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(54) Titel: **WIND TURBINE BLADE VORTEX GENERATORS**

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(57) Sammendrag:
A wind turbine blade comprising: a root end for connecting the wind turbine blade to a wind turbine hub, a tip end opposite the root end, a leading edge; a trailing edge, a pressure surface extending between the leading edge and the trailing edge, and a suction surface extending between the leading edge and the trailing edge; and a plurality of pairs of vortex generators disposed on the suction surface, each vortex generator having a vane aligned at an angle to the leading edge, and each pair of vortex generators comprising two nearest adjacent vortex generators, wherein the vanes of a first pair of the vortex generators converge in a direction from the leading edge to the trailing edge, and the vanes of a second pair of the vortex generators diverge in the direction from the leading edge to the trailing edge; and wherein the first pair of vortex generators is situated nearer to the root end than the second pair of vortex generators is.

Fortsættes...

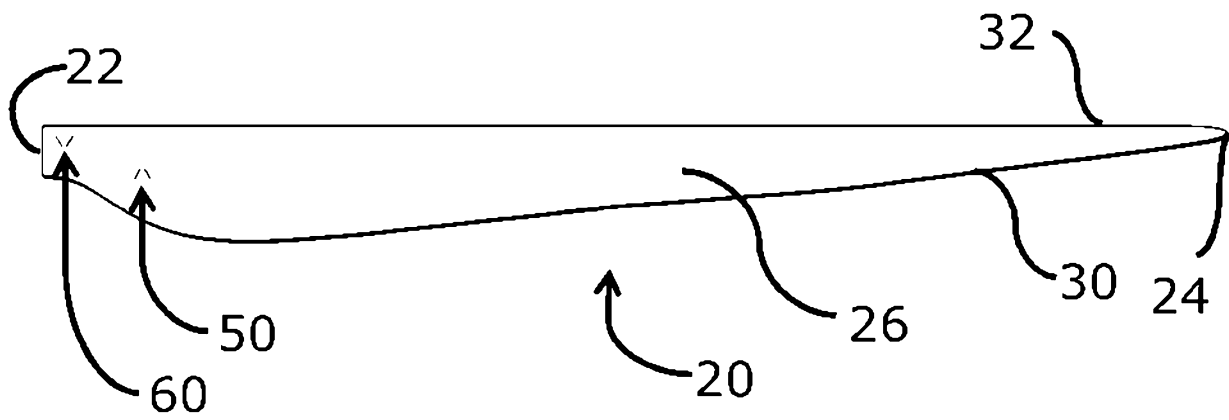


Fig. 8

WIND TURBINE BLADE VORTEX GENERATORS

FIELD OF THE INVENTION

The invention relates to the field of improving the aerodynamic performance of wind turbine blades.

BACKGROUND TO THE INVENTION

WO 2013/014080 A2 discloses a method for retrofitting vortex generators on a wind turbine blade. However, further improvements in aerodynamic performance of wind turbine blades are desirable.

SUMMARY OF THE INVENTION

According to a first aspect, there is provided a wind turbine blade comprising: a root end for connecting the wind turbine blade to a wind turbine hub, a tip end opposite the root end, a leading edge, a trailing edge, a pressure surface extending between the leading edge and the trailing edge and a suction surface extending between the leading edge and the trailing edge; and a plurality of pairs of vortex generators disposed on the suction surface, each vortex generator having a vane aligned at an angle to the leading edge, and each pair of vortex generators comprising two nearest adjacent vortex generators, wherein the vanes of a first pair of the vortex generators converge in a direction from the leading edge to the trailing edge, and the vanes of a second pair of the vortex generators diverge in the direction from the leading edge to the trailing edge; and wherein the first pair of vortex generators is situated nearer the root end than the second pair of vortex generators is.

With such an arrangement, the aerodynamic performance of the wind turbine blade can be improved.

In an embodiment, at any spanwise point the wind turbine blade has a cross section, the cross section having a chord which is the longest straight line distance between the leading edge and the trailing edge and a thickness perpendicular to the chord, and wherein the first pair of vortex generators is located where the cross section has a thickness to chord ratio of approximately 0.6 or greater and the second pair of vortex

generators is located where the cross section has a thickness to chord ratio of between approximately 0.6 and approximately 0.3. With such an arrangement, the amount of lift generated by the wind turbine blade can be increased and the drag experienced by the wind turbine blade can be reduced.

- 5 In an example, the vortex generator vanes of each pair of vortex generators are spaced from each other by a distance D measured between the ends of the vanes of the vortex generators of the pair of vortex generators nearer the trailing edge of the wind turbine blade and each vortex generator pair is spaced from an adjacent vortex generator pair by a distance S measured between the ends of the vanes of adjacent vortex generators
10 nearer the trailing edge of the wind turbine blade such that S is greater than or equal to D .

The distance S can be $3.5D$ or greater for converging vortex generator pairs and/or can be $2D$ or greater for diverging vortex generator pairs.

- Which such an arrangement, the pairs of vortex generators are sufficiently closely
15 spaced to produce the desired flow characteristics, without causing undesirable side effects to adjacent pairs of vortex generators. In an example, each pair of vortex generators substantially has mirror symmetry. With such an arrangement, the vortex generators can be arranged such that zero spanwise vorticity is introduced into the flow. The vanes of the vortex generators are purely passive devices.

- 20 In an example, the vortex generators of the first pair converge at an angle between approximately 20 degrees and approximately 50 degrees, optionally between approximately 40 and approximately 50 degrees. With such an arrangement, counter rotating vortices of an appropriate strength are produced.

- In an example, the vortex generators of the second pair diverge at an angle between
25 approximately 30 degrees and approximately 50 degrees, optionally between approximately 30 and approximately 40 degrees. With such an arrangement, the second pair of vortex generators produces counter rotating vortices of an appropriate strength.

- In an example, the vortex generators of each pair of vortex generators are connected
30 to a common panel having a shape which is arranged to conform to the suction surface of the wind turbine blade. With such an arrangement, the vortex generators may be more easily retrofitted to existing wind turbine blades.

