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(54) Title: METHOD AND APPARATUS FOR APPLYING A LAYER OF MATERIAL TO A LEADING EDGE OF A WIND TURBINE BLADE

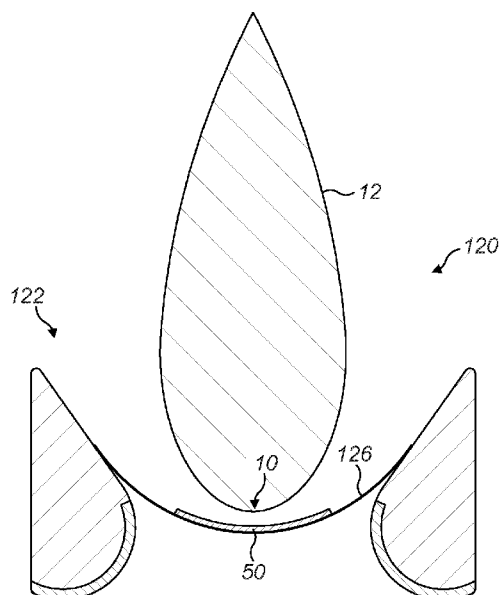


FIG. 1b

(57) Abstract: Apparatus for applying a layer of material to a leading edge of a wind turbine blade. The apparatus comprises a flexible substrate capable of supporting the layer of material. The flexible substrate is reconfigurable between a presentation configuration in which a part of the layer of material contacts the leading edge to define an initial area of contact, and a transfer configuration in which the flexible substrate, and thereby the layer of material, is wrapped around, and adopts the contours of, at least a part of the leading edge. The apparatus also comprises a substrate support for supporting the flexible substrate in the presentation and transfer configurations. At least a part of the substrate support is moveable to reconfigure the flexible substrate between the presentation and transfer configurations such that the layer of material can be offered up to the leading edge of the wind turbine blade with the flexible substrate in the presentation configuration, and thereafter the flexible substrate can be reconfigured by increasing the area of contact between the layer of material and the leading edge until the flexible substrate is in the transfer configuration.

Method and apparatus for applying a layer of material to a leading edge of a wind turbine blade

Field of the invention

The invention relates to a method and apparatus for applying a layer of material to a leading edge of a wind turbine blade.

Background to the invention

It is often necessary to apply layers of material such as paint, resin, adhesives, pre-cured polymer tapes, or other pre-shaped layers to the leading edge of a wind turbine blade during its manufacture and during on-site maintenance. For example, an erosion-resistant paint or leading edge protection layer is applied to the leading edge of the blade during manufacture to resist erosion of the leading edge due to precipitation and airborne particles while the blade is in use. During use, the erosion-resistant paint can be gradually eroded and it can therefore be necessary to re-apply the paint to the leading edge of the wind turbine blade on-site.

It is important that such paint is applied uniformly to the surface of the wind turbine blade and that the thickness of the layer is carefully controlled. If the paint is not uniform, some regions will be too thin, and will not provide sufficient erosion resistance. An even layer is particularly important at the leading edge of the blade, because any roughness or inconsistencies at the leading edge will disturb the air flow around the blade and lead to a reduction in the aerodynamic efficiency of the wind turbine.

The erosion-resistant paint is typically applied by spraying or using a brush or roller. However, it is difficult to apply such layers of material evenly and smoothly to the curved surface at the leading edge of a wind turbine blade. For example, in a typical two-component erosion-resistant paint, the paint is very fluid in its initial state when it has just been mixed, and has a low viscosity. When applied to the curved surface of the leading edge, the low viscosity means that the paint tends to run down the contours of the curves making it difficult to apply evenly. Shortly after the paint has been mixed (in some cases, within a few minutes), the paint begins to gel and the viscosity of the paint increases; however, in this gelled state it is too viscous to be spread evenly and smoothly. Given that the paint has a low gel point (meaning that it gels quickly) there is therefore only a very short window in which the paint is at a viscosity that is suitable for even spreading. Thus, it is very difficult to achieve a paint viscosity that allows even application of the paint to the leading edge of the wind turbine blade.

Pre-cured polymer tapes are typically attached manually using adhesives applied to a blade-facing surface of the tape. However, applying tapes in this way requires significant skill and diligence. If the tape is not skilfully applied, the tape may be uneven or damaged.

- 5 It would be desirable to overcome or mitigate the problems described above.

Summary of the invention

Against this background, the invention resides in apparatus for applying a layer of material to a leading edge of a wind turbine blade. The apparatus comprises a flexible substrate capable of supporting the layer of material. The flexible substrate is reconfigurable between a presentation configuration in which a part of the layer of material contacts the leading edge to define an initial area of contact, and a transfer configuration in which the flexible substrate, and thereby the layer of material, is wrapped around, and adopts the contours of, at least a part of the leading edge. The apparatus also comprises a substrate support for supporting the flexible substrate in the presentation and transfer configurations. At least a part of the substrate support is moveable to reconfigure the flexible substrate between the presentation and transfer configurations such that the layer of material can be offered up to the leading edge of the wind turbine blade with the flexible substrate in the presentation configuration, and thereafter the flexible substrate can be reconfigured by increasing the area of contact between the layer of material and the leading edge until the flexible substrate is in the transfer configuration.

By virtue of the flexible substrate that can be reconfigured between the presentation and transfer configurations using the moveable substrate support, a layer of material of predetermined thickness can be gradually and gently wrapped around the leading edge of the blade as the flexible membrane is reconfigured to adopt the contours of at least a portion of the leading edge. Over the majority of the layer of material, away from edge regions of the layer, this gentle wrapping motion allows the layer of material to be brought into contact with the leading edge substantially without displacing the material in the majority of the layer of material, so that the majority of the layer remains at the predetermined thickness. As the wrapping motion continues to an end region of the layer, a small amount of material in the edge region may be displaced outwards so that the material in the edge region tapers to zero thickness.

The resulting layer of material that is applied to the leading edge of the blade is therefore of the predetermined thickness throughout the majority of the layer, so that the thickness of the layer can be easily and reliably controlled, but may be of tapering thickness in the edge region of the layer, thereby avoiding any 'step' on the leading edge where the layer
5 of material ends, which improves the aerodynamic performance of the blade.

By "flexible" is meant that the substrate can be deformed elastically. In particular, the substrate can be deformed elastically between the presentation and transfer configurations; so that the substrate can be wrapped around the leading edge of the blade.

10 When the flexible substrate is in the presentation configuration, at least a part of the flexible substrate may be arranged to present a concave surface to the leading edge of the wind turbine blade.

The substrate support may be configured to change the curvature of the flexible substrate as the flexible substrate is moved between the presentation and transfer
15 configurations.

The substrate support may comprise a rotatable body, and the flexible substrate may be fixed to the rotatable body at a fixing point, such that a part of the flexible substrate wraps around the rotatable body as the rotatable body rotates. Fixing the substrate to a rotatable body is a particularly effective means of providing a gentle transition from the
20 presentation configuration to the transfer configuration, since the rotation provides a smooth and continuous motion, and any rotational movement of the rotatable body will provide a comparatively small change in the configuration of the substrate, allowing for gentle movement of the substrate and hence minimal disturbance to the layer of material being applied.

25 The rotatable body may be eccentrically mounted on a pivot axis. Such an eccentric motion contributes to the reconfiguration of the substrate as the body rotates. The eccentric motion also allows for non-linear progress of the reconfiguration, such that the reconfiguration may be faster or slower at different stages of the reconfiguration process. In this way, the reconfiguration process can be carefully controlled by the eccentric
30 shape of the body.

For particularly smooth reconfiguration, the rotatable body may comprise a curved surface, at least a portion of which may be of increasing radius with respect to the pivot

axis, and the substrate support may be configured such that a part of the flexible substrate wraps around the portion of increasing radius as the rotatable body rotates.

To accommodate variations in the surface geometry of a leading edge of a blade, at least
5 a part of the surface of the rotatable body may be defined by a flexible material. In such
embodiments, the substrate support may be configured such that, when the flexible
substrate is in the transfer configuration, the part of the surface that is defined by the
flexible material pushes against the leading edge of the blade. Pushing the rotatable
10 body into the leading edge in this way can contribute to the creation of the taper at the
edge of the layer of material. Pushing the flexible material into the leading edge, rather
than a non-flexible part of the rotatable body, guards against damage to the leading edge
of the blade.

For even reconfiguration of the flexible substrate, the substrate support may comprise
15 windward and leeward bodies configured to be arranged at windward and leeward sides
of the leading edge, and the substrate may be fixed to, and extend between, the
windward and leeward bodies.

The substrate support may comprise an attachment arrangement for attaching the
20 substrate support to a wind turbine blade. Such an attachment arrangement stabilises
the substrate support with respect to the wind turbine blade.

To accommodate fluctuations in blade geometry, the attachment arrangement may
comprise an adjustment part for adjusting the position of the substrate support relative to
25 the wind turbine blade.

To this end, the attachment arrangement may comprise support arms for spacing the
moveable part of that substrate support away from the wind turbine blade, and the
support arms may be adjustable to vary the spacing between the moveable part of that
30 substrate support and the wind turbine blade. Alternatively or additionally, the attachment
arrangement may comprise an attachment plate for attachment to the wind turbine blade,
and the attachment plate may be adjustable to vary the position of the moveable part of
that substrate support relative to the attachment plate.

For ease of application of the layer of material, the apparatus may comprise an
35 applicator for applying a layer of liquid material to the flexible substrate. In this way, the

layer of material can be applied to the flexible substrate in the vicinity of the wind turbine blade and applied to the leading edge before the layer has gelled. This is particularly advantageous for liquid layers which may otherwise begin to set or cure.

5 The applicator may comprise a container provided with slot for dispensing the material onto the flexible substrate. The slot is a simple and effective means of controlling the thickness of the layer of material applied to the substrate. The slot may be, for example of a predetermined constant height or of a predetermined varying height.

