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(54) Benævnelse: **Vindenergianlæg-rotorblad med en lynafleder og et potentialudligningselement**

(56) Fremdragne publikationer:

**WO-A2-2013/097855**
**US-A1- 2007 074 892**
**US-A1- 2011 182 731**
**US-B2- 7 651 320**

The invention relates to a wind turbine rotor blade with a blade root, a lightning receptor, a lightning protection conductor that is electrically connected to the lightning receptor and is intended for diverting a lightning current in the direction toward the blade root, another electrically conductive element, and a potential equalization element that electrically connects the lightning protection conductor to the other electrically conductive element.

It is known to protect wind turbine rotor blades from damage due to a lightning strike with a lightning protection apparatus. For this purpose, a lightning protection receptor is typically arranged in the region of the blade tip. The current from lightning striking the lightning protection receptor is then diverted via a lightning protection conductor toward the blade root and from there via the nacelle and the tower of the wind turbine into the ground. Particular difficulties arise when multiple electrically conductive elements are arranged more or less parallel within the wind turbine rotor blade. As a result of the high lightning currents, large potential differences occur between the different electrically conductive elements due to electromagnetic induction, which can lead to flashovers and thereby to damage or even destruction of the wind turbine rotor blade. It is known to counteract such flashovers through potential equalization elements.

A wind turbine rotor blade is known from publication EP 1 692 752 B1 in which an internal, electrically conductive spar is connected to an adjacently arranged lightning protection conductor. In this context, potential equalization elements are provided that connect the spar and the lightning protection conductor to each other via an electrical line. The contact with the spar is established via a conductive, flat band.

A wind turbine rotor blade with multiple electrically conductive girders made of a carbon fiber material is known from publication EP 1 112 448 B2. To increase the electrical conductivity of the girders, metal-coated carbon fibers are used so that the current-carrying capacity of the girders should be sufficient for use as lightning protection conductors. Additionally, a centrally arranged metallic lightning protection conductor can be used. The girders and, if applicable, the additional metallic lightning protection conductor are connected to each other at multiple longitudinal positions via potential equalization elements in the form of internal, electrical conductors.

A wind turbine rotor blade is known from publication EP 1 664 528 B1 with electrically conductive main girders made from a carbon fiber material and two lightning protection conductors arranged in the interior of the rotor blade. A potential equalization between a main girder and a lightning protection conductor is established via a copper mesh that contacts the main girder and an electrical connection line. A middle section of the connection line is screwed to the lightning protection conductor. A free end of the connection line is screwed to a lightning protection receptor together with solid metallic connection elements and the copper mesh.

Publication WO 2013/097855 A2 shows a wind turbine rotor blade with a lightning protection conductor. The lightning protection conductor is connected to a lightning receptor at the blade tip. A further electrically conductive element consists of a receptor band that runs along the outer side of the rotor blade in a longitudinal direction and that is connected to the lightning protection conductor via lateral lightning receptors and braided copper cables.

A wind turbine rotor blade with a lightning protection conductor and multiple lightning receptors is known from publication US 2011/0182731 A1. In one exemplary embodiment, the lightning receptors are connected to the lightning protection conductor via a cable. For this purpose, a connection part is used that is formed through welding, soldering or explosion cladding/explosion welding.

Publication US 2007/0074892 A1 describes a wind turbine rotor blade with the features of the preamble of claim 1. An electrical conductor establishes a potential equalization between a carbon-fiber-containing support structure component and a lightning protection conductor. The electrical connection between the lightning protection conductor and the electrical conductor is established with the assistance of differently designed terminals.

Publication US 7,651,320 B2 also describes a wind turbine rotor blade with the features of the preamble of claim 1. In the exemplary embodiment from Fig. 1, the electrical conductor can establish a potential equalization between the main laminate and a lightning protection conductor. However, this does not occur directly, but rather via a further electrical conductor that is connected to the lightning protection conductor and the conductor via multiple screwed connections.

Starting from this background, it is the object of the invention to provide a wind turbine rotor blade of the initially cited type that has a more reliable potential equalization and is simpler to produce.

This object is achieved by the wind turbine rotor blade with the features of claim 1. Advantageous embodiments are indicated in the subsequent dependent claims.

The wind turbine rotor blade has a blade root, a lightning receptor, a lightning protection conductor that is electrically connected to the lightning receptor and is intended for diverting a lightning current in the direction toward the blade root, another electrically conductive element, and a flat potential equalization element that electrically connects the lightning protection conductor to the other electrically conductive element. In the invention, at least one metallic connection body is present that is produced in an exothermic welding method and in which the lightning protection conductor is fused with the potential equalization element.