In an example, the wind turbine blade further comprises a plurality of the first pairs of vortex generators and/or a plurality of the second pairs of vortex generators, and the plurality of the first pairs of vortex generators are arranged along a first line and/or the plurality of second pairs of vortex generators are arranged along a second line. With
5 such an arrangement, the vortex generators may be positioned so that each vortex generator is a short distance upstream of a separation point in a flow path so that flow attachment can be achieved over a greater portion of the suction surface.

In an example, the first line and/or the second line are straight or curved, optionally wherein the first line and the second line form a single straight line. With such an
10 arrangement, the vortex generators form a formation appropriate for following just upstream of the separation line along a wind turbine blade suction surface.

In an example, the vortex generators are configured such that vortices produced by each vortex generator of a vortex generator pair interact to form a combined vortex structure. With such an arrangement, the vortex generators can have an improvement
15 on the aerodynamic performance of the wind turbine blade which is greater than what would be expected by summing the individual effects of each vortex generator vane.

In an example, the vanes of the vortex generators have a height, H , measured from the blade surface of the wind turbine blade to a point on the vane of the vortex generator furthest from the blade surface, and the vortex generators of a pair of vortex
20 generators are spaced apart a distance, D , measured between the ends of the vanes of the vortex generators of a pair of vortex generators nearer the trailing edge of the wind turbine blade, and: D is between approximately 2 and 5 times, optionally between 2 and 3 times, H for the first pair of vortex generators and/or D is between approximately 3 and 6 times H for the second pair of vortex generators. With such an
25 arrangement, the vortex generators of each pair of vortex generators have flow interactions which result in greater vorticity.

According to a second aspect, there is provided a wind turbine comprising at least one wind turbine blade according to the first aspect.

According to a third aspect, there is provided a method of arranging vortex generators
30 on a wind turbine blade, comprising: providing a wind turbine blade having a root end for connecting the wind turbine blade to a wind turbine hub, a tip end opposite the root end, a leading edge, a trailing edge, a pressure surface extending between the leading edge and the trailing edge, and a suction surface extending between the leading edge and the trailing edge; providing a plurality of pairs of vortex generators, each vortex

generator having a vane aligned at an angle to the leading edge, and each pair of vortex generators comprising two nearest adjacent vortex generators, attaching the pairs of vortex generators to the suction surface of the wind turbine blade, wherein the vanes of a first pair of the vortex generators converge in a direction from the leading edge to the trailing edge and the vanes of a second pair of the vortex generators diverge in the direction from the leading edge to the trailing edge; and wherein the first pair of vortex generators is situated nearer to the root end than the second pair of vortex generators is. With such an arrangement, there is provided a method for arranging vortex generators to improve aerodynamic performance of a wind turbine blade.

In an example, the vortex generators of each pair of vortex generators are attached to a common panel or baseplate. With such an arrangement, the vortex generator pairs can be easily attached to the suction surface of the wind turbine blade.

In an example, the method further comprises forming each pair of vortex generators and common panel as a single element. With such an arrangement, the manufacture of each pair of vortex generators can be made simpler.

In an example, the method further comprises providing a plurality of the first pairs of vortex generators and/or a plurality of the second pairs of vortex generators, and attaching the plurality of first pairs of vortex generators and/or the plurality of second pairs of vortex generators to the suction surface of the wind turbine blade. With such an arrangement, a sufficient number of vortex generators are provided to have a substantial effect on the aerodynamic performance of the wind turbine blade.

In an example, the wind turbine blade is the wind turbine blade according to the first aspect.

In an example, the method further comprises attaching the wind turbine blade to a wind turbine. With such an arrangement, the method provides a more complete system for generating electricity.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 shows a wind turbine;

Figure 2 shows a wind turbine blade;

Figure 3 shows a cross section of the wind turbine blade taken along line A-A;

Figure 4 shows a cross section of the wind turbine blade taken along line B-B;

Figure 5 shows a diverging vortex generator pair;

5 Figure 6 shows a converging vortex generator pair;

Figure 7 shows two adjacent diverging vortex generator pairs;

Figure 8 shows a wind turbine blade having two vortex generator pairs;

Figure 9 shows a portion of a wind turbine blade having multiple vortex generator pairs;

Figure 10 shows a portion of a wind turbine blade having multiple vortex generator
10 pairs; and

Figure 11 shows a vortex generator pair having a common panel.

DETAILED DESCRIPTION OF EMBODIMENT(S)

In this specification, terms such as leading edge, trailing edge, pressure surface,
15 suction surface, thickness and chord are used. While these terms are well known and
understood to a person skilled in the art, definitions are given below for the avoidance
of doubt.

The term leading edge is used to refer to an edge of the blade which will be at the front
of the blade as the blade rotates in the normal rotation direction of the wind turbine
20 rotor.

The term trailing edge is used to refer to an edge of a wind turbine blade which will be
at the back of the blade as the blade rotates in the normal rotation direction of the wind
turbine rotor.

The chord of a blade is the straight line distance from the leading edge to the trailing
25 edge in a given cross section perpendicular to the blade spanwise direction.

A pressure surface (or windward surface) of a wind turbine blade is a surface between
the leading edge and the trailing edge, which, when in use, has a higher pressure than
a suction surface of the blade.

A suction surface (or leeward surface) of a wind turbine blade is a surface between the leading edge and the trailing edge, which will have a lower pressure acting upon it than that of a pressure surface, when in use.

5 The thickness of a wind turbine blade is measured perpendicularly to the chord of the blade and is the greatest distance between the pressure surface and the suction surface in a given cross section perpendicular to the blade spanwise direction.

The term spanwise is used to refer to a direction from a root end of a wind turbine blade to a tip end of the blade, or vice versa. When a wind turbine blade is mounted on a wind turbine hub, the spanwise and radial directions will be substantially the same.

10 Figure 1 shows a wind turbine 10 including a nacelle 12 supported on a tower 13 that is mounted on a foundation 14. The wind turbine 10 depicted here is an onshore wind turbine such that the foundation 14 is embedded in the ground, but the wind turbine 10 could be an offshore installation in which case the foundation 14 would be provided by a suitable marine platform, such as a monopile or jacket.