10 The flexible substrate may be a flexible membrane. The flexible membrane may have a thickness that is less than approximately 2 mm. Such a thickness provides a particularly soft membrane, which encourages particularly gentle wrapping of the membrane around the leading edge, which minimises displacement of the material even further. To this same end, the flexible membrane may alternatively or additionally be made of a silicon rubber, or of another plastics material such as polyurethane, polyethylene, polypropylene or nylon. Such plastics materials provide a particularly smooth finish when the substrate
15 is removed from the layer of material. By flexible is meant that the substrate can change shape between the presentation and transfer configurations without breaking.

The substrate support may comprise an actuator for effecting movement of the moveable part of the substrate support. The actuator provides a particularly simple means for driving movement of the moveable part of the substrate support so as to selectively
20 reconfigure the substrate between the presentation and transfer configurations.

From another aspect, the invention resides in a method of applying a layer of material to a leading edge of a wind turbine blade. The method comprises: providing a layer of material applied on a flexible substrate; arranging the flexible substrate in relation to the leading edge of the wind turbine blade with the flexible substrate in a presentation
25 configuration such that an initial area of contact is be defined between the layer of material and the leading edge; reconfiguring the flexible substrate into a transfer configuration in which the flexible substrate adopts the contours of the leading edge by increasing the area of contact between the layer of material and the leading edge; and transferring the layer of material from the flexible substrate to the leading edge of the
30 wind turbine blade.

When the flexible substrate is in the presentation configuration, at least a part of the flexible substrate may be arranged to present a substantially concave surface to the leading edge of the wind turbine blade.

The concave surface of the substrate in the presentation configuration may define a minimum point, and the step of arranging the flexible substrate in the presentation configuration may comprise moving the minimum point of the concave surface towards the leading edge of the blade until the layer of material meets the leading edge. For example, the minimum point may be raised towards the concave surface.

The flexible substrate may be fixed to a rotatable body. In this case, the method may comprise rotating the rotatable body about a pivot axis to wrap a part of the substrate around the rotatable body to effect movement of the minimum point of the concave surface towards the leading edge of the blade. Alternatively or additionally, the step of reconfiguring the flexible substrate into a transfer configuration may comprise rotating the rotatable body to wrap a part of the substrate around the rotatable body and thereby to bring the flexible substrate into the transfer configuration.

Reconfiguring the substrate using rotation of a rotatable body results in a particularly smooth and gentle reconfiguration, and hence a particularly smooth and gentle increase in contact between the layer of material and the leading edge, resulting in a smooth and even layer of material.

The surface of the substrate in the presentation configuration may define a maximum point, and the step of arranging the flexible substrate in the presentation configuration may comprise moving the maximum point of the surface towards the leading edge until the flexible substrate meets the leading edge. For example, the maximum point may be raised towards the concave surface.

The step of reconfiguring the flexible substrate into the transfer configuration may comprise moving the maximum point towards the leading edge.

At least a part of the rotatable body may be eccentrically mounted on the pivot axis, and the step of moving the maximum point of the surface towards the leading edge of the blade may comprise rotating the rotatable body such that a part of the substrate may be wrapped around the eccentrically-mounted part of the rotatable body.

The step of providing a flexible substrate having a layer of material applied thereon may comprise applying a layer of material to a flexible substrate. Alternatively, the flexible substrate may have been pre-prepared with a layer of material.

The method may comprise arranging the flexible substrate in a substantially flat application configuration before applying the layer of material to the flexible substrate. A

flat configuration is particularly beneficial during application, as it is relatively easy to apply a layer of uniform thickness to the substrate when it is substantially flat.

The layer of material applied to the flexible substrate may comprise a liquid layer.

The layer of material applied to the flexible substrate may comprise a solid layer.

- 5 The layer of material applied to the flexible substrate may comprise a solid film a layer of adhesive is applied to the solid film.

For particularly effective transfer, the step of transferring the layer of material from the flexible substrate to the leading edge of the wind turbine blade may comprise curing the layer of material on the flexible substrate.

- 10 To allow for application of the material throughout the lifetime of a wind turbine blade, the layer of material may be applied to the blade in-situ on a wind turbine.

For particularly stable application of the material, the method may comprise supporting the flexible substrate on a substrate support and fixing the substrate support to the wind
15 turbine blade to apply the layer of material.

Brief description of the drawings

In order that the present invention may be more readily understood, examples of the invention will now be described with reference to the remaining figures, in which:

- 20 Figure 1 and 1b are, respectively, a perspective and a cross-section view of a wind turbine blade and apparatus for applying a layer of material to a leading edge of a wind turbine blade according to an aspect of the invention;

- 25 Figures 2a and 2b are cross-section views of a substrate support forming part of the apparatus of Figure 1b in a presentation configuration and a transfer configuration respectively, and Figure 2c is a perspective view from one side of a wind turbine blade and a rotatable body forming a part of the substrate support;

Figures 3 and 4 are cross-section views of the rotatable body of Figure 2c;

Figure 5 is a schematic view of an applicator forming part of the apparatus of Figure 1;

- 30 Figure 6 is a perspective view of a dispensing container forming part of the applicator of Figure 5;

Figure 7 is a cross-section view of the substrate support in an application configuration, ready to receive a layer of material;

Figure 8 is a cross-section view of the substrate support with a layer of material being applied to the substrate by the applicator of Figure 5;

5 Figure 9 is a cross-section view of the substrate support with the applicator removed and the layer of material in place on the substrate;

Figure 10 is a cross-section view of the substrate support attached to the leading edge of a wind turbine blade, with a layer of material in place on the substrate and the substrate being arranged ready for application;

10 Figure 11 is a cross-section view of the substrate support in a presentation configuration, with the layer of material in contact with the leading edge of the blade;

Figure 12 is a cross-section view of the substrate support in a transfer configuration in which the substrate has adopted the contours of the leading edge of the wind turbine blade such that the layer of material is wrapped around the leading edge; and

15

Figure 13 is a cross-section view of the leading edge of the wind turbine blade after the substrate support has been removed, with the layer of material applied to the leading edge.

20 It will be appreciated that the elements illustrated in the Figures are not drawn to scale.

Detailed description of embodiments of the invention

Figure 1a illustrates a wind turbine rotor blade 12 which extends from a root end 8 to a tip end 9. The blade comprises a leading edge 10 to which a layer of material is applied as described further below. Figure 1b illustrates in cross section an apparatus 120 for

25 applying a layer of material 50 to a leading edge 10 of a wind turbine blade 12. In the context of this invention, the leading edge 10 is the edge region to which the layer of material will be applied, and includes the actual leading edge as well as the area on the suction surface and the pressure surface which surround the leading edge, to which the layer of material will be applied. The apparatus 120 comprises a substrate support

30 122 and a substrate 126 in the form of a flexible membrane.

The layer of material 50 may take many different forms. For example, the layer of material 50 may be a liquid layer, which may or may not be permitted to partially pre-cure before being applied to the leading edge 10. Alternatively, the layer of material 50 may be a solid layer to which a layer of adhesive is applied. The layer of material 50 may be a paint, or it may be another material such as a resin or liquid adhesive (for example a polyurethane, epoxy, methacrylate) or a pressure sensitive adhesive (PSA), hot melt adhesive or other coating. The layer may be fully cured or it may be partially cured. In the forgoing example, the layer is exemplified as a layer of erosion-resistant paint.

Figures 2a to 2c show the substrate support 122 and membrane 126 in more detail.

10 The membrane 126 is made of a soft, flexible material, such as a silicon rubber. Alternatively, the membrane may be made from another suitable plastics material such as polyurethane, polyethylene, polypropylene or nylon. The membrane has a thickness of less than 2mm, and preferably less than 1mm. In this way, the membrane 126 is flexible so as to allow easy reconfiguration of the membrane.

15 The substrate support 122 has a moveable part that comprises left and right (or windward and leeward) membrane supports in the form of rotatable bodies 129. The flexible membrane 126 extends between the left and right rotatable bodies 129 so that the bodies 129 support the membrane 126 at its left and right sides.

Figure 2c shows the right rotatable body 129 in perspective view, and reveals that the rotatable body 129 extends in a longitudinal direction generally parallel to the leading edge 10 of the wind turbine blade 12. Figure 2c also reveals that the body 129 is mounted on a spindle 130 that defines a rotation axis that allows the body 129 to rotate about the longitudinal axis. The spindle is supported by support arms 132 that can be mounted to the blade via support plates 133 when the apparatus is in use, for example by means of a vacuum suction arrangement (not shown). Together, the support arms 132 and the support plates 133 define an attachment arrangement.

Referring to Figure 3, which illustrates the cross section of the body 129 in more detail, each rotatable body 129 has a cross section in a plane that is perpendicular to the longitudinal direction of the leading edge 10. The cross section defines an eccentric shape that, in this example, generally takes the form of a rounded wedge having a rounded rear end 131 and a pointed nose 132 at the front of the wedge. Between the rear end 131 and the nose 132, the wedge defines a curved surface 134 that faces the leading edge 10 when the apparatus is in use. A substantially flat surface 136 faces

away from the leading edge 10 when the apparatus is in use. In this way, as is visible in Figure 2a, the curved surfaces 134 of the left and right rotatable bodies 129 face towards each other.

5 The body 129 is mounted to the spindle 130 at a pivot point 138. Along the curved surface 134, the radius varies with respect to the pivot point 138. At the rear end 131 of the wedge, the radius R_1 is relatively large. Moving from the rear end 131 towards the nose 132, the radius gradually decreases, to an intermediate radius R_2 at an intermediate position, and to a relatively small radius R_3 at a position that is closer to the nose 132. As the curved surface 134 extends towards the nose 132, the curved surface
10 134 transitions into a flat surface 140 that defines a nose region 143.

Figure 3 also reveals that the membrane 126 is fixed to each body 129 at a fixing point 142. The fixing point 142 is located on the curved surface 134, slightly nose-wards of the pivot point 138. The membrane 126 may be held in place at the fixing point 142 by a clamp (not visible), or by any other suitable means.

