comprising:

    Adding (809) a reinforcement material to the wound at least one high voltage coil (112, 120) for mechanical stabilization.

7. The method of any of the preceding claims, further comprising:

    Casting (810) the at least one high voltage coil (112, 120) and the heat pipe evaporator (101) such that a casted high voltage coil evaporator unit is formed.

8. The method of any of the preceding claims, further comprising:

    Attaching (811) a heat pipe condenser to the heat pipe evaporator (101) to form a dry-type transformer (1000) with a heat pipe.

9. The method of claim 4 or of any of the claims 5 to 8 if referring back to claim 4, wherein the step of pre-fabricating (807) the heat pipe evaporator (101) comprises:

    attaching a liquid return tube to the cavity (103) of the heat pipe evaporator (101),
    the liquid return tube being adapted to enable a separate liquid return flow of a coolant in a direction from a condenser to a bottom part of the cavity (103).

10. The method of any of the preceding claims, further comprising:

    Connecting (812) the heat pipe evaporator (101) to a heat pipe condenser via a heat pipe connector (302).

11. The method of claim 10,
wherein connecting (812) the heat pipe evaporator (101) to the heat pipe connector (302) comprises:

Attaching (901) a connector base (304) of the connector (302) to a top gap (210) or a bottom gap (211) of the heat pipe evaporator (101); wherein the connector base (304) comprises a connector gap (501) matching the top and the bottom gaps (210, 211);
Attaching (902) a connector cap (305) with a through hole (502) to the connector base (304); and
Attaching (903) a connector insulating tube (306) to the connector cap (305) through the through hole (502).

**12.** The method of any of the preceding claims, wherein the at least one high voltage coil (112, 120) comprises disk windings (604).

**13.** The method of any of the preceding claims, wherein the heat pipe evaporator (101) comprises an evaporator material similar to the high voltage coil insulation material and with a similar thermal conductivity and thermal expansion coefficient, wherein the evaporator material is selected from the group comprising an epoxy, glass fibres, and a glass-reinforced plastic.

**14.** Dry-type transformer (1000) manufactured by the method of any of claims 1 to 13.

**15.** Use of dry transformer (1000) manufactured by the method of any of claims 1 to 13 for a wind energy plant (1100) with a housing (1101) comprising the dry transformer (1000),
wherein a heat pipe of the transformer (1000) comprises a condenser (1102) which is placed outside the housing (1101) and cooled by wind.

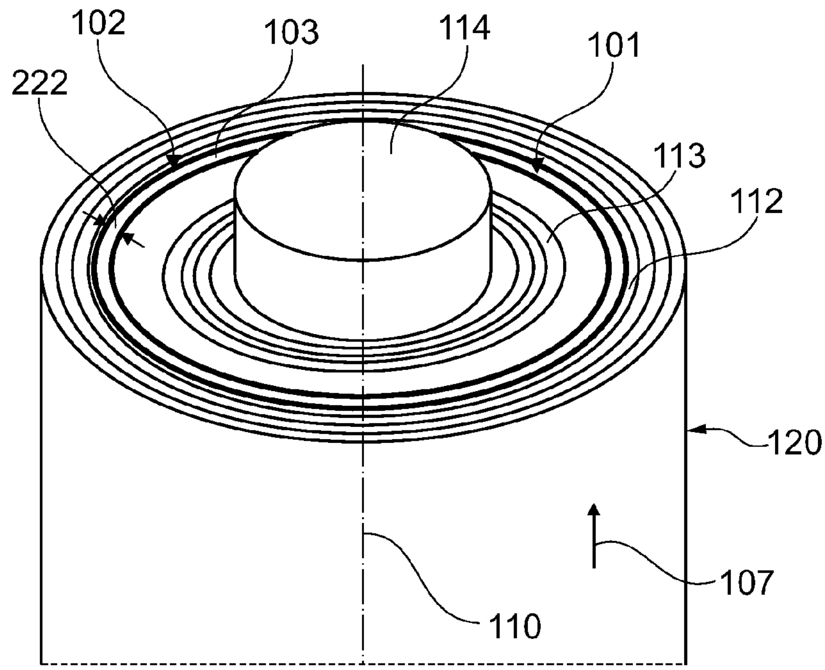
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Fig. 1

