**Title:** LEADING EDGE PROTECTION OF A WIND TURBINE BLADE

**Abstract:** The invention relates to a method of preparing a wind turbine blade with a leading edge protection. The method includes applying a first layer of paint on the surface portion comprising the part of the leading edge to be protected, applying a layer of a fibrous material on top of the first layer of paint, applying a second layer of paint on the layer of fibrous material, and allowing the applied leading edge protection to cure. The method may be performed as a part of the manufacture of the blade and/or as a post-processing step for example during repair on site. The proposed method results in an increased erosion resistance and improved protection against impacting particles. The invention further relates to a wind turbine blade comprising a leading edge protection established as mentioned above.
LEADING EDGE PROTECTION OF A WIND TURBINE BLADE

FIELD OF THE INVENTION

The present invention relates to a method of preparing a wind turbine blade with a leading edge protection. The invention furthermore relates to a wind turbine blade comprising a leading edge protection.

BACKGROUND OF THE INVENTION

Modern wind turbines continue to grow in size and be equipped with increasingly long wind turbine blades in order to increase the power production. As the blades get longer, the velocities of the particles impacting on the blade surface are correspondingly increased. Rain, hail, salt spray and other debris particles impact the blade surface at up to 400 km/h or even more potentially causing significant erosion damage. Especially the leading edge of the wind turbine and in particular the outermost part of the wind turbine blade closest to the tip is exposed to erosion. If the wind turbine blades are not sufficiently protected or if the protection is worn away, the blades are over time seen to suffer pitting, gouging and delamination, which affects the aerodynamic efficiency significantly and can even have an impact on the structural integrity of the entire blade. Poor blade performance may reduce annual energy production, and repair downtime is costly.

Leading edge protection can be obtained by mounting a pre-manufactured protection cover or shield on the outer surface of the finished wind turbine as described in e.g. EP2416950, WO 2008/157013, or WO 2013/092211. However, a pre-manufactured cover is difficult to manufacture such as to closely fit the 3-dimensional blade geometry along a length of the leading edge which is necessary to obtain a strong bond to the blade and to obtain a resulting leading edge with a well-controlled geometry and with a smooth transition from the cover to the blade shell. Furthermore, pre-manufactured leading edge covers are difficult if not impossible to handle and manage during repair of a damaged wind turbine blade still attached to the wind turbine hub.

It is also known to apply surface films or tapes to the leading edge area for increased erosion protection. These are likewise difficult to apply on site for increased protection or repair of a wind turbine blade as mounted. Further, erosion tapes have been seen to rupture with partly loose
tape portions left to freely flutter in the wind. This decreases the aerodynamic performance of the blade and may form a significant source of noise.

Different coatings are also specially designed and marketed to provide improved erosion resistance, such as 3M Wind Blade Protection Coating W4600 and W4601, ReNEW W-Series, HC05XP1 by Hontek, or a RELEST Wind coat by BASF. In general, the thicker the coating layer, the longer the blade can withstand the erosion. However, coatings can only be applied in thin coats to prevent runners. Further, there are issues with air inclusions, moist inclusion when painting in the field etc. The desired coating layer thickness can then be built up by the application of multiple thinner layers, which is labour intensive and time consuming. The interfaces between the layers of coatings have further been seen to weaken the strength and erosion resistance of the overall coat compared to a single layer coat of the same thickness.

OBJECT OF THE INVENTION

It is an object of embodiments of the present invention to overcome or at least reduce some or all of the above described disadvantages by providing a method of preparing a wind turbine blade yielding improved leading edge protection against erosion and wear.

It is an object of embodiments of the invention to provide a method of preparing a wind turbine blade applicable to both the manufacturing process of the wind turbine blade as well as for repair or maintenance and in particular for on-site operations.

A further object of embodiments of the invention is to provide a simple yet effective method for improving the erosion resistance which can be performed in a limited number of process steps and with only simple and limited need for special equipment and tools.