The potential equalization element can, for example, have an area in the range of 0.1 $m^2$ to 1 $m^2$ and a width in the range of 5 cm to 1 m. An edge of the potential equalization element which is substantially straight can abut the lightning protection conductor in a flat manner. A single metallic connection body or multiple, for example two or three, metallic connection bodies per potential equalization element can be designed. The metallic connection body or bodies not only establish the electrical connection between the lightning protection conductor and the potential equalization element but also at the same time permanently fix the relative arrangement of these two elements in relation to each other.

In the exothermic welding method, a chemical reaction, mostly triggered by an initial supply of heat by igniting an ignition powder, takes place in a welding granulate that has in particular a metal oxide and aluminum. The liquid metal that arises from the strongly exothermic reaction flows into a mold, in particular made of graphite, in which the sections of the lightning protection conductor and the potential equalization element to be connected are arranged. In the process, the lightning protection conductor and the potential equalization element melt and bond with the liquid metal flowing into the mold. After cooling, a metallic connection body exists in which the lightning protection conductor is fused with the potential equalization element. In this manner, a direct, integral and permanent connection arises between the lightning protection conductor and the potential equalization element with a transition resistance that is as low as possible. At the same time, the effective cross-section of the lightning protection conductor in the region of the connection to the potential equalization element is not decreased, but rather increased by the metallic connection body so that the current-carrying capacity of the lightning protection conductor is not impeded.

A further advantage of the invention is that the lightning protection conductor and the potential equalization elements connected thereto via the at least one metallic connection body can be prefabricated so that the assembly of the wind turbine rotor blade is simplified. In particular, such a prefabricated semi-finished product can be laid into a production mold during production of the wind turbine rotor blade together with other constituent parts, in particular reinforcing fibers, and, for example, be embedded into a plastic matrix in a vacuum infusion method.

In one embodiment, the lightning protection conductor has a plurality of individual wires. The use of a lightning protection conductor with a plurality of individual wires ensures a sufficient flexibility of the lightning protection conductor so that there is no risk of a line break, even in the region directly bordering on the metallic connection body.

In one embodiment, the lightning protection conductor is a braided tube made from the individual wires, for example a copper braided tube. In principle, the individual wires of the lightning protection conductor can also be bundled in a different manner, for example twisted or at least partially sheathed. A braided tube is characterized by its high flexibility and in that it can be pressed easily into a flat, overall for example approximately rectangular cross-section. Independent of the arrangement of the individual wires of the lightning protection conductor, the lightning protection conductor can have an overall cross-section in the range of 10 $mm^2$ to 100 $m^2$, in particular of about 50 $mm^2$.

In one embodiment, the potential equalization element has a fabric, mesh, lattice or a perforated foil. The fabric, mesh or lattice can consist of a plurality of individual wires. The individual wires of the fabric, mesh or lattice can be fused in the at least one metallic connection body, in particular with individual wires of the lightning protection conductor. Due to the mentioned material, the potential equalization element is very flexible and can adapt to the shape of the further electrical element. In addition, it can be connected to the further electrical element, for example by means of vacuum infusion.

In one embodiment, the potential equalization element is a filter braid. Filter braids with different mesh sizes are offered as filter media, for example for solids recovery filtration or for clarifying filtration. They are therefore cost-effectively attainable. Due to their relatively fine structure, they enable a particularly large-area contact of the further electrically conductive element and can be draped well.

In one embodiment, the at least one metallic connection body consists of the same metal as the lightning protection conductor and the potential equalization element. In this case, the result is a particularly intimate connection between the different components. The metal oxide reactant of the welding granulate is then an oxide of the metal of the lightning protection conductor and the potential equalization element.

In one embodiment, the lightning protection conductor and/or the potential equalization element consist of copper. Copper has a high electrical conductivity and is easy to process. Welding in the exothermic welding method can occur using a welding granulate having copper oxide and aluminum.

In the invention, the further electrically conductive element is a carbon-fiber-containing support structure component of the wind turbine rotor blade. For example, it can be a spar, girder or bar, in particular a main girder.

In one embodiment, the potential equalization element abuts the electrically conductive element. In this manner, an effective electrical contact is established.