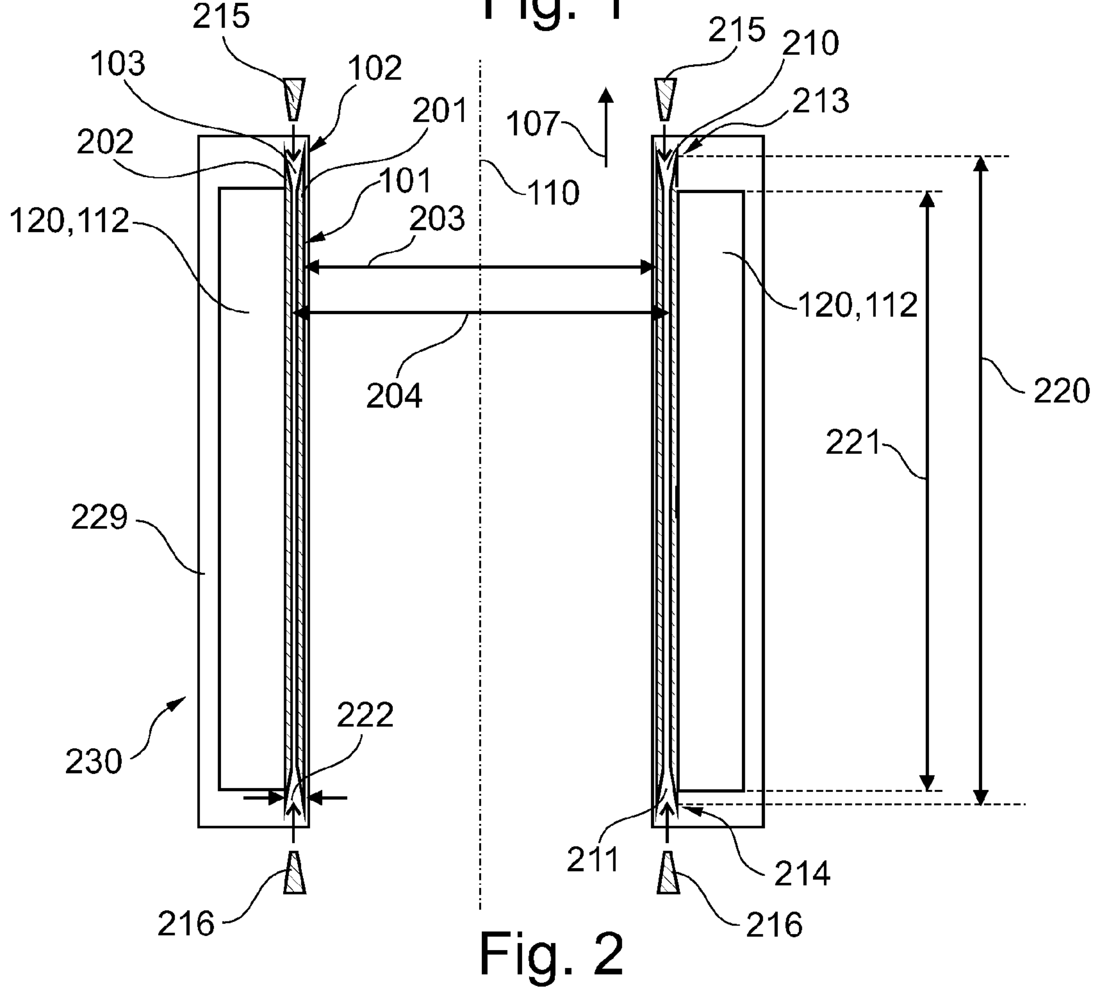
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Fig. 2