15 The nacelle 12 supports a rotor 15 comprising a hub 16 to which three blades 20 are attached. It will be noted that the wind turbine 10 is the common type of horizontal axis wind turbine (HAWT) such that the rotor 15 is mounted at the nacelle 12 to rotate in a normal direction of rotation, R, about a substantially horizontal axis defined at the centre at the hub 16. As is known, the blades 20 are acted on by the wind which causes
20 the rotor 15 to rotate about its axis thereby operating generating equipment through a gearbox that are housed in the nacelle 12. The generating equipment and gearbox are not shown in figure 1 since it is not central to the examples of the invention.

Figure 2 shows one of the wind turbine blades 20 having a root end 22 for connecting the wind turbine blade 20 to the hub 16 of the wind turbine 10. Opposite the root end 22 is a tip end 24. A leading edge 32 extends from the root end 22 to the tip end 24.
25 Opposite the leading edge 32 is the trailing edge 30, which also extends between the root end 22 and the tip end 24.

Between the leading edge 32 and the trailing edge 30, a pressure surface 28 can be seen on the underside of the blade in the view and a suction surface 26 can be seen
30 extending between the leading edge 32 and the trailing edge 30, opposite the pressure surface 28.

Figure 3 shows the cross section through the wind turbine blade 20 taken along line A-A. In the cross section, the leading edge 32, the trailing edge 30, the suction surface 26 and the pressure surface 28 can be seen. The chord measurement of the cross section is shown as the dimension labelled C, extending between the leading edge 32 and the trailing edge 30 and the thickness measurement can be seen from the dimension labelled T, which is perpendicular to the chord measurement C.

As can be seen from figure 3, this section of the wind turbine blade has a cross section which is substantially circular, because the blade near the root must have sufficient structural strength to support the blade outboard of that section and to transfer loads into the hub 16.

The blade 20 transitions from a circular profile to an aerofoil profile moving from the root end 22 of the blade towards a "shoulder" of the blade, which is the widest part of the blade where the blade has its maximum chord. The blade 20 has an aerofoil profile of progressively decreasing thickness in an outboard portion of the blade, which extends from the shoulder to the tip end 24.

The cross section of figure 3 will have a high aerodynamic drag due to separation of the flow from the suction surface 26 at a point approximately a third of the way or more from the leading edge to the trailing edge. The separation is caused by the boundary layer on the section surface 26 losing energy and speed as it travels over the surface. This problem can be reduced by the use of vortex generators to introduce fast moving air from the freestream flow (above the boundary layer) into the boundary layer in order to energise the boundary layer and keep the flow attached.

As can be seen from figure 3, the thickness to chord ratio (also known as the relative thickness) is approximately 0.9.

Figure 4 shows a cross section of the wind turbine blade 20 taken along line B-B. As can be seen, at this position further outboard than the cross section shown in figure 3, the wind turbine blade 20 has a cross section which more closely resembles an aerofoil. However, the shape of the cross section is still partially determined by structural requirements and so the cross section of the blade at this point will produce relatively high drag and low lift due to separation of the flow from the suction surface 26, compared to an aerofoil outboard of the shoulder of the blade, the shoulder of the blade being the spanwise section at which the chord of the blade is longest.

It can be seen from figure 4 that the relative thickness is less than that of the cross section of figure 3, but still relatively high.

In view of the above-mentioned shortcomings of wind turbine blade aerodynamic performance, there is a requirement to increase flow attachment over the suction surface at portions of the blade where the relative thickness is high, in the region between the circular root end and the shoulder.

In order to increase flow attachment over the suction surface 26, vortex generators can be attached to the suction surface 26. Further, the vortex generators can be arranged in pairs and these pairs can be either converging or diverging.

Convergence or divergence of a pair of vortex generators is defined along the intended direction of flow over the wind turbine blade, which is from the leading edge to the trailing edge. A converging pair of vortex generators has a pair of vanes which are separated by a distance which decreases in a direction from the leading edge to the trailing edge. A diverging pair of vortex generators has a pair of vanes which are separated by a distance which increases in a direction from the leading edge to the trailing edge.

Figure 5 shows a pair of diverging vortex generators 50. The diverging pair 50 has two separate vortex generator vanes 52, which are arranged to exhibit mirror symmetry about mirror line P. The intended direction of air flow F over the vortex generator (from the leading edge to the trailing edge) is also shown. The vortex generators have a length L which is the length of the vortex generators along the suction surface, when the vortex generators are connected to a suction surface. Each vortex generator also has a height h_{VG} , which is the distance from the suction surface to a point on the vortex generator furthest from the suction surface. Typically, this point will be at the end of the vortex generators nearest the trailing edge.

While delta type vortex generators are shown in figure 5, it will be known to a skilled person that other shapes of vortex generators could alternatively be used, such as rectangles or trapezia or cropped delta. The vanes of the vortex generators may extend generally orthogonal to the blade surface.

The diverging vortex generators are angled to the mirror line P at an angle β . The angle β between each vortex generator vane 52 and the central mirror line P will be between 15° and 25° , meaning that the vanes 52 diverge from each other at an angle of between 30° and 50° . It will be known to a person skilled in the art that different angles of divergence may be used in different applications, such as where a different suction surface profile is present or where a different wind speed is present.

The separation of the vortex generator vanes 52 is defined by the distance D, which is measured between the ends of the vortex generators vanes 52 which are nearer to the trailing edge. The distance, d, is the separation between the ends of the vortex generator vanes 52 nearer to the leading edge.

Diverging vortex generators are better suited for maintaining attached flow for longer chordwise distances than converging vortex generators, meaning that they are not as suited for use where there is a significant adverse pressure gradient. However, where separation is likely and the adverse pressure gradient is less severe, they can ensure attachment of the boundary layer over the suction surface for a longer distance since the vortex generated by the vanes of a pair dissipates less quickly i.e. over a longer distance downstream.