15 Referring back to Figures 2a and 2b, because each rotatable body 129 is mounted on a spindle 130, the bodies 129 can rotate eccentrically about their longitudinal axes. In particular, each body 129 can be rotated by an actuator 128 (visible in Figure 3) to turn the rotatable bodies 129 inwardly or outwardly. The actuators 128 may be, for example, motors that effect rotation of the spindle 130 of each rotatable body 129. The actuators
20 128 may be controlled by a controller that can effect rotation the rotatable bodies simultaneously or separately as required. Alternatively, the actuators may be levers attached to the bodies to permit manual rotation of the bodies by pulling or pushing the levers.

25 The fixing point 142 and eccentric shape of the body 129 cause the membrane 126 to be moved into different configurations as the bodies 129 rotate.

In particular, Figure 2a illustrates the substrate support 122 with the membrane 126 in a generally slack or downwards configuration. In this configuration, the rotatable bodies 129 are oriented about their pivot points 138 in a comparatively inwardly-rotated orientation. Said another way, the left-hand rotatable body 129 as shown is at a
30 comparatively clockwise orientation and the right-hand rotatable body 129 as shown is at a comparatively anticlockwise orientation.

The membrane 126 defines a concave surface having a lowermost point 144 at the minimum of the curve and uppermost points 146 at the maximums of the curve, which in

this configuration are at the fixing points 142. In this configuration, the membrane 126 is comparatively slack, and the lowermost point 144 and uppermost points 146 are in comparatively low positions.

Figure 2b illustrates the substrate support 122 with the membrane 126 in a generally taut or upwards configuration that corresponds to a transfer configuration. In this configuration, the rotatable bodies 129 have been rotated outwardly (that is to say, the left-hand rotatable body 129 has been rotated in an anticlockwise direction, and right-hand rotatable body 129 has been rotated in a clockwise direction).

Rotation of the bodies 129 causes the fixing points 142 at which the membrane 126 is attached to the bodies 129 to be displaced outwardly, with respect to each other. In this way, the membrane 126 is rolled onto the curved surfaces 134 of the bodies 129. This changes the configuration of the membrane 126 in two ways.

Firstly, the membrane 126 is stretched over an increasingly large portion of the curved surface 134 of the body 129, such that some of the slack in the membrane 126 is taken up and the membrane 126 is pulled more taut. This has the effect of raising the lowermost point 144 of the membrane 126.

Secondly, because the radius of the body 129, and hence the distance between the pivot point 138 and the curved surface 134, increases moving towards the rear end 131 of the body 129, the uppermost point 146 on the membrane changes and moves upwards relative to the pivot point as the body 129 rotates and the membrane 126 is wrapped around the curved surface. Therefore, the uppermost point 146, and hence the entire membrane 126, is displaced generally upwardly as the bodies 129 rotate outwardly.

Thus, outward rotation of the bodies 129 causes the membrane 126 to be pulled taut and to move generally upwardly. In this way, referring back to Figure 1b, rotation of the bodies 129 allows the membrane 126 to be moved towards and away from the leading edge 10 of the wind turbine blade 12.

Referring to Figure 4, the body 129 is configured to permit adjustments that can accommodate minor differences in the shape of individual blades as will now be described.

Firstly, the spindle 130 is mounted such that the spindle 130 and hence the rotation axis of the body 129 can be moved towards and away from the blade 12 in direction *X* and parallel to the surface of the blade in direction *Y*. Movement in direction *X* may be

achieved, for example, by providing an adjustment means on the support arms 132. For example, the support arms 132 may be sprung so that they can be bent to bring the spindle 130 towards and away from the blade 12. Alternatively, extendable support arms may be used. Movement in direction Y may be achieved by providing an adjustment
5 means that allows for lateral movement the support arms 132 relative to the plane of the plates 133, for example by mounting the support arms 132 to the support plates 133 via springs.

Secondly, at a rear portion 148 of the body 129, the curved outer surface 134 of the body 129 is flexible to accommodate variations in geometry in the direction Z as will be later
10 described. To achieve this flexibility, the body 129 is provided with a layer of flexible material 150 that defines the curved outer surface 134 in the rear portion 148. The layer of flexible material may be made from any suitable flexible or compressible material, such as for example a rubber or flexible foam. The layer 150 may be made, for example, from a silicone rubber, polyurethane, polyethylene, EPDM rubber or neoprene.

15 Figures 5 and 6 illustrate in detail an applicator 124 for applying a layer of material to the flexible membrane 126 of the substrate support 122.

Referring to Figure 5, the applicator 124 comprises a dispensing container 40 for holding the material to be applied, a storage volume 42 for storing the material and a transmission means 44 for transmitting the material from the storage volume 42 to the
20 dispensing container 40.

As seen in Figure 6, the dispensing container 40 is formed as a frame, with four side walls and no top or bottom surface. A front wall of the dispensing container comprises a slot 46. In use, material is dispensed through the slot 46 onto the flexible membrane 126 (not visible in Figure 6).

25 In the embodiment shown, the storage volume 42 is a substantially cylindrical tube that is sealed at both ends, and the transmission means 44 is a length of flexible pipe that joins the storage volume 42 to the dispensing container 40.

The use of the apparatus 120 in applying the layer of material 50 to the leading edge 10 of the wind turbine blade 12 will now be described with reference to Figures 7 to 13.

30 First, the substrate support 122 is provided in the vicinity of the wind turbine blade (not shown). As shown in Figure 7, the membrane 126 is supported in an application configuration in which a portion of the membrane 126 lies in a generally flat

configuration. This may be achieved by resting the membrane 126 against a flat support surface 145 in the form of a table.

Next, a layer of material 50 having a predetermined thickness, in this case liquid paint, is applied to the flat portion of the flexible membrane 126 using the applicator 124, as shown in Figure 8. The liquid paint is passed from the storage volume 42 to the dispensing container 40 via the transmission means 44. Once in the dispensing container 40, liquid paint is dispensed onto the flexible membrane 126 from the slot 46. The applicator 24 is dragged along the length of the flexible membrane to apply the layer of paint along the entire length or just part of the length of the flexible membrane 126.

The resulting layer of material 50 is of a uniform and predetermined thickness that is controlled by the size and shape of the slot 46. The layer of material may be of any suitable predetermined thickness, and is typically between 0.5 mm and 1 mm thick, though layers are also envisaged that are 5 mm or more in thickness. If the desired width of the layer of material is greater than that of the width of the slot 46, the applicator can be used to apply multiple layers of material in parallel on the substrate.

After application, the liquid paint 50 may be allowed to gel or partially cure. In particular the liquid paint may be allowed to gel until it has a sufficiently high viscosity that it will not flow under the action of gravity. This may take less than 5 minutes, and may, for example require a period of only 1 minute. At this stage, the membrane 126 can be moved without disturbing the layer of liquid material.

Once the layer of liquid paint has gelled sufficiently, the membrane 126 is then allowed to relax back into its concave configuration, shown in Figure 9. In this configuration, the layer of material 50 is ready to be applied to the leading edge 10 of a blade 12.

As shown in Figure 10, with the layer of material 50 now applied to the flexible substrate 126, the membrane 126 is arranged below the blade 12, with the left and right bodies 129 disposed at windward and leeward sides of the blade 12. The substrate support 122 is attached to the wind turbine blade 12 via the attachment arrangement. The adjustment mechanisms of the support arms 132 and the support plate 133 may be adjusted as required to account for the shape of the leading edge 10.

The layer of material 50 is then offered up to the leading edge 10 of the wind turbine blade 12.

To offer up the layer of material 50 to the leading edge 10, the membrane 126 is moved upwardly toward the blade. This is achieved by rotating the bodies 129 outwardly. This outward rotation of the bodies 129 causes the concave membrane 126 to rise towards the leading edge 10 of the blade 12 as has been described in detail above. Rotation of the bodies 129 continues until the layer of material 50 comes into contact with the leading edge 10 of the blade 12 as shown in Figure 11, at which point the membrane is in the presentation configuration.

Initial contact occurs between the convex tip of the leading edge 10 and the layer of material 50 at the lowermost point 144 of the concave membrane 126. In this way, the initial area of contact between the layer of material 50 and the leading edge 10 is relatively small, in this case being defined by a line of contact that runs along the tip of the leading edge 10.

The flexibility of the membrane 126, the relatively soft and thin material from which the membrane 126 is made, and the relatively low tautness of the membrane 126 at the time when contact is made, means that the layer of material 50 and the leading edge 10 can be brought into contact with one another very gently. This very gentle initial contact over a relatively small initial area means that there is very little displacement of the liquid paint within the layer of material 50 as contact is made. Thus, the layer of material 50 remains at, or close to, the predetermined thickness.

Furthermore, in embodiments where the layer of liquid paint has been allowed to partially pre-cure before it is arranged in contact with the leading edge, contact can be controlled such that it occurs only when the viscosity has increased to a level that is high enough to decrease the chance of thinning as the liquid paint is applied, but low enough to still give good adhesion. This further facilitates the ability to keep the layer of material 50 at, or close to, the predetermined thickness

After initial contact has been made, rotation of the bodies 129 continues further and the membrane 126 is pulled gradually more taut and raised gradually higher. As the bodies 129 continue to rotate, the flexible membrane 126 is pushed gradually further against the leading edge 10 of the blade 12.

As the flexible membrane 126 is pushed further against the leading edge 10, more of the layer of material 50 is pushed into contact with the leading edge 10. The minimum point 144 of the membrane 126 remains fixed against the leading edge 10, but the maximum

points are moved toward the blade 12, until the curvature of the membrane 126 matches the curvature of the leading edge 10.

Thus, the membrane 126 wraps around the leading edge 10 so that the area of contact between the layer of material 50 and the leading edge 10 gradually increases, with the
5 area of contact growing outwardly towards edges of the flexible membrane 126. The flexible membrane 126 therefore gradually wraps around the leading edge 10, adopting the contours of the leading edge 10 as it does so.