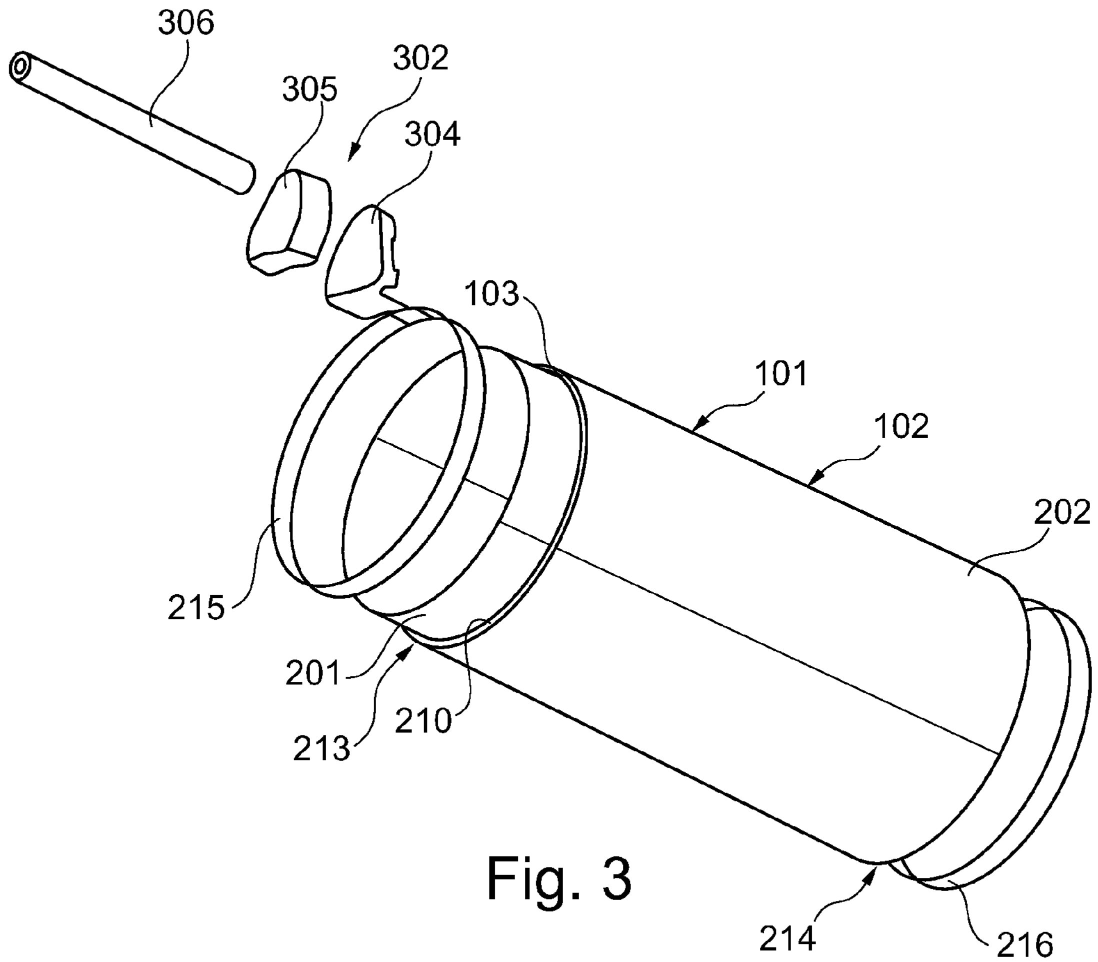
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Fig. 3