So, in a first aspect the present invention relates to a method of preparing a wind turbine blade with a leading edge protection. The wind turbine blade extends a length between a root end and a tip end of the blade, and a width between a trailing edge and a leading edge, and the wind turbine blade comprises an outer surface portion comprising at least a part of the leading edge. The method according to the first aspect of the invention comprises:

- applying a first layer of paint on the surface portion of the blade,

- applying a layer of a fibrous material on top of the first layer of paint,
- applying a second layer of paint on the layer of fibrous material,

and allowing the applied leading edge protection to cure.

Hereby is obtained an improved protection of the leading edge of the wind turbine blade which is generally the part of the blade exposed to the highest loading by impacting particles or projectiles such as rain, hail, or dust. Through the application of a layer of fibrous material on top of the first layer of paint and with a second layer of paint is obtained a leading edge protection of considerably higher thickness than otherwise obtainable by the application of a coating or paint alone where only a limited thickness can be obtained before the paint will start to run or drip. This is advantageous in that the thicker layer of paint provides a correspondingly improved erosion resistance and protection against wear and impacting particles. Here, the layer of fibrous material is seen to act as a bonding agent, allowing a thicker layer of wet paint to exist in a stable manner without running or dripping. The layer of fibrous material in this way aids in building up a thick leading edge protection coat which when manufactured can be seen as a single layer coat.

Because of this bonding effect of the fibrous layer, the hereby obtained leading edge protection is furthermore seen to be stronger and to yield a considerably higher erosion resistance than a protection layer of the same overall thickness but built up by the application of a number of layers of paint alone and without any fibrous binding agent. Furthermore, the method according to the invention is advantageous in being far less time consuming and labour intensive in that the layers of material can be applied in a semi continuous manner without time needed for each paint layer to cure separately.

The experimentally observed increased erosion performance is believed to be caused by the more homogeneous thickness that can be applied and reduced number of layer interfaces, leading to an absence of weak spots from which erosion damage can grow.

Further, the fibrous layer embedded in the paint layer can be advantageous if the leading edge protection coat spans over surface cracks that are either present in the original substrate or introduced by external impacts (i.e. large hail stones), in this case the fibrous material could give the coat crack stopping abilities that are superior to that of a "plain" coating.

Further, the fibres in the fibrous layer increase the impact strength of the protected portion of the wind turbine blade yielding an improved ability to absorb shock and impact energy without breaking. The leading edge protection hereby reduces the risk of damage of the blade from impacting rain, hail, dirt particles, and the like.
In addition to the mentioned advantage of being a way to obtain the desired increased thickness of paint without the otherwise inherent problems of running paint, the proposed method according to the invention is advantageous in that it can be performed by simple hand operations and requires only basic tools. This enables the method to be performed on an existing wind turbine blade optionally while mounted, for example from a platform or using rope-access. Additionally, the method can be performed in the open with for example no need for special vacuum generating equipment, positioning jigs, lay-up machines or the like.

The protection method is further advantageous in that the fibrous layer can be comprised of a material that is simple to drape and lay out even on double curved surfaces. Hereby the leading edge protection can be applied with only minimal modifications to the overall outer shape of the wind turbine blade profile and without measurably affecting the aerodynamic properties of the blade.

Further, the leading edge protection can be established relatively fast which is especially advantageous when to be applied as repair or maintenance operation on site and especially for blades on offshore turbines where the working conditions can be acceptable for only short periods of time.

One or more of the layers of paint may be a coating, a lacquer, or any type of a covering applied to the surface of the wind turbine blade.

The outer surface portion typically extends across the leading edge such as to comprise a part of both the suction side surface and the pressure side surface of the blade. The outer surface portion may extend a similar distance to both sides of the leading edge, or extend a larger distance onto the pressure side than onto suction side, or vice versa. The outer surface portion may be of equal or similar cross sectional width along the length of the blade or may have a varying width such as for example covering a larger part of the wind turbine blade profile closer to the tip end of the blade. Hereby, the leading edge protection covers a larger part of the blade profile towards the tip end where the velocities of the impacting particles and projectiles are larger.