This is because diverging vortex generator pairs will produce counter-rotating vortices which directs the flow towards the blade surface (i.e. downwards between vortex cores), making the vortex pair and the mixing process more effective over longer distances downstream, delaying vortex break-up and decay in the process. The delay in vortex decay can be linked to the reduction of the interaction between the viscous cores of the neighbouring vortices. Figure 6 shows a converging vortex generator pair 60 made of two vortex generator vanes 62. Labels that are the same as those used in figure 5 are not repeated here for brevity. A typical convergence angle β between a vortex generator vane 62 and the central mirror line P would be between 10° and 25° , meaning that the vortex generator vanes 62 converge towards each other at an angle of between 20° and 50° .

Converging vortex generators produce a more immediate vorticity than diverging vortex generators in order to ensure some level of increase in flow attachment, although there is a drawback that the vortex generated by the vanes of a pair will dissipate faster i.e. over a shorter distance downstream. This makes converging vortex generators desirable in flows where there is a strong adverse pressure gradient.

This is because converging vortex generators will produce counter-rotating vortices which directs the flow away from the blade surface (i.e. upwards between vortex cores), which is more effective because the strength of the combined vortex pair is immediate, resulting in increased turbulent stresses between the vortex cores. Over longer
5 downstream distances, however, converging vortex generator pairs becomes less effective because the combined vortex pair starts to migrate away from the blade surface causing the mixing process to be reduced and the vortices to disperse and decay sooner. The accelerated decay can be associated with the interaction between the viscous cores of the closely neighbouring vortices which grow in size as they
10 propagate downstream.

It has been found that a converging vortex generator pair placed on a wind turbine blade at a spanwise location where the cross section has a high relative thickness can reduce drag more effectively than a diverging vortex generator pair. For example, a spanwise location of the blade where the relative thickness is greater than
15 approximately 0.6 would have a strong adverse pressure gradient on the suction surface. The use of a converging vortex generator pair results in a relatively strong vortex to counteract the strong adverse pressure gradient and so promote flow attachment over the suction surface, albeit over a relatively short distance downstream, thus reducing drag. By contrast a diverging vortex generator pair at this location may
20 produce an insufficiently strong vortex to promote flow attachment by comparison to a converging vortex generator pair.

Regarding spanwise locations on a wind turbine blade where the relative thickness is between approximately 0.6 and 0.3, it has been found that the adverse pressure gradient in these locations is typically less strong than in regions where the relative
25 thickness is greater than 0.6. Hence, diverging vortex generator pairs can be beneficially used at these locations to maintain the attached flow. The vortices produced by diverging vortex generator pairs have a delayed effect as compared to the vortices produced by similarly dimensioned converging vortex generator pairs. Accordingly the flow attachment can be maintained for a greater downstream distance
30 by using diverging vortex generator pairs than by using converging vortex generator pairs at spanwise locations of the blade where the relative thickness is between approximately 0.6 and approximately 0.3, thus reducing drag.

Figure 7 shows two pairs of vortex generators 50. The vortex generators 50 are separated by a separation distance S. The separation distance S is measured between the downstream ends of adjacent vortex generator vanes 52 of adjacent vortex generator pairs 50.

- 5 The separation distance S can be measured the same way for converging vortex generators.

Figure 8 shows two vortex generator pairs on a wind turbine blade 20. As can be seen from the figure, the wind turbine blade 20 has a plurality of pairs of vortex generators situated on the suction surface 26. A first pair of vortex generators 60 which are
10 converging and situated nearer to the root end 22 of the blade 20 and a second pair of vortex generators 50, which are diverging and situated further from the root end 22 than the first pair 60.

The vortex generator pairs 50, 60 are situated a short distance upstream of a separation line (a line along the wind turbine blade 20 where the flow might be expected
15 to separate). Near the root end 22, the separation line will be approximately one third of the way from the leading edge 32 to the trailing edge 30 and will move nearer to the trailing edge 30 along the wind turbine blade 20 in the spanwise direction from root to tip, a trend which is reflected in the position of the second vortex generator pair 50.

The position of a separation line can be determined by many methods known to a
20 person skilled in the art, such as computational fluid dynamics or field tests.

Figure 9 shows a possible formation for a plurality of vortex generator pairs 50, 60 on a wind turbine blade. It can be seen in figure 9 that a plurality of first (converging) vortex generator pairs 60 may be positioned in a first straight line and that a plurality of second (diverging) vortex generator pairs 50 may be positioned in second straight line. As is
25 shown in figure 9, the lines may intersect at an angle. However, the lines may alternatively form a single straight line or may be offset such that the lines do not intersect. It is envisaged that the lines may be parallel optionally where both lines are parallel to the leading edge 32 and where the line of second vortex generator pairs 50 may be positioned nearer to the trailing edge 30 than the line of first vortex generator
30 pairs 60 is.

Figure 10 shows that the plurality of vortex generator pairs 50, 60 may be positioned in curved lines, optionally these curved lines may join to form a single continuous curve or may be positioned separately in two separate curves having the same or different radii of curvature with the same or different centres.

- 5 Figure 11 shows an example of how a vortex generator pair may be constructed. The vortex generator pair may be formed as a single element 100, which has two vortex generator vanes 102 and a common surface 104. The common surface 104 may be rigid or flexible such that it can be adapted to have the same shape as a suction surface in order for easy attachment to a wind turbine blade. While only a single vortex
- 10 generator pair is shown as being positioned within a single element (or component), multiple vortex generator pairs which are either converging or diverging may be attached to common surface.

While the above disclosure focuses on the prospect of flow separation from the suction surface of a wind turbine blade, it is envisaged that, where separation occurs on the

15 pressure surface of a wind turbine blade, vortex generators may be attached to the pressure surface of a wind turbine blade. Where vortex generators are attached to the pressure surface of a blade, the same arrangements as mentioned above are envisaged.

The pairs of vortex generators 50, 60 may be attached to the wind turbine blade

20 during manufacture of the blade or may be retrofitted to an existing wind turbine blade.

Although the invention has been described above with reference to one or more preferred embodiments, it will be appreciated that various changes or modifications may be made without departing from the scope of the invention as defined in the appended claims.