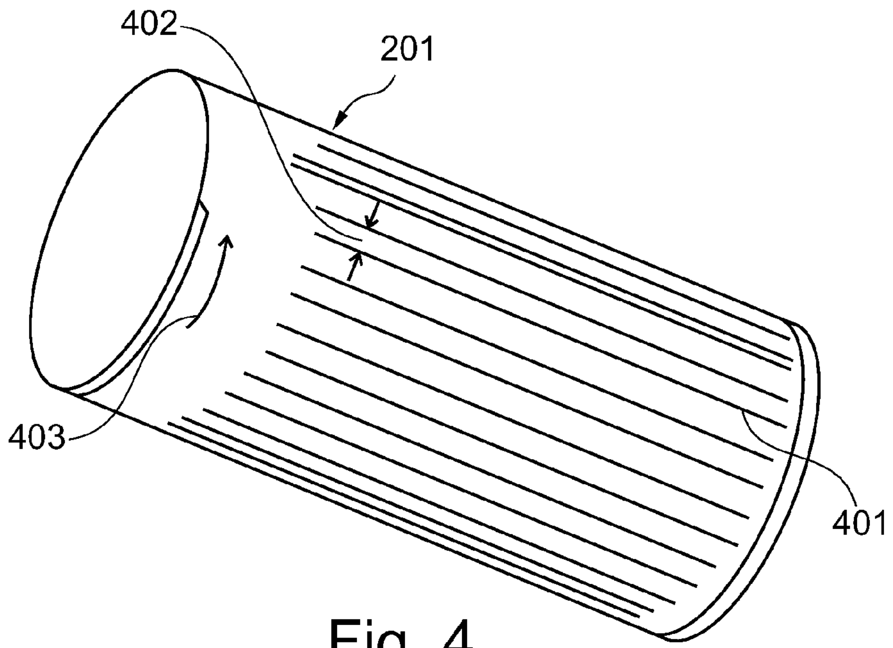
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Fig. 4

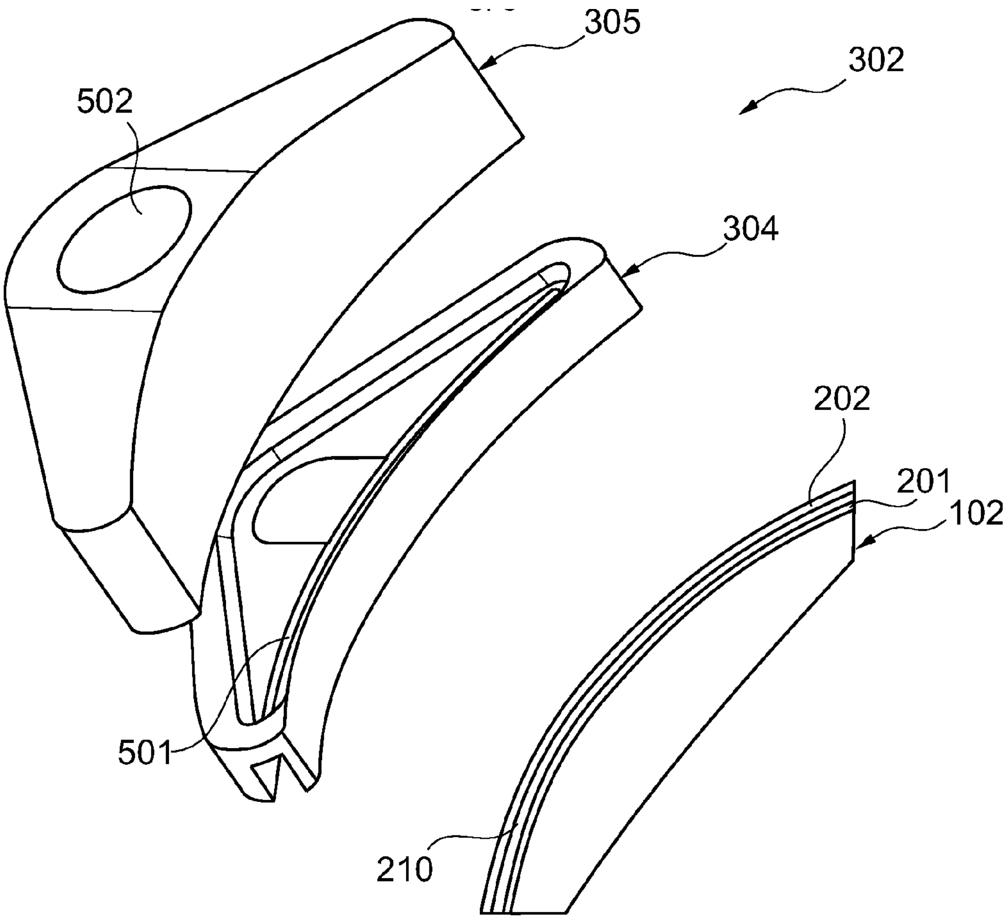
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Fig. 5