In one embodiment, the potential equalization element has a diamond shape. Due to the diamond shape, the material of the potential equalization element is scarfed in the longitudinal direction, whereby voltage jumps can be avoided.

In one embodiment, the at least one metallic connection body has an electrical connection to which a lightning receptor and/or another electrical conductor can be attached. The other electrical conductor can, for example, be a further potential equalization element that establishes a potential equalization between the lightning protection conductor and, for example, a signal cable shield, an electrical heating apparatus or another electrically conductive element of the wind turbine rotor blade. Accordingly, the at least one metallic connection body is used in an advantageous manner not only for connecting the lightning protection conductor to the flat potential equalization element, but additionally as an electrical connection. The metallic connection body is particularly suitable for this, without fearing a weakening of the current-carrying capacity of the lightning protection conductor.

In one embodiment, the electrical connection has a threaded hole. The threaded hole can be located in the metallic connection body. The electrical contact to a lightning receptor or another electrical conductor can then be established by screwing the lightning receptor into the threaded hole or by a clamp fastening with the assistance of a clamping screw that is screwed into the threaded hole. The screw connection can hereby establish a sufficient electrical contact surface in the region of the threads that are engaged with each other so that outer surfaces of the metallic connection body do not have to be accessible to establish the electrical connection. Therefore, the metallic connection body can be optionally fully embedded in a plastic matrix during production of the wind turbine rotor blade.

In one embodiment, the at least one metallic connection body is disk-shaped with a thickness that decreases toward the edges. The disk can, for example, be designed square, rectangular or round. Its shape can be determined by the mold in which the exothermic welding method is performed. With a relatively large-format, disk-shaped shape, for example, a very large number of individual wires can be included readily in the connection. Due to the thickness decreasing toward the edges, the entire arrangement can be embedded particularly well in a laminate made of reinforcing fibers.

In one embodiment, multiple potential equalization elements that are spaced apart from each other are arranged at different radial positions of the wind turbine rotor blade and are connected to the lightning protection connector via at least one of the metallic connection bodies in each case. In this embodiment, a prefabricated semi-finished product can also be produced that then ensures a sufficient potential equalization over the entire length of the further conductive element or respectively the lightning protection conductor.

In one embodiment, the lightning protection conductor and/or the potential equalization element and/or the at least one metallic connection body are embedded in a plastic matrix. In particular, the mentioned elements can be embedded in a laminate of the wind turbine rotor blade, for example of a rotor blade half shell. Both the potential equalization element and the lightning protection conductor can be integrated in this manner into the wind turbine rotor blade unproblematically and permanently due to their structure, which is finely broken up into a plurality of individual wires. At the same time, permanent corrosion protection is also attained in the region of the metallic connection body.

The invention is explained in greater detail below with reference to an exemplary embodiment shown in figures. In the figures:

Fig. 1 shows a schematic representation of a wind turbine rotor blade according to the invention,

Fig. 2 shows a schematic representation of a part of a lighting protection conductor with a potential equalization element connected to three metallic connection bodies,

Fig. 3 shows an enlarged representation of the region indicated by A in Fig. 2,

Fig. 4 shows a cross-sectional representation along the plane indicated by B-B in Fig. 2.

The wind turbine rotor blade 10 from Fig. 1 has a blade root 12 and a blade tip 14 at which a lightning receptor 16 is arranged.

A further conductive element 18 in the form of a carbon-fiber-containing main girder extends from the blade root 12 in the longitudinal direction of the wind turbine rotor blade to a region near the blade tip 14. Parallel to the further conductive element 18, a lightning protection conductor 20 is arranged in the wind turbine rotor blade 10 that extends from the blade root 12 to the region of the blade tip 14 and is connected there to the blade tip receptor 16 via an electrical line 22.

A potential equalization between the lightning protection conductor 20 and the further electrically conductive element 18 is established via multiple potential equalization elements 24 that consist of copper filter braids in the example.

In the region of one of the potential equalization elements 24, a further lightning receptor 26 is shown that is screwed to a metallic connection body (see Fig. 2 to 4). In addition, a signal line 28 is also shown in Fig. 1 that leads to a sensor 30. A shield of the signal line 28 is connected to a metallic connection body (see Fig.

2 to 4) of another potential equalization element 24 via a potential equalization conductor 32.

Each of the potential equalization elements 24 abuts a longitudinal section of the further electrically conductive element 18 over a large area.