Gradually increasing the area of contact so as to grow the area towards the edges of the membrane means that the contact can remain consistently gentle. This gentle contact
10 guards against displacement of the liquid paint within the layer of material 50 as the area of contact increases. Growing the area of contact in this way also tends to cause air to be effectively expelled towards the edges of the membrane as the area of contact grows, which guards against air becoming trapped between the layer of material 50 and the leading edge 10 of the wind turbine blade 12.

Thus, the flexible membrane 126 and hence the layer of material 50 are wrapped around
15 the leading edge 10 of the wind turbine blade 12, so that the layer of material 50 is forced to adopt the contours of the leading edge 10 of the wind turbine blade 12. The layer of material 50 on the flexible membrane 126 also adopts the contours of the leading edge 10.

As the area of contact reaches the edges of the layer of material 50, some of the material
20 in the edge region is displaced slightly outwardly to give a layer thickness that tapers to zero in the edge region, as can be seen in the partial close-up inset into Figure 12. In this way, the wrapping motion provides a layer that is of substantially uniform thickness throughout the bulk of the layer, but provides a small edge region in which the thickness
25 of the layer tapers to zero. As a result, there is no step at the edge of the paint layer, unlike in conventional painting in which there is a step at the edge of the paint. The absence of the step at the edge of the paint layer gives the blade an improved aerodynamic performance during use.

As the bodies 129 rotate outwardly, the curved surface 134 of each body 129 progresses
30 towards the blade 12. By the time the membrane is in the transfer configuration shown in Figure 12, the curved surface 134 has coincided with the leading edge 10, such that a part of the curved surface 134 pushes against the leading edge 10.

The rotatable body 129 is configured such that when the curved surface 134 pushes against the leading edge, the region of contact between the leading edge 10 and the curved surface 134 is at a position that coincides with the edge of the layer of material 50. In this way, the action of the curved surface 134 pushing against the leading edge 10 can help to define the tapered edges of the layer of material 50.

The rotatable body 129 is also configured such that the part of the curved surface 134 that pushes against the leading edge 10 is defined by the layer of flexible material 150 at the rear of the body 129. This configuration can be ensured for a given blade 12 by adjusting the exact position of the rotatable bodies 129 relative to the leading edge 10 using the adjustment means of the substrate support 122.

By configuring the body 129 such that it is the layer of flexible material 150 that pushes against the leading edge 10, rather than an inflexible part of the curved surface 134, the shape of the curved surface at the point of contact can be adapted to match the exact contours of the leading edge, thereby ensuring a smooth edge at the edges of the layer of material. Furthermore, the comparatively soft and flexible nature of the surface at the point of contact guards against damage to the leading edge 10 that might otherwise occur.

Once the flexible membrane 126 has been sufficiently wrapped around the leading edge 10, the entirety of the layer of material 50 is in contact with the leading edge 10 and has adopted the contours of the leading edge 10. The flexible membrane 126 is then in the transfer configuration, which is shown in Figure 12.

In this transfer configuration, the tautness of the membrane 126 tends to exert an upward force on the leading edge. In this way, owing to the elastic properties of the membrane 126, the membrane 126 gently pushes the layer of material onto the leading edge.

Once the flexible membrane 126 has been arranged in the transfer configuration, the layer of material 50 is transferred to the leading edge 10 of the wind turbine blade 12.

After the transfer stage, the layer of material 50 is allowed to cure. This may involve simply waiting for a period of time for the material to cure at room temperature. It may also involve heating the layer of material to facilitate curing. To this end, a heating means (not shown) may be incorporated into the substrate support to heat the flexible membrane 126. Because the surface of the flexible membrane 126 is a non-stick surface, the layer of material 50 tends to bond more strongly to the surface of the leading edge 10 of the blade 12, and is thereby transferred from the flexible membrane 126 to

the leading edge 10. A release coating may be used to further facilitate transfer from the membrane to the leading edge. The smoothness of the membrane also provides for a particularly smooth finish on the external surface of the layer of material that is applied to the leading edge, which improves the aerodynamic performance of the blade.

- 5 Once a sufficient time period has elapsed the flexible membrane 126 is moved gently away from the leading edge 10 of the blade 12. As the flexible membrane 126 is moved away, the layer of material 50 remains in contact with the leading edge 10, as shown in Figure 13. The layer of material 50 is of substantially uniform and pre-determined thickness, except at the edge regions in which the thickness tapers to zero. The layer of
- 10 material 50 also has substantially no air bubbles, and is effectively bonded to the leading edge 10 of the wind turbine blade 12.

The apparatus 120 can then be used to apply further layers of material to the leading edge of the same blade or to the leading edge of different blades.

- A single piece of apparatus 120 may be use to apply the layer of material to the entire
- 15 leading edge if desired. Alternatively, a single piece of apparatus 120 may be use to apply the layer of material to only a part of the leading edge, and multiple sets of apparatus may be required to apply the layer of material to the entire leading edge.

In the embodiment described, the layer of material is a layer of liquid paint. However, the material need not be paint; for example, the material may be an adhesive or resin.

- 20 Embodiments are also envisaged in which a layer of a solid material is applied to the leading edge. For example, a solid film of a material 50 may be applied to the membrane 126 simply by placing it on the membrane 126 in a desired location. A layer of adhesive may then be applied to the surface of the solid film 50, using the applicator described, or by other means. For example, the layer of adhesive may be a solid layer of pressure
- 25 sensitive adhesive. The solid film 50 and adhesive may then be offered up to the leading edge 10 in the same way as described above, with the membrane 126 being arranged in the presentation configuration. The membrane 126 and hence the solid film 50 and adhesive layer may then be wrapped around the leading edge as described above, by rotating the rotatable bodies 129 outwardly to move the membrane 126 into the transfer
- 30 configuration. The layers may then be transferred to the leading edge 10, for example by curing the adhesive to adhere the solid film 50 to the leading edge 10. Using the apparatus to apply a solid film to the leading edge prevents voids forming between the film and the leading edge as air is expelled outwards toward the edges of the film.

In particular, the solid film may take the form of a pre-dried film of paint, and the adhesive may take the form of the paint in a liquid state, which acts as an adhesive. Alternatively the adhesive may have been pre-applied to the solid film before it is placed on the membrane.

- 5 Although in the exemplary embodiments described the layer of material that is applied to the leading edge of the wind turbine blade is a layer of paint, the material need not be a paint and may be, for example, an adhesive or other suitable type of material. The material may take the form of a liquid layer or a solid layer.

- 10 In the embodiment described the layer of paint is applied to the membrane when the membrane is supported on the substrate support. However, embodiments are also envisaged in which the membrane is removed from the substrate support when the paint is applied. Embodiments of the invention are also envisaged in which the membrane is supplied with the layer of material pre-applied to the membrane, and the membrane with the pre-applied layer is fixed to the substrate support to apply the layer of material to the
15 leading edge of the blade.

Although the invention is particularly effective in applying uniform layers of material to a leading edge of a wind turbine blade, it is also envisaged that the invention may be used to apply layers of non-uniform thickness. For example, the slot in the dispensing container may be shaped to as to provide a layer of varying thickness.

- 20 Although in the embodiment described the layer of liquid material is applied using an applicator of the sort shown in Figures 5 and 6, the layer of liquid material could be applied by other means, for example by pouring the liquid material onto the surface or using a device such as a brush or spatula.

- The method and apparatus described can be used to apply a layer of material to the
25 leading edge of the wind turbine blade during manufacture of the blade, or they can be used to apply a layer of material to the leading edge of the wind turbine blade in-situ when it is installed on wind turbine.

- The rotatable body may be of any suitable shape. For example, the rotatable body need not have a wedge-shaped cross-section but may have any suitable cross-section. For
30 example, the body may have a circular cross-section, which may be eccentrically mounted on the pivot axis.

The present invention is therefore not limited to the exemplary embodiments described above and many other variations or modifications will be apparent to the skilled person without departing from the scope of the present invention as defined in the following claims.

Claims

1. Apparatus for applying a layer of material (50) to a leading edge (10) of a wind turbine blade (12), the apparatus comprising:

a flexible substrate (126) capable of supporting the layer of material (50), the flexible substrate being reconfigurable between a presentation configuration in which a part of the layer of material contacts the leading edge (10) to define an initial area of contact, and a transfer configuration in which the flexible substrate, and thereby the layer of material, is wrapped around, and adopts the contours of, at least a part of the leading edge; and

a substrate support (122) for supporting the flexible substrate (126) in the presentation and transfer configurations;

wherein at least a part of the substrate support (122) is moveable to reconfigure the flexible substrate between (126) the presentation and transfer configurations, such that the layer of material (50) can be offered up to the leading edge (10) of the wind turbine blade (12) with the flexible substrate in the presentation configuration, and thereafter the flexible substrate can be reconfigured by increasing the area of contact between the layer of material and the leading edge until the flexible substrate is in the transfer configuration.

2. The apparatus of Claim 1, wherein, when the flexible substrate (126) is in the presentation configuration, at least a part of the flexible substrate is arranged to present a concave surface to the leading edge (10) of the wind turbine blade (12).

3. The apparatus of Claim 1 or Claim 2, wherein the substrate support (122) is configured to change the curvature of the flexible substrate (126) as the flexible substrate is moved between the presentation and transfer configurations.

4. The apparatus of any preceding claim, wherein the substrate support (122) comprises a rotatable body (129), and wherein the flexible substrate is fixed to the rotatable body at a fixing point (142), such that a part of the flexible substrate wraps around the rotatable body as the rotatable body rotates.

5. The apparatus of Claim 4, wherein the rotatable body (129) is eccentrically mounted on a pivot axis (138).

6. The apparatus of Claim 5, wherein the rotatable body (129) comprises a curved surface (134), at least a portion of which is of increasing radius with respect to the pivot axis

(138), and wherein the substrate support (122) is configured such that a part of the flexible substrate (122) wraps around the portion of increasing radius as the rotatable body rotates.

7. The apparatus of any of claims 4 to 6, wherein at least a part of the surface of the rotatable body (129) is defined by a flexible and/or compressible material (150).