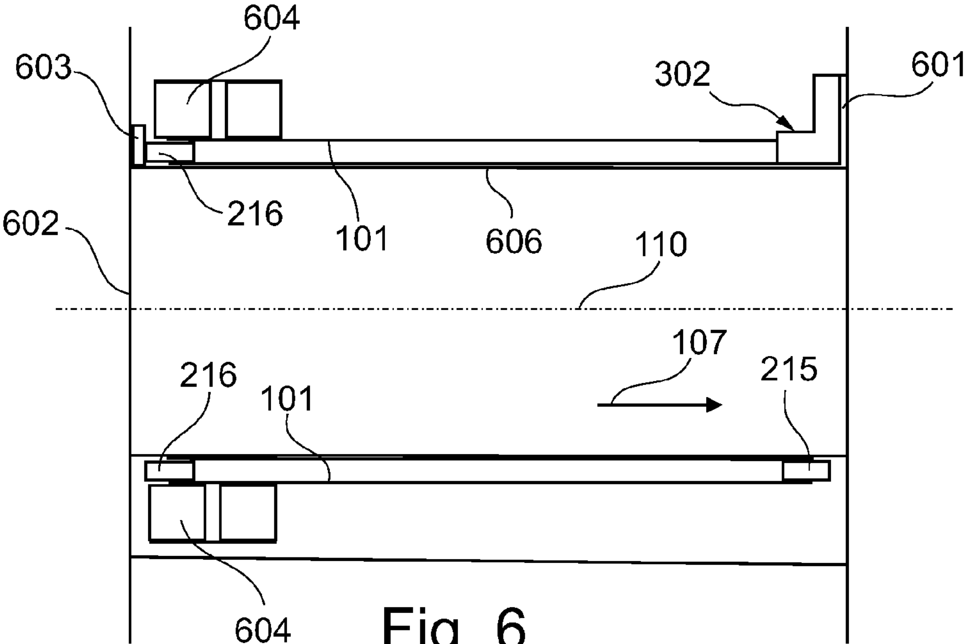
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Fig. 6