Because the blade tip and the outermost part of the wind turbine blade are exposed to particles of higher velocities and thereby have a higher risk of erosion damage, the leading edge protection is preferably applied to protect the outermost part of the blade leading edge next to or including the blade tip, such as for example to the outermost 5-40% of the length of the leading edge such as the outermost 10-20%. 
In an embodiment of the invention, the second layer of paint is applied to at least partially impregnate the layer of fibrous material. In an embodiment, the layer of fibrous material is partly or fully impregnated by the paint of the first layer, by the paint of the second layer, or by a combination hereof. The partial or full impregnation may be realized by the pressing (for example simply by a gloved hand) the fibrous layer into the first layer of paint, and/or by the application of the second layer of paint for example by rolling or brushing or spraying. By the partial or full impregnation of the fibrous layer, the two paint layers effectively form a single layer of leading edge protection with a fibrous material embedded within it. The strength of this layer can be higher than that of a stack of layers of the same thickness due to the elimination of inter-layer interfaces in combination with the fibrous material acting as a bonding agent.

According to an embodiment of the invention, the layer of fibrous material comprises a dry fibrous material. By a dry layer is to be understood a non-impregnated or essentially non-impregnated layer, possibly with a binding agent or sizing applied. Hereby the paint of the neighbouring layers can better impregnate the fibrous layer and the fibrous layer in turn better act to bond the layers of paint.

In an embodiment, the layer of fibrous material comprises a weave or a random fibre mat. This is advantageous in yielding a layer of some structural integrity which can easily be applied or laid up for example by simple hand operations and without the need for special tools or machinery. Further, weaves or random fibre mats can be configured to show good drapability properties and can fairly simply be cut into appropriate sizes according to the specific need. Also, weaves or random mats in general are adequate and well suited for impregnation by the application of paint.

In yet a further embodiment, the fibrous material comprises fibres of at least one material belonging to the group of glass fibre, carbon fibre, polyester, aramid, and nylon. These materials all have different strength, stiffness and surface properties allowing the designer to tune the leading edge protection characteristics depending on the coating and/or substrate materials at hand as well as the dominant failure criteria.

In an embodiment, the first and second layers of paint are of the same material. Hereby is ensured a complete compatibility between the first and second layer of paint without the risk of experiencing any issues of interlayer weaknesses. The resulting leading edge protection may in this way be perceived as or observed to appear as a single layer of paint of considerable thickness and reinforced by a fibrous material, thereby obtaining both a thicker layer than otherwise traditionally obtainable combined with the reinforcing effect from the fibrous material.
In an embodiment, the paint is a coating comprising a two-component polyurethane coating such as the Wind Blade Protection Coating W4600 and W4601 from 3M, or the ReNEW W-Series, HC05XP1 by Hontek, which materials have been reported to have superior erosion resistance properties. Additionally or alternatively, the paint is a coating comprising a three component polyurethane coating, an epoxy resin, or a polyester resin or other paint which might or might not be used with additional particles included such as grains, short fibres or nano particles.

In an embodiment, the method further comprises applying alternatingly a further layer of fibrous material and a further layer of paint thereby laying up a plurality of layers of fibrous material with layers of paint in between. Hereby is obtained a leading edge protection of even further increased thickness and thereby of further improved erosion resistance properties and impact strength. Using this method a leading edge protection can be built up to have a desired predetermined minimum thickness. Furthermore, the method simply repeats the application of layers in a number of successive steps and is thereby relatively simple to perform even under difficult working conditions. Embodiments comprise applying 2, 3, 4, or any number up to 6, 7, or 8 layers of fibrous material. The layers of fibrous material may be of the same, partially the same or different materials.