8. The apparatus of Claim 7, wherein the flexible and/or compressible material (150) is provided as a layer at the surface of the rotatable body (129).

9. The apparatus of Claim 7 or Claim 8, wherein the substrate support (122) is configured such that, when the flexible substrate (126) is in the transfer configuration, the part of the surface that is defined by the flexible material (150) pushes against the leading edge (10) of the blade (12).

10. The apparatus of any of Claims 4 to 9, wherein the substrate support (122) comprises windward and leeward rotatable bodies (129) configured to be arranged at windward and leeward sides of the leading edge (10), and wherein the flexible substrate (126) is configured to be fixed to, and extend between, the windward and leeward rotatable bodies.

11. The apparatus of any preceding claim, wherein the substrate support (122) comprises an attachment arrangement (132, 133) for attaching the substrate support to the wind turbine blade (12).

12. The apparatus of Claim 11, wherein the attachment arrangement (132, 133) comprises an adjustment part for adjusting the position of the substrate support (122) relative to the wind turbine blade.

13. The apparatus of Claim 12, wherein the attachment arrangement (132, 133) comprises support arms (132) for spacing the moveable part of the substrate support away from the wind turbine blade, and wherein the support arms are adjustable to vary the spacing between the moveable part of the substrate support and the wind turbine blade.

14. The apparatus of Claim 12 or Claim 13, wherein the attachment arrangement comprises an attachment plate (133) for attachment to the wind turbine blade (12), and wherein the attachment plate is adjustable to vary the position of the moveable part of the substrate support relative to the attachment plate.

15. The apparatus of any preceding claim, wherein the apparatus comprises an applicator (124) for applying a layer of material (50) to the flexible substrate (126).
16. The apparatus of Claim 15, wherein the applicator (124) comprises a container (40) provided with slot (46) for dispensing the material onto the flexible substrate (126).
17. The apparatus of any preceding claim, wherein the flexible substrate (126) comprises a flexible membrane.
18. The apparatus of Claim 17, wherein the flexible membrane (126) has thickness that is less than approximately 2 mm.
19. The apparatus of Claim 17 or Claim 18, wherein the flexible membrane (126) is made of a material selected from the group of: silicon rubber, polyurethane, polyethylene, polypropylene or nylon.
20. The apparatus of any preceding claim, wherein the substrate support (122) comprises an actuator (128) for effecting movement of the moveable part of the substrate support.
21. A method of applying a layer of material (50) to a leading edge (10) of a wind turbine blade (12), the method comprising:
 providing a layer of material (50) on a flexible substrate (126),
 arranging the flexible substrate (126) in relation to the leading edge (10) of the wind turbine blade (12) with the flexible substrate in a presentation configuration such that an initial area of contact is defined between the layer of material and the leading edge;
 reconfiguring the flexible substrate (126) into a transfer configuration in which the flexible substrate adopts to the contours of the leading edge (10) by increasing the area of contact between the layer of material and the leading edge; and
 transferring the layer of material (50) from the flexible substrate (126) to the leading edge (10) of the wind turbine blade (12).
22. The method of Claim 21, wherein, when the flexible substrate (126) is in the presentation configuration, at least a part of the flexible substrate is arranged to present a substantially concave surface to the leading edge (10) of the wind turbine blade (12).

23. The method of Claim 22, wherein the concave surface of the flexible substrate (126) in the presentation configuration defines a minimum point (144), and wherein the step of arranging the flexible substrate in the presentation configuration comprises moving the minimum point of the concave surface towards the leading edge (10) of the blade (12) until the layer of material (50) meets the leading edge.

24. The method of Claim 23, wherein the flexible substrate (126) is fixed to a rotatable body (129) and the method comprises rotating the rotatable body around a pivot axis (138) to wrap a part of the flexible substrate (126) around the rotatable body to effect moving of the minimum point (144) of the concave surface towards the leading edge (10) of the blade (12).

25. The method of any of Claims 22 to 24, wherein the flexible substrate (126) is fixed to a rotatable body (129) and the step of reconfiguring the flexible substrate into the transfer configuration comprises rotating the rotatable body to wrap a part of the flexible substrate around the rotatable body.

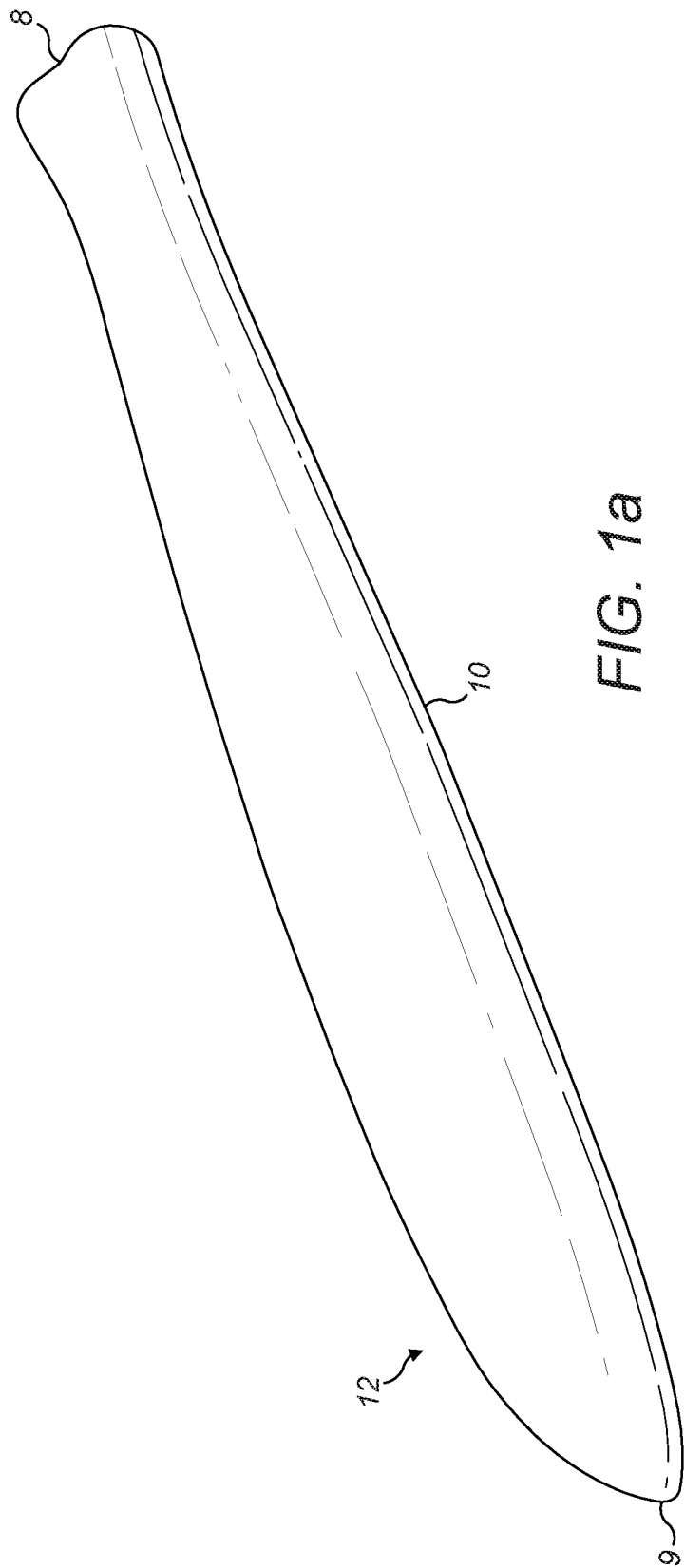
26. The method of any of Claims 22 to 25, wherein the concave surface of the flexible substrate (126) in the presentation configuration defines a maximum point (146), and wherein the step of arranging the flexible substrate in the presentation configuration comprises moving the maximum point of the surface towards the leading edge (10) until the layer of material (50) meets the leading edge.

27. The method of any of Claims 22 to 26, wherein the surface of the flexible substrate in the presentation configuration defines a maximum point (146), and wherein the step of reconfiguring the flexible substrate into the transfer configuration comprises moving the maximum point towards the leading edge (10).

28. The method of Claim 26 or Claim 27, when dependent on Claim 23 or Claim 24, wherein at least a part of the rotatable body (129) is eccentrically mounted on the pivot axis (138), and wherein the step of moving the maximum point of the surface towards the leading edge of the blade comprises rotating the rotatable body such that a part of the substrate is wrapped around the eccentrically-mounted part of the rotatable body.

29. The method of any of Claims 21 to 28, wherein the step of providing a flexible substrate (126) having a layer of material (50) applied thereon comprises applying a layer of material to a flexible substrate.

30. The method of Claim 29, comprising arranging the flexible substrate (126) in a substantially flat application configuration before applying the layer of material (50) to the flexible substrate.
31. The method of Claims 21 to 30, wherein the layer of material (50) applied to the flexible substrate (126) comprises a liquid layer.
32. The method of Claims 21 to 30, wherein the layer of material (50) applied to the flexible substrate (126) comprises a solid layer.
33. The method of Claim 32, wherein the layer of material applied to the flexible substrate further comprises a layer of adhesive.
34. The method of any of Claims 21 to 33, wherein the step of transferring the layer of material (50) from the flexible substrate (126) to the leading edge of the wind turbine blade comprises curing the layer of material on the flexible substrate.
35. The method of any of Claims 21 to 34, wherein the layer of material (50) is applied to the blade in-situ on a wind turbine.
36. The method of any of Claims 21 to 35, wherein the method comprises supporting the flexible substrate (126) on a substrate support (122) and fixing the substrate support to the wind turbine blade (12) to apply the layer of material (50) to the leading edge (10).