Fig. 2 shows an enlarged representation of a section of the lightning protection conductor 20 that consists of a copper braided tube with an effective cross-section of about 50 mm$^2$. This is pressed flat so that its cross-section is approximately rectangular. A potential equalization element 24 consists of a diamond-shaped cut of a copper filter braid. An edge section 34 of the potential equalization element 24 abuts the lightning protection conductor 20. A permanent electrical connection between the potential equalization element 24 and the lightning protection conductor 20 is established via three metallic connection bodies 36 that are produced in an exothermic welding method. Individual wires of the lightning protection conductor 20 and individual wires of the potential equalization element 24 are fused with each other in the metallic connection body 36.

Two of the three shown metallic connection bodies 36 each have a threaded hole 38 that is more easily recognizable in Fig. 3 and 4. In Fig. 3, it can be seen that the metallic connection bodies 36 are disk-shaped with an approximately square basic shape with slightly rounded corners. This shape of the metallic connection body is determined by a production mold in which the exothermic welding method is performed.

In the cross-sectional representation from Fig. 4, it can be seen especially well that the lightning protection conductor 20 and the edge section 34 of the potential equalization element 24 abut each other. The metallic connection body 36 has a substantially even thickness that decreases slightly toward the edges. The thickness of the metallic connection body 36 is greater than the height of the lightning protection conductor 20 with the edge section 34 of the potential equalization element 24 arranged thereupon.

A threaded bolt section of the further lightning receptor 26 can be screwed into the internal thread 38 so that the further lightning protection receptor 36 can be arranged directly adjacent to the lightning protection conductor 20. Further connection elements are not needed for this purpose. Other electrical conductors can, for example, be brought into electrical contact with the lightning protection conductor 20 via a threaded bolt that is screwed into the internal thread 38.

List of Reference Numbers Used:

| | |
|---|---|
| 10 | Wind turbine rotor blade |
| 12 | Blade root |
| 14 | Blade tip |
| 16 | Lightning receptor |
| 18 | Further electrically conductive element |
| 20 | Lightning protection conductor |
| 22 | Electrical line |
| 24 | Potential equalization element |
| 26 | Further lightning receptor |
| 28 | Signal line |
| 30 | Sensor |
| 32 | Potential equalization conductor |
| 34 | Edge section |
| 36 | Metallic connection body |
| 38 | Threaded hole |

## Patentkrav

1. Vindenergianlæg-rotorblad (10) med en bladrod (12), en lynreceptor (16), en lynafleder (20), som er elektrisk forbundet med lynreceptoren (16) og indrettet til afledning af en lynstrøm i retning af bladroden (12), et yderligere elektrisk ledende element (18), som er en kulfiberindeholdende bærestrukturkomponent i vindenergianlæg-rotorbladet (10) fladt potential udligningselement (24), som forbinder lynaflederen (20) elektrisk med det yderligere elektrisk ledende element (18), **kendetegnet ved,** at der findes mindst et metallisk forbindelseslegeme (36), som er fremstillet ved en exotermisk svejseproces, og hvori lynaflederen (20) er smeltet sammen med det flade potentialudligningselement (24).

2. Vindenergianlæg-rotorblad (10) ifølge krav 1, **kendetegnet ved,** at lynaflederen (20) omfatter et antal enkelttråde.

3. Vindenergianlæg-rotorblad (10) ifølge krav 2, **kendetegnet ved,** at lynaflederen (20) er en flettet slange af enkelttrådene.

4. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 3, **kendetegnet ved,** at potentialudligningselementet (24) omfatter en vævet, flettet, gitterformet eller en perforeret folie.

5. Vindenergianlæg-rotorblad (10) ifølge krav 4, **kendetegnet ved,** at potentialudligningselementet (24) er en filtertresse.

6. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 5, **kendetegnet ved,** at det i det mindste ene metalliske forbindelseslegeme (36) er af samme metal som lynaflederen (20) og potentialudligningselementet (24).

7. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 6, **kendetegnet ved,** at lynaflederen (20) og/eller potentialudligningselementet (24) er af kobber.

8. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 7, **kendetegnet ved,** at potentialudligningselementet (24) ligger an imod det yderligere elektrisk ledende element (18).

9. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 8, **kendetegnet ved,** at potentialudligningselementet (24) har en rombeformet form.

10. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 9, **kendetegnet ved,** at det mindst ene metalliske forbindelseslegeme (36) omfatter en elektrisk tilslutning, til hvilken en lynreceptor (16) og/eller en speciel elektrisk leder (32) kan tilsluttes.