In an embodiment, the layers of paint are applied by rolling, brushing, or spraying. The layers of paint can hereby be applied by simple hand operations yet providing an effective impregnation of the fibrous layer.

In an embodiment, the method further comprises applying a peel ply as the outermost layer prior to curing, peeling off the peel ply after curing, and applying a layer of a paint as an outermost layer. The peel ply may be applied to cover an edge or the full extent of the outermost applied layer of fibrous material and is pressed into the uncured paint. Hereby is obtained a gradual transition between the surface portion comprising the leading edge protection and the neighboring surface regions of the blade, minimizing the aerodynamic impact of the leading edge protection application.

The method steps as described in the preceding may form part of a manufacture of the wind turbine blade or may alternatively or additionally be performed as post processing during repair or maintenance of the wind turbine blade. In other words the leading edge protection can be applied to a wind turbine blade when first manufactured and is also very well suited to be applied at a later time to existing wind turbine blades. A special advantage is, that the preparation method can be performed on blades in the open, on site, or even on blades mounted on the wind turbine as the method may be performed by simple hand operations and simple tools without any
requirements such as for example to a special atmosphere (apart from weather conditions matching the operating window for the paint used) or special manufacturing equipment or machinery.

In a further aspect the present invention relates to a wind turbine blade extending a length between a root end and a tip end of the blade, and extending a width between a trailing edge and a leading edge, the wind turbine blade comprising an outer surface portion comprising at least a part of the leading edge, wherein the wind turbine further comprises a leading edge protection prepared as described in the preceding.

The advantages of the wind turbine blade are as described in relation to the method of preparing in the previous.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following different embodiments of the invention will be described with reference to the drawings, wherein:

Fig. 1 shows a wind turbine,

Fig. 2 shows a wind turbine blade comprising a leading edge protection,

Fig. 3 illustrates a part of a wind turbine blade as seen in a cross-sectional view and comprising a leading edge protection according to embodiments of the invention, and

Figs. 4A-C illustrate the method of preparing a blade with a leading edge protection according to embodiments of the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

Figure 1 shows a wind turbine 100 comprising a tower 101, a nacelle 102 at the tower top, the nacelle housing machine components, such as gearbox, generator etc. (not shown). At one end of the nacelle, a hub section 103 supports a plurality of wind turbine blades 110.

Figure 2 shows a wind turbine blade 110 extending a length 201 between a root end 202 and a tip end 203 of the blade, and extending a width between a trailing edge 205 and a leading edge
206 as indicated by the arrow 204. An outer surface portion 210 of the wind turbine blade covers a part of the leading edge 206 and is provided with a leading edge protection according to the invention.

Figure 3 illustrates a part of the wind turbine blade 101 as seen in a cross-sectional view and corresponding to the indicated profile 300 in figure 2. The outer or exterior surface portion 210 of the blade covers and extends across the leading edge 206 of the blade. The leading edge protection comprises a first layer of paint 301 applied to the surface portion 210, a layer of a fibrous material 302, and a further layer of a paint 303 applied on top of and impregnating and wetting out the fibrous material.

The successive steps in the application method are illustrated in figure 4A-C. In a first step illustrated in figure 4A, a first layer of paint 301 is applied to the surface portion 210 and such as to cover the leading edge. The paint may for example be applied by brush, roller or spray 401. Then (figure 4B) the layer of fibrous material 302 is applied on top of the paint 301. The fibrous layer may for example be a weave or mat, or may comprise fibres of for example glass fibre, nylon, Kevlar or polyester or combinations hereof. If desired, the fibrous layer 302 may be applied as multiple patches for example of more easily handled sizes or to better drape on the curved outer surface of the blade. The fibrous layer may be pressed slightly into the paint.