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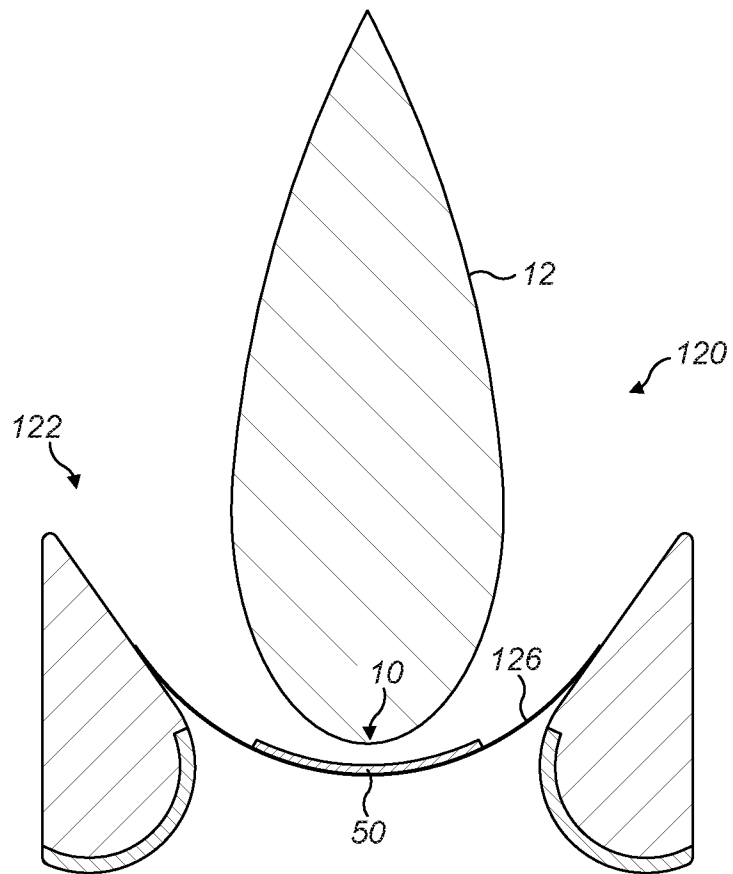


FIG. 1b

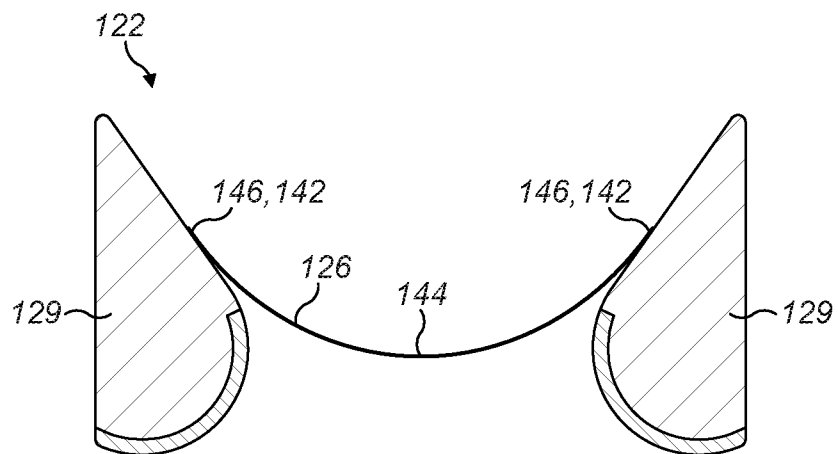


FIG. 2a

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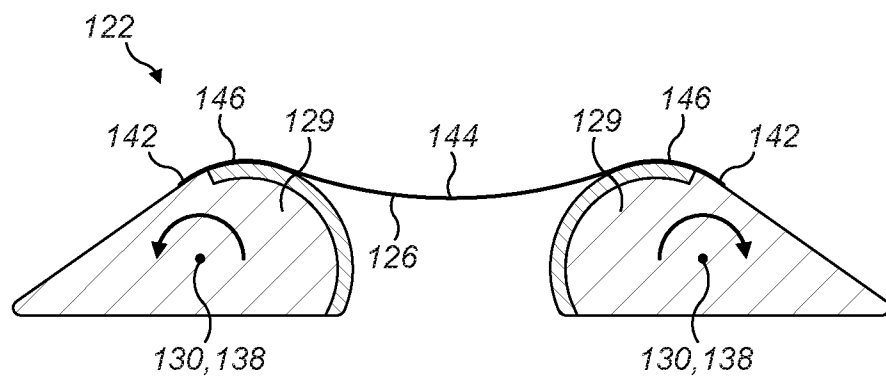


FIG. 2b

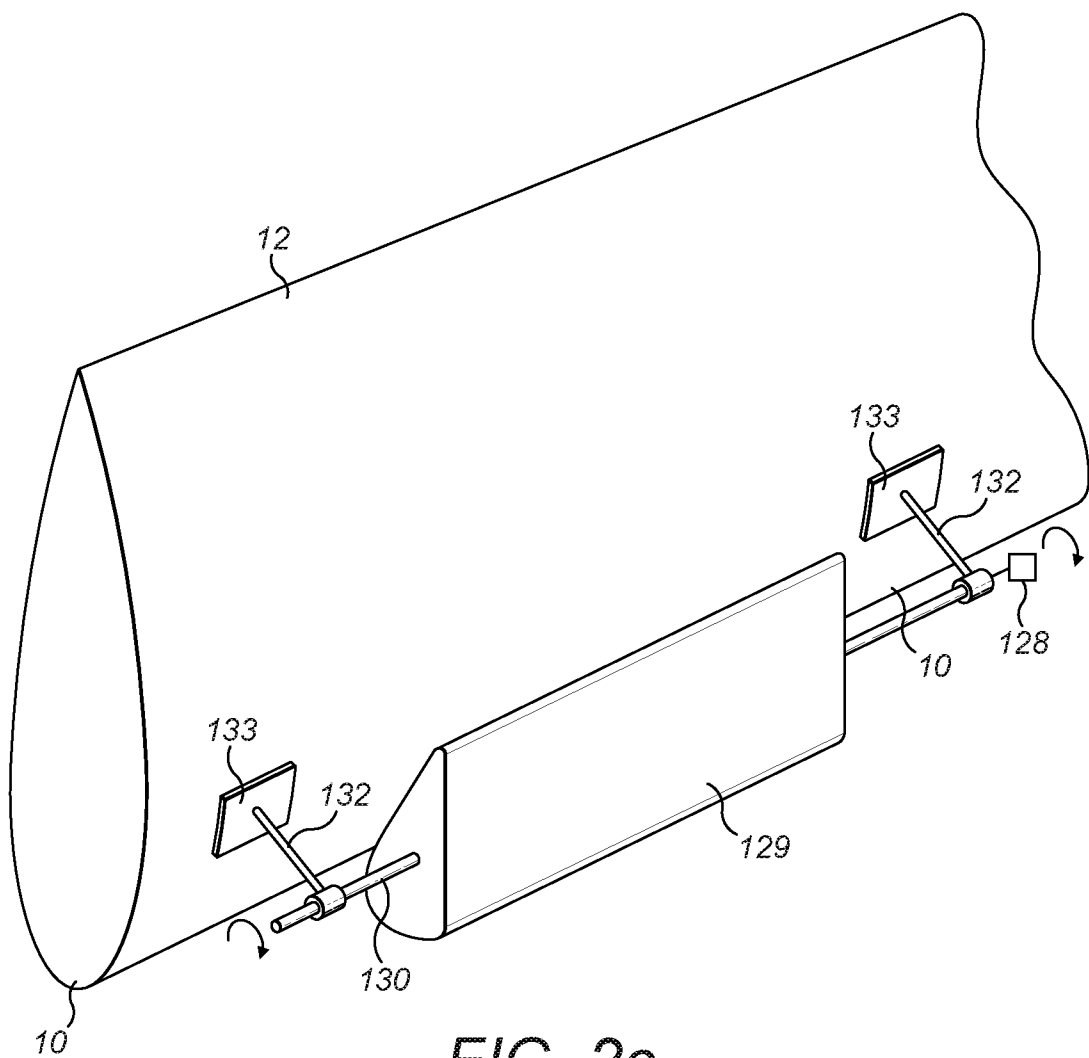


FIG. 2c

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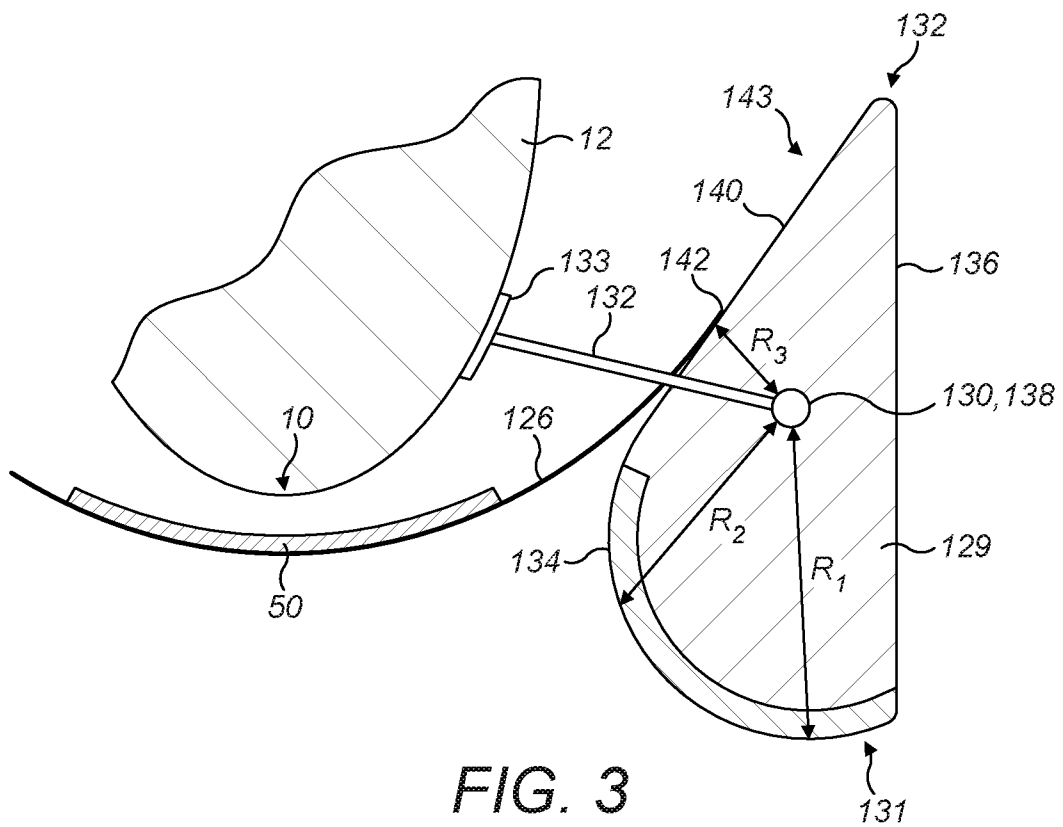