11. Vindenergianlæg-rotorblad (10) ifølge krav 10, **kendetegnet ved,** at den elektriske tilslutning har en gevindboring (38).

12. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 11, **kendetegnet ved,** at det mindst ene metalliske forbindelseslegeme (36) er skiveformet med en tykkelse, som aftager ud imod kanten.

13. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 12, **kendetegnet ved,** at flere med indbyrdes afstand placerede potentialudligningselementer (24) er anbragt på forskellige radiuspositioner på vindenergianlæg-rotorbladet (10) og er forbundet via hver sit mindst ene metalliske forbindelseslegeme (36) med lyn-aflederen (20).

14. Vindenergianlæg-rotorblad (10) ifølge et af kravene 1 til 13, **kendetegnet ved,** at lynaflederen (20) og/eller potentialudligningselementet (24) og/eller det mindst ene metalliske forbindelseslegeme (36) er indlejret i en plastmatrix.

Fig. 1

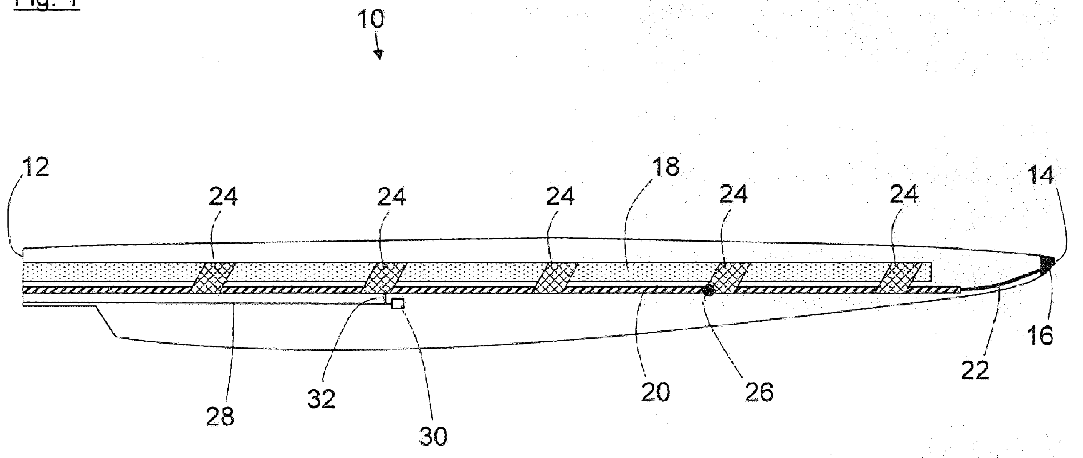

Fig. 2

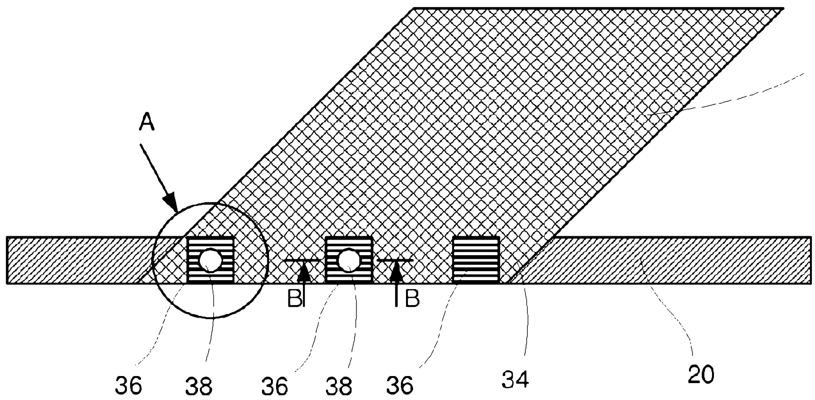


Fig. 3

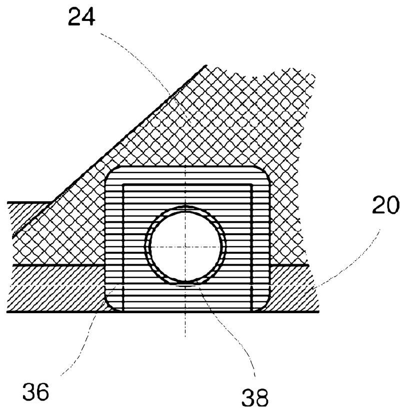


Fig. 4