Then in a following step (figure 4C) is applied a second layer of paint 303 impregnating the fibrous layer 302. Again, the paint may for example be applied by brush, roller or spray 401 as convenient. Hereafter the leading edge protection can be left to cure.

A leading edge protection of even further increased thickness may be realized by the application of more layers of fibrous material with layers of paint in between, i.e. repeating the steps of figure 4B and 4C a number of times such as to apply for example 2, 3, 4, 5, or 6 layers of fibrous material. The fibrous material in the different layers may be the same, partially the same or all different.

While preferred embodiments of the invention have been described, it should be understood that the invention is not so limited and modifications may be made without departing from the invention. The scope of the invention is defined by the appended claims, and all devices that come within the meaning of the claims, either literally or by equivalence, are intended to be embraced therein.
CLAIMS

1. A method of preparing a wind turbine blade with a leading edge protection, the wind turbine blade extending a length between a root end and a tip end of the blade, and extending a width between a trailing edge and a leading edge, the wind turbine blade comprising an outer surface portion comprising at least a part of the leading edge, the method comprising:
   - applying a first layer of paint on the surface portion of the blade,
   - applying a layer of a fibrous material on top of the first layer of paint,
   - applying a second layer of paint on the layer of fibrous material, and allowing the applied leading edge protection to cure.

2. A method of preparing a wind turbine blade according to claim 1, wherein the second layer of paint is applied to at least partially impregnate the layer of fibrous material.

3. A method of preparing a wind turbine blade according to any of the preceding claims, wherein the layer of fibrous material comprises a dry fibrous material.

4. A method of preparing a wind turbine blade according to any of the preceding claims, wherein the layer of fibrous material comprises a weave or a random fibre mat.

5. A method of preparing a wind turbine blade according to any of the preceding claims, wherein the fibrous material comprises fibres of at least one material belonging to the group of glass fibre, polyester, Kevlar, and nylon.

6. A method of preparing a wind turbine blade according to any of the preceding claims, wherein the first and second layers of paint are of the same material.

7. A method of preparing a wind turbine blade according to any of the preceding claims, wherein the paint is a coating comprising a two-component polyurethane coating, a three component polyurethane coating, an epoxy resin, or a polyester resin.

8. A method of preparing a wind turbine blade according to any of the preceding claims, the method further comprising applying alternatingly a further layer of fibrous material and a further layer of paint thereby laying up a plurality of layers of fibrous material with layers of paint in between.
9. A method of preparing a wind turbine blade according to any of the preceding claims, wherein the layers of paint are applied by rolling, brushing, or spraying.

10. A method of preparing a wind turbine blade according to any of the preceding claims, the method further comprising applying a peel ply as the outermost layer prior to curing, peeling off the peel ply after curing, and applying a layer of a paint as an outermost layer.

11. A method of preparing a wind turbine blade according claim 10, wherein the peel ply is applied to cover an edge of the outermost applied layer of fibrous material and is pressed into the uncured paint.

12. A method of preparing a wind turbine blade according to any of claims 1 to 11, wherein the method steps form part of a manufacture of the wind turbine blade.

13. A method of preparing a wind turbine blade according to any of the preceding claims, wherein the method steps are performed as post processing during repair or maintenance of the wind turbine blade.

14. A wind turbine blade extending a length between a root end and a tip end of the blade, and extending a width between a trailing edge and a leading edge, the wind turbine blade comprising an outer surface portion comprising at least a part of the leading edge, wherein the wind turbine blade further comprises a leading edge protection prepared according to any of claims 1 to 13.
### A. CLASSIFICATION OF SUBJECT MATTER

INVENTION:

F03D1/06  F03D80/50

### ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F03D  C09D

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

### C. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>US 2010/135820 Al (OLSON STEVEN [US]) 3 June 2010 (2010-06-03) figures 4-6 paragraphs [0022] - [0025], [0029], [0030], [0037]</td>
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[X] Further documents are listed in the continuation of Box C.  
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