FIG. 3

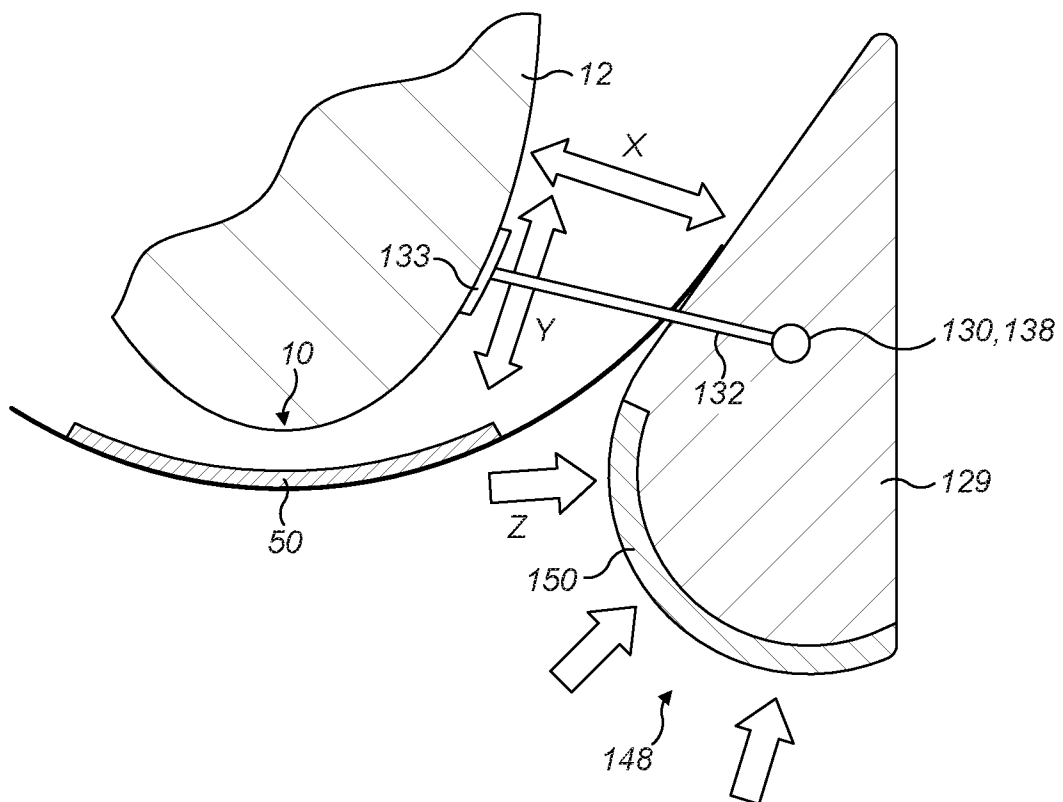


FIG. 4

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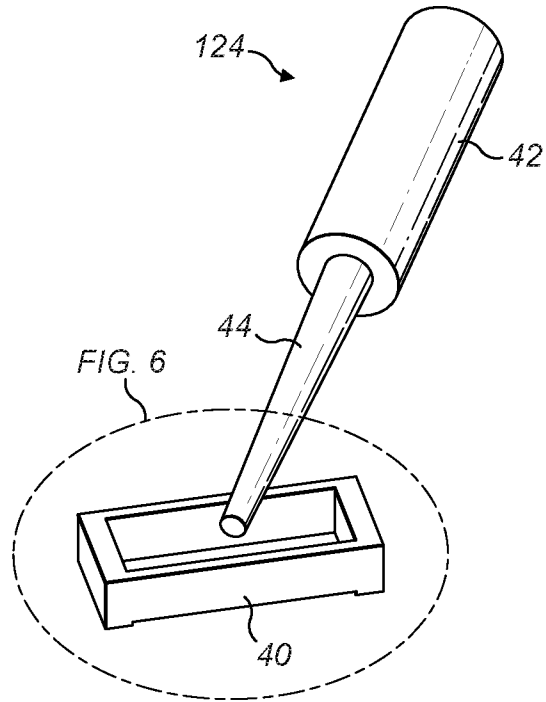


FIG. 5

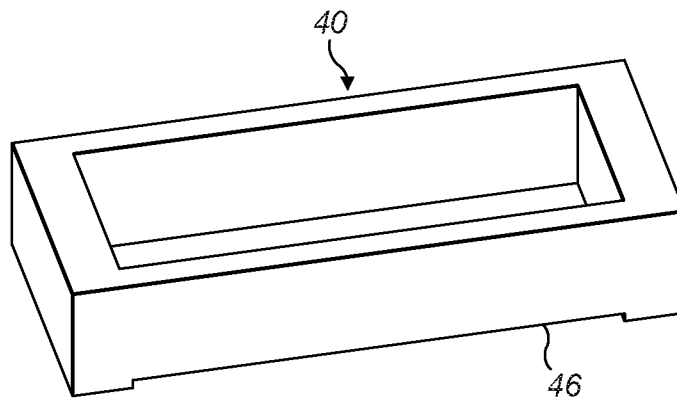


FIG. 6

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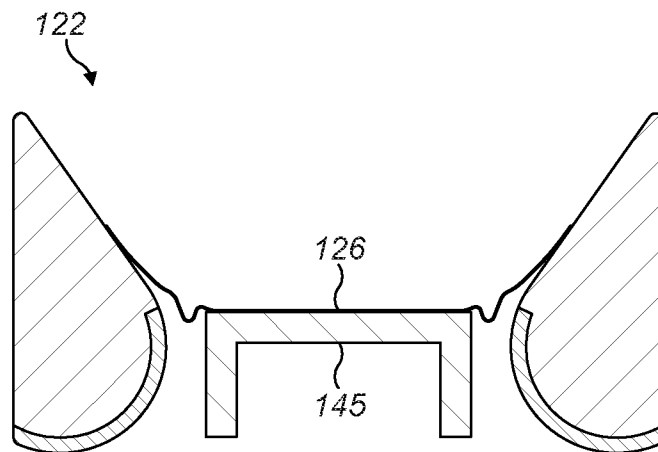


FIG. 7

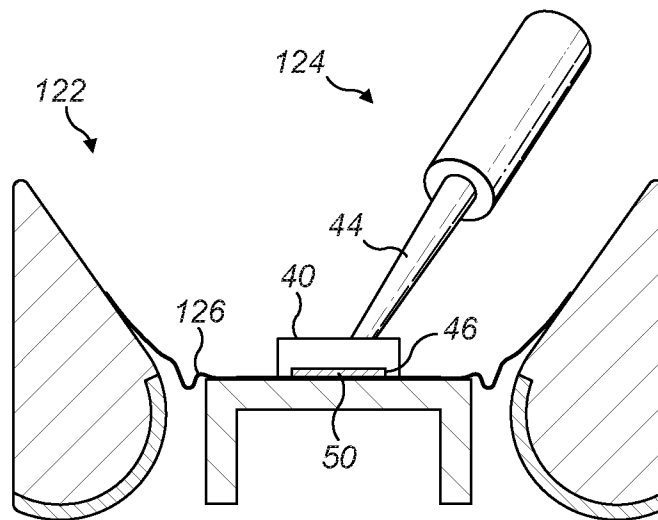


FIG. 8

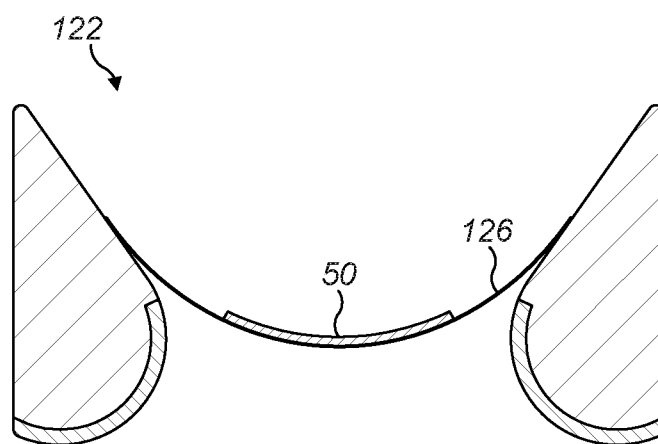


FIG. 9

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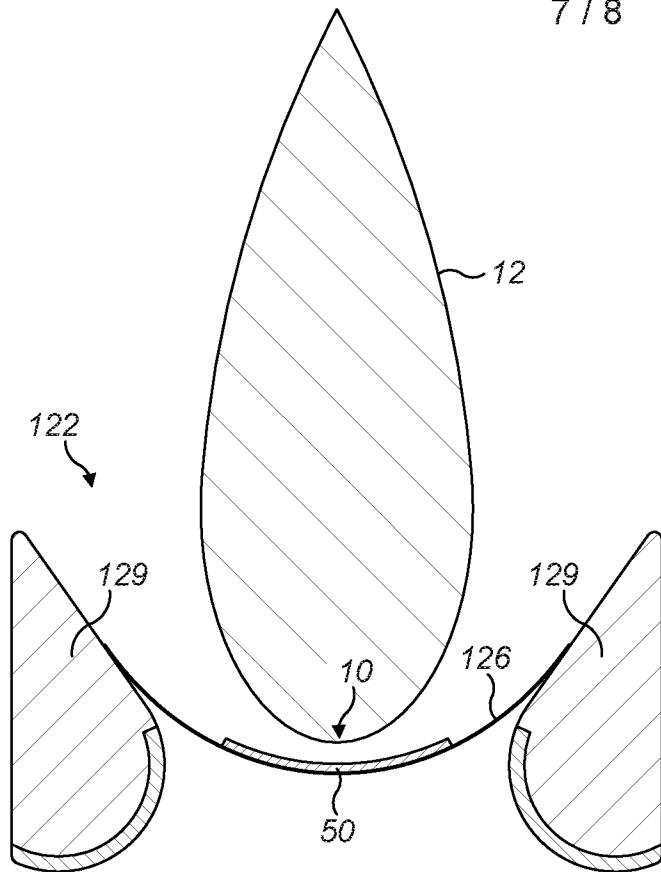