CLAIMS

1. A wind turbine blade comprising:
 - 5 a root end for connecting the wind turbine blade to a wind turbine hub, a tip end opposite the root end, a leading edge, a trailing edge, a pressure surface extending between the leading edge and the trailing edge, and a suction surface extending between the leading edge and the trailing edge; and
 - a plurality of pairs of vortex generators disposed on the suction surface, each vortex generator having a vane aligned at an angle to the leading edge, and each pair of
10 vortex generators comprising two nearest adjacent vortex generators,
 - wherein the vanes of a first pair of the vortex generators converge in a direction from the leading edge to the trailing edge, and the vanes of a second pair of the vortex generators diverge in the direction from the leading edge to the trailing edge; and
 - wherein the first pair of vortex generators is situated nearer to the root end than the
15 second pair of vortex generators is.
2. The wind turbine blade of claim 1, wherein at any spanwise point the wind turbine blade has a cross-section, the cross section having a chord which is the longest straight-line distance between the leading edge and the trailing edge and a thickness perpendicular to the chord, and
20 wherein the first pair of vortex generators is located where the cross section has a thickness to chord ratio of approximately 0.6 or greater.
3. The wind turbine blade of claim 1 or 2, wherein at any spanwise point the wind turbine blade has a cross-section, the cross section having a chord which is the longest straight-line distance between the leading edge and the trailing edge and a
25 thickness perpendicular to the chord, and

wherein the second pair of vortex generators is located where the cross-section has a thickness to chord ratio of between approximately 0.6 and approximately 0.3.

4. The wind turbine blade of any preceding claim, wherein the vortex generators of each pair of vortex generators are spaced from each other by a distance D measured between the ends of the vanes of the vortex generators of the pair of vortex generators nearer the trailing edge of the wind turbine blade and each vortex generator pair is spaced from an adjacent vortex generator pair by a distance S measured between the ends of the vanes of adjacent vortex generators nearer the trailing edge of the wind turbine blade such that S is greater than or equal to $2D$.
5. The wind turbine blade of any preceding claim, wherein each pair of vortex generators substantially has mirror symmetry.
- 10 6. The wind turbine blade of any preceding claim, wherein the vortex generators of the first pair converge at an angle between approximately 20° and approximately 50° .
7. The wind turbine blade of any preceding claim, wherein the vortex generators of the second pair diverge at an angle between approximately 30° and approximately 50° .
- 15 8. The wind turbine blade of any preceding claim, wherein the vortex generators of each pair of vortex generators is connected to a common base plate having a shape which is arranged to conform to the suction surface of the wind turbine blade.
9. The wind turbine blade of any preceding claim, further comprising:
 - a plurality of the first pairs of vortex generators and/or
 - a plurality of the second pairs of vortex generators, and
- 20 wherein the plurality of first pairs of vortex generators are arranged along a first line and/or
- wherein the plurality of second pairs of vortex generators are arranged along a second line.
10. The wind turbine blade of claim 9, wherein the first line and/or the second line are
- 25 straight or curved, optionally wherein the first line and the second line form a single straight line.

11. The wind turbine blade of any preceding claim wherein the vortex generators are configured such that vortices produced by each vortex generator of a vortex generator pair interact to form a single vortex structure.
12. The wind turbine blade of any preceding claim wherein the vanes of the vortex generators have a height, h , measured from the suction surface of the wind turbine blade to a point on the vane of the vortex generator furthest from the suction surface, and the vortex generators of a pair of vortex generators are spaced apart a distance, D , measured between the ends of the vanes of the vortex generators of the pair of vortex generators nearer the trailing edge of the wind turbine blade, and
- 10 wherein:
- D is between approximately 2 and 5 times h for the first pair of vortex generators and/or
- D is between approximately 3 and 6 times h for the second pair of vortex generators.
13. A wind turbine comprising at least one blade according to any preceding claim.
- 15 14. A method of arranging vortex generators on a wind turbine blade, comprising:
- providing a wind turbine blade having a root end for connecting the wind turbine blade to a wind turbine hub, a tip end opposite the root end, a leading edge, a trailing edge, a pressure surface extending between the leading edge and the trailing edge and a suction surface extending between the leading edge and the trailing edge;
- 20 providing a plurality of pairs of vortex generators, each vortex generator having a vane aligned at an angle to the leading edge, and each pair of vortex generators comprising two nearest adjacent vortex generators,
- attaching the pairs of vortex generators to the suction surface of the wind turbine blade,

wherein the vanes of a first pair of the vortex generators converge in a direction from the leading edge to the trailing edge, and the vanes of a second pair of the vortex generators diverge in the direction from the leading edge to the trailing edge; and

5 wherein the first pair of vortex generators is situated nearer to the root end than the second pair of vortex generators is.

15. The method of claim 14, wherein the vortex generators of each pair of vortex generators are attached to a common panel.

16. The method of claim 15, forming each pair of vortex generators and corresponding panel as a single element.

10 17. The method of any one of claims 14 to 16, further comprising providing a plurality of the first pairs of vortex generators and a plurality of the second pairs of vortex generators, and

attaching the plurality of first pairs of vortex generators and the plurality of second pairs of vortex generators to the suction surface of the wind turbine blade.

15 18. The method of any one of claims 14 to 17, wherein the wind turbine blade is the wind turbine blade of any one of claims 1 to 12.