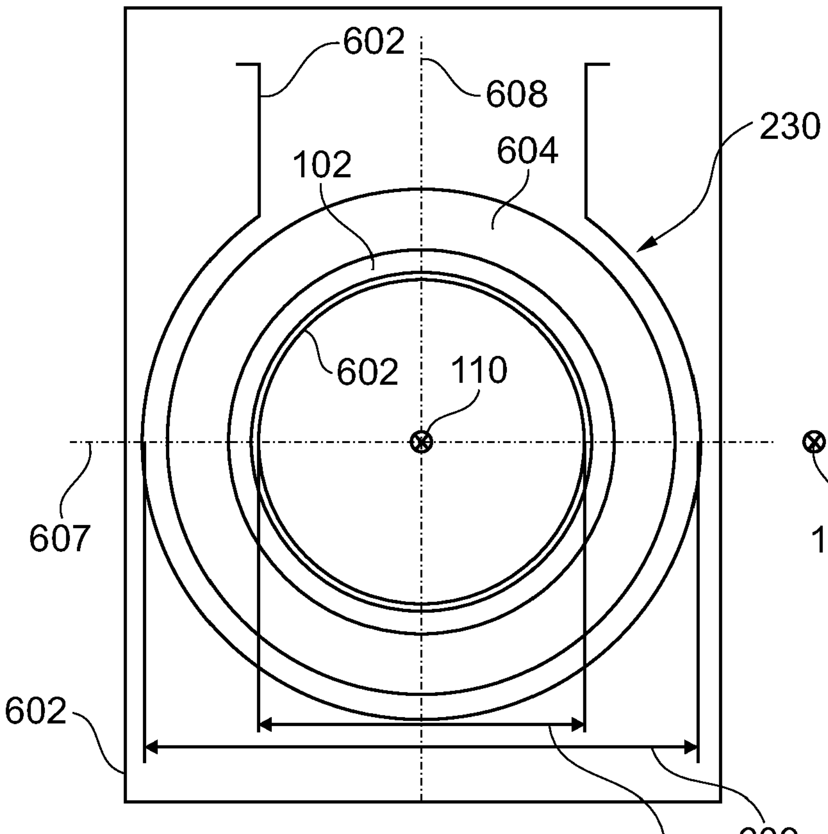



Fig. 7

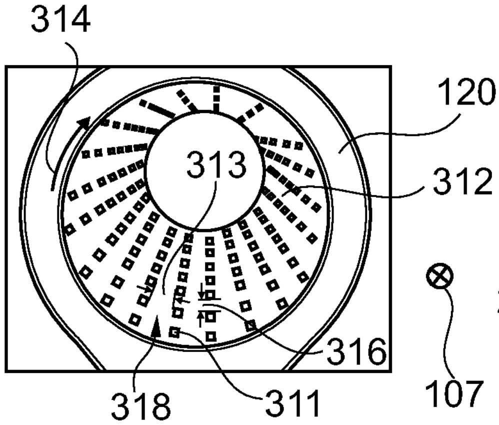



Fig. 8

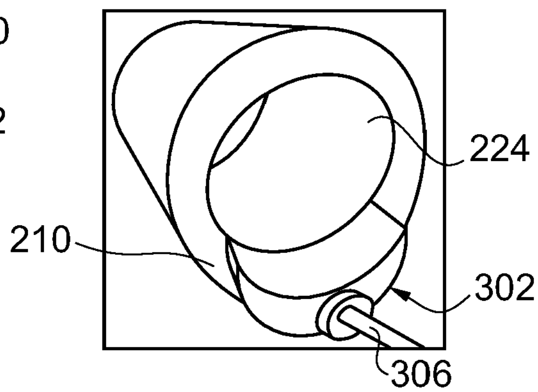
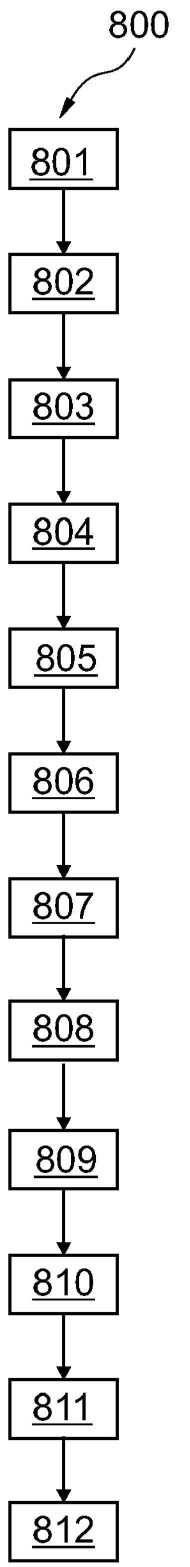



Fig. 9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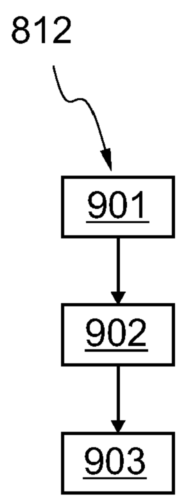
812