FIG. 10

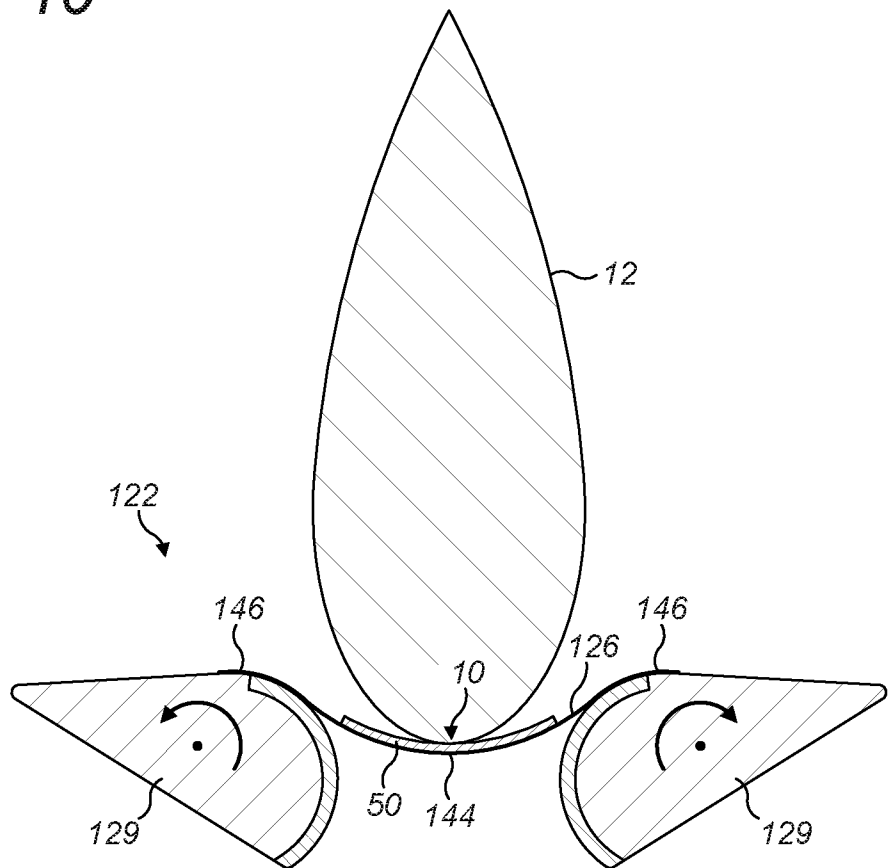


FIG. 11

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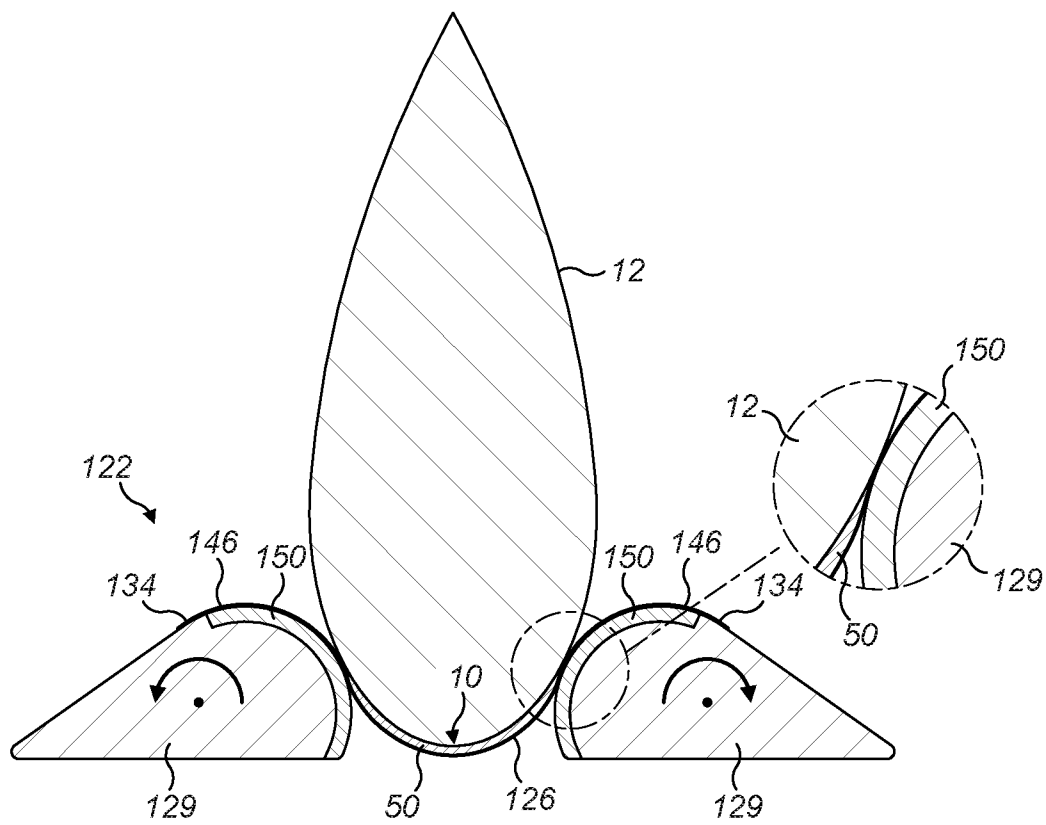


FIG. 12

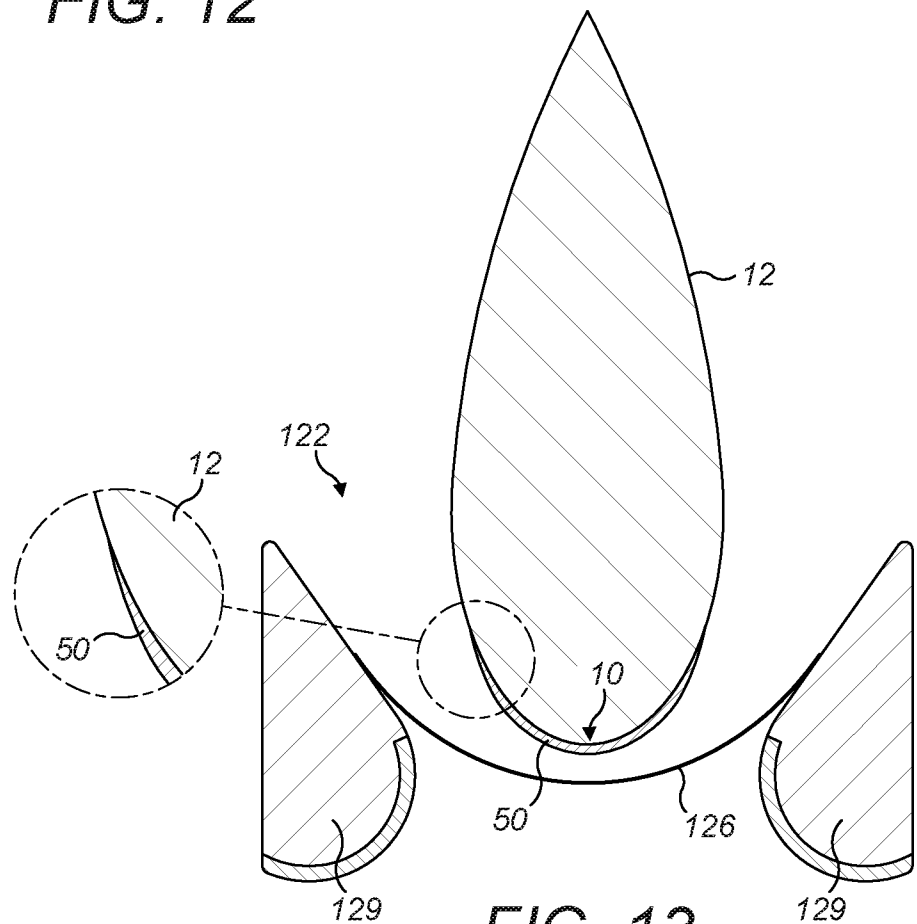


FIG. 13

INTERNATIONAL SEARCH REPORT

International application No

PCT/DK2016/050430

A. CLASSIFICATION OF SUBJECT MATTER

INV. B29C63/00 B29C63/04
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)

B29C

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

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2009/295015 A1 (KUNTZ MICHAEL P [US] ET AL) 3 December 2009 (2009-12-03) figures 6-16 and relating description -----	1-36
X	GB 412 300 A (HEINRICH SUKOHL; GUSTAV SCHWARZ G M B H) 28 June 1934 (1934-06-28) figure 6 -----	1-36
A	DE 689 03 896 T2 (GUILHEM CHRISTIAN [FR]) 24 June 1993 (1993-06-24) figures 1-7 -----	1-36



Further documents are listed in the continuation of Box C.



See patent family annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

20 February 2017

Date of mailing of the international search report

28/02/2017

Name and mailing address of the ISA/

European Patent Office, P.B. 5818 Patentlaan 2
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Authorized officer

Schneider, Dominik

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/DK2016/050430

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