19. The method of any one of claims 14 to 18, further comprising attaching the wind turbine blade to a wind turbine.

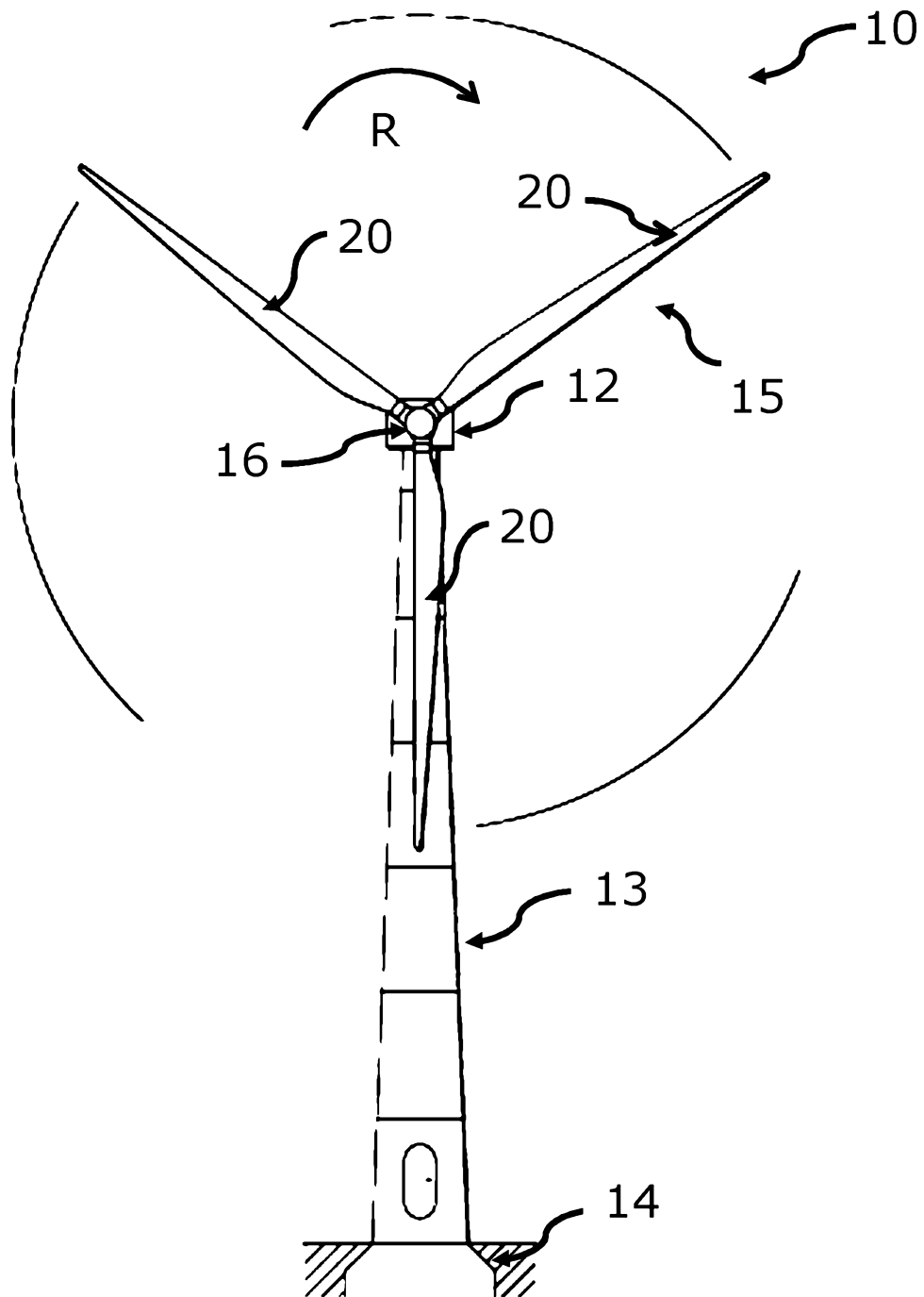
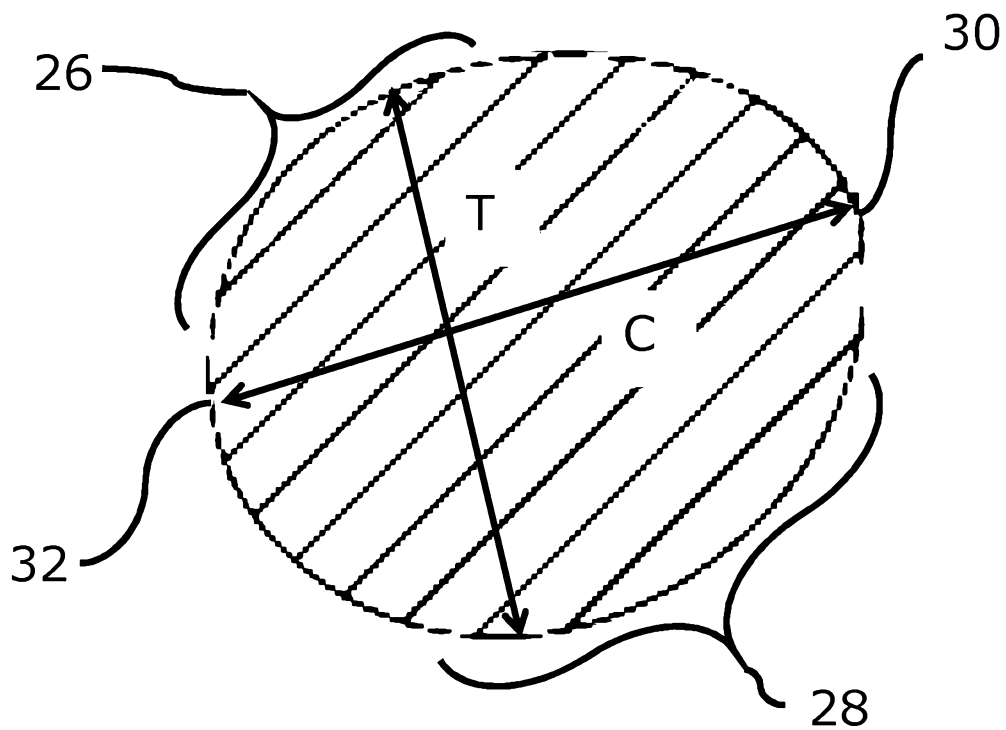
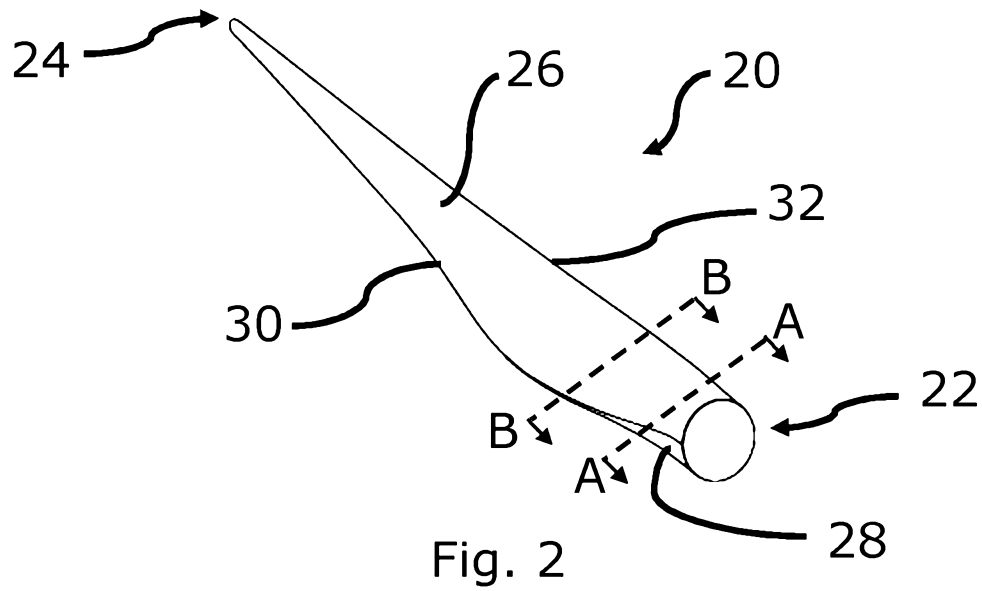