Fig. 10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901
902
903

Fig. 11

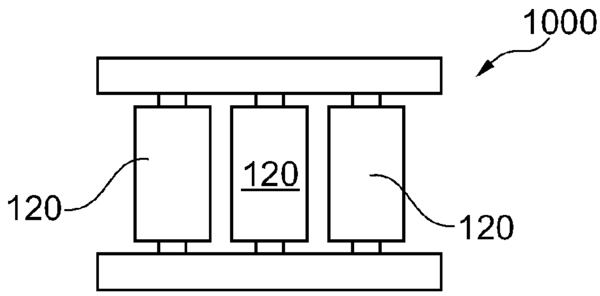


Fig. 12

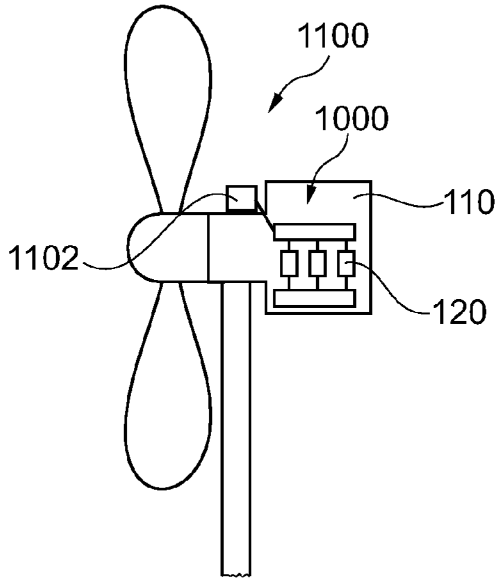


Fig. 13

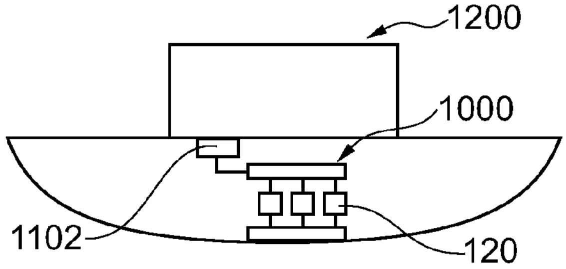


Fig. 14

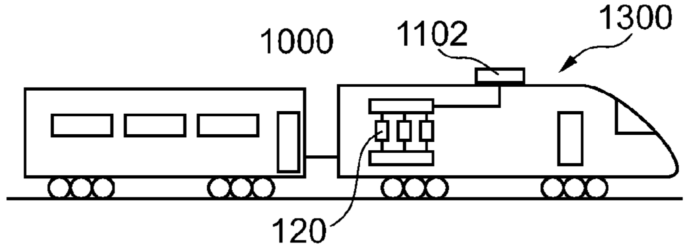


Fig. 15

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# EUROPEAN SEARCH REPORT

Application Number
EP 10 19 4530

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC) |
|---|---|---|---|
| X | WO 2010/139597 A1 (ABB TECHNOLOGY AG [CH]; CHARTOUNI DANIEL [CH]; MURILLO RAFAEL [ES]; BU) 9 December 2010 (2010-12-09)<br>* page 9, line 17 - page 14, line 26 *<br>----- | 1-15 | INV.<br>H01F27/02<br>H01F27/18<br>H01F27/28<br>H01F27/32 |
| A | US 6 368 530 B1 (ADUBATO JOHN D [US] ET AL) 9 April 2002 (2002-04-09)<br>* column 4, lines 5-19 *<br>* column 5, line 55 - column 6, line 4 *<br>----- | 1,4 | |
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TECHNICAL FIELDS SEARCHED (IPC)

H01F

The present search report has been drawn up for all claims

3

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| Munich | 26 April 2011 | Gols, Jan |

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## ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 10 19 4530

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26-04-2011

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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