Fig. 1



Section A-A

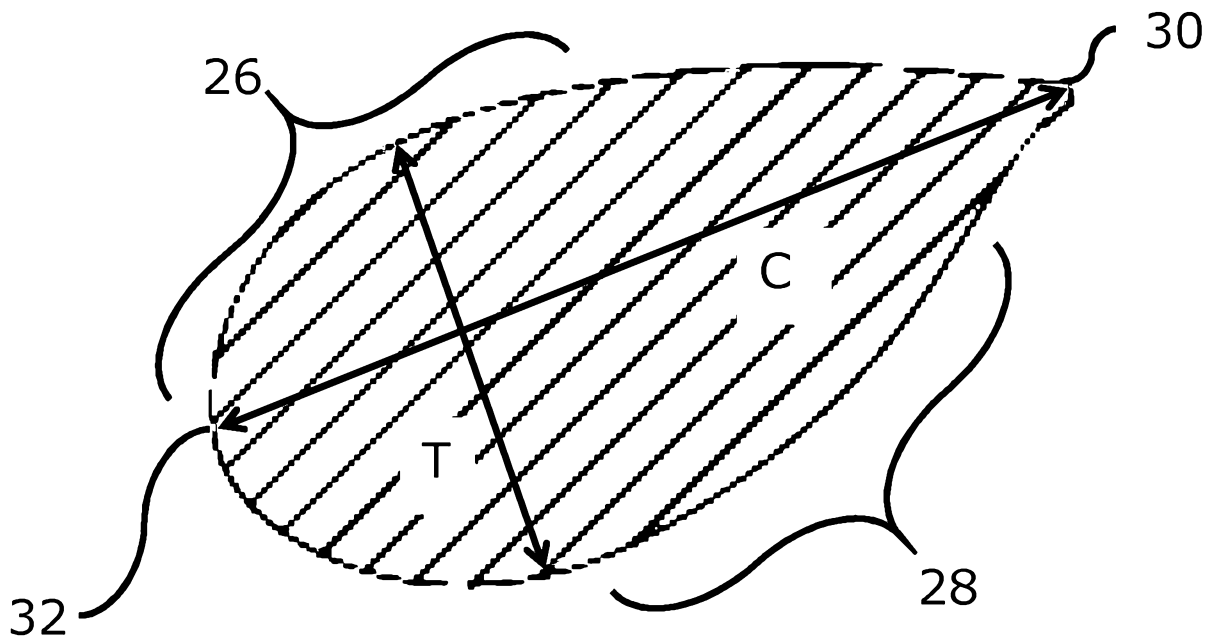


Fig. 4
Section B-B

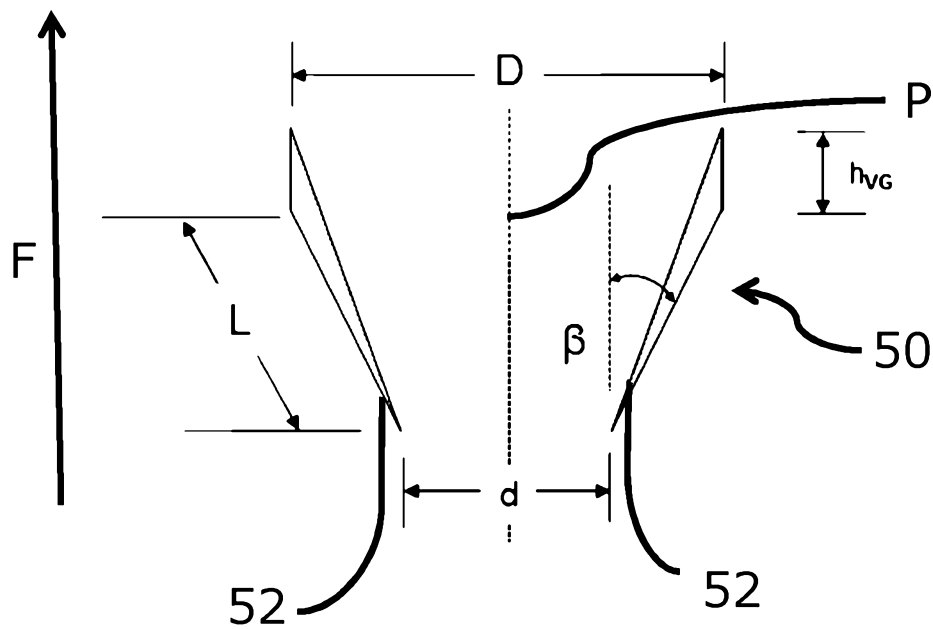


Fig. 5

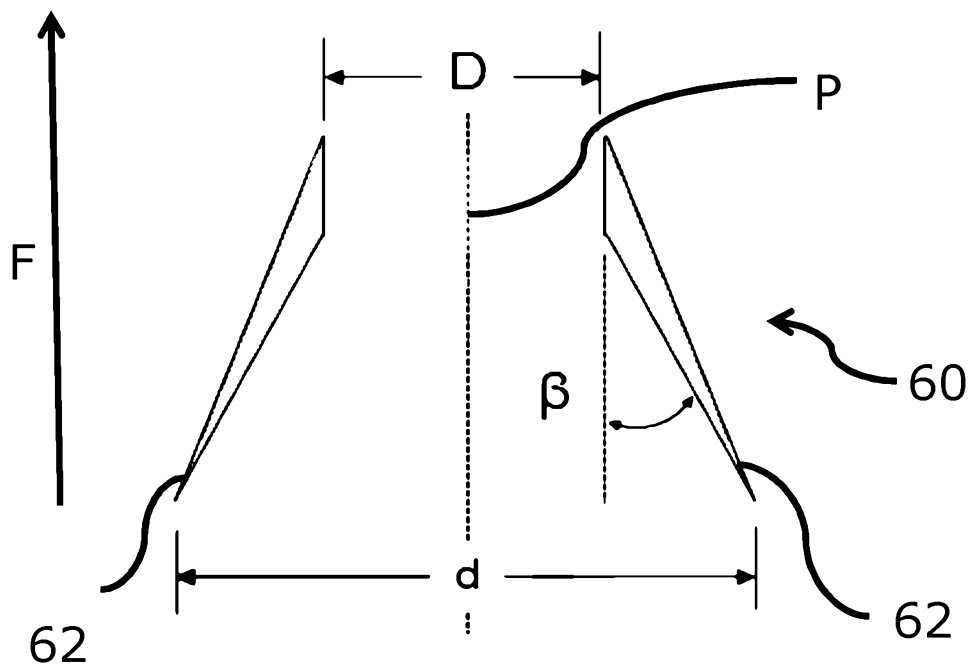


Fig. 6

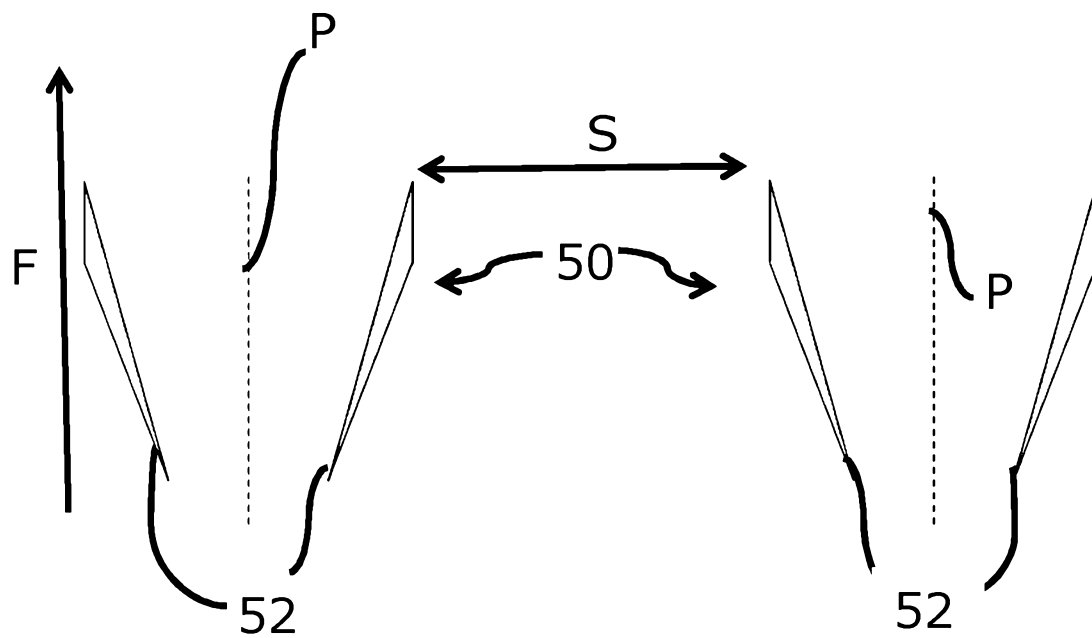


Fig. 7

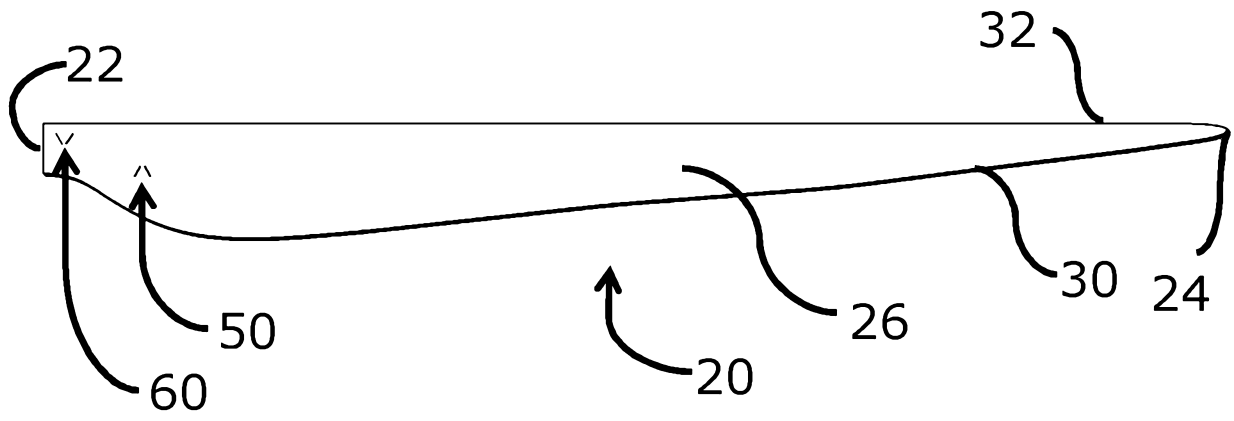


Fig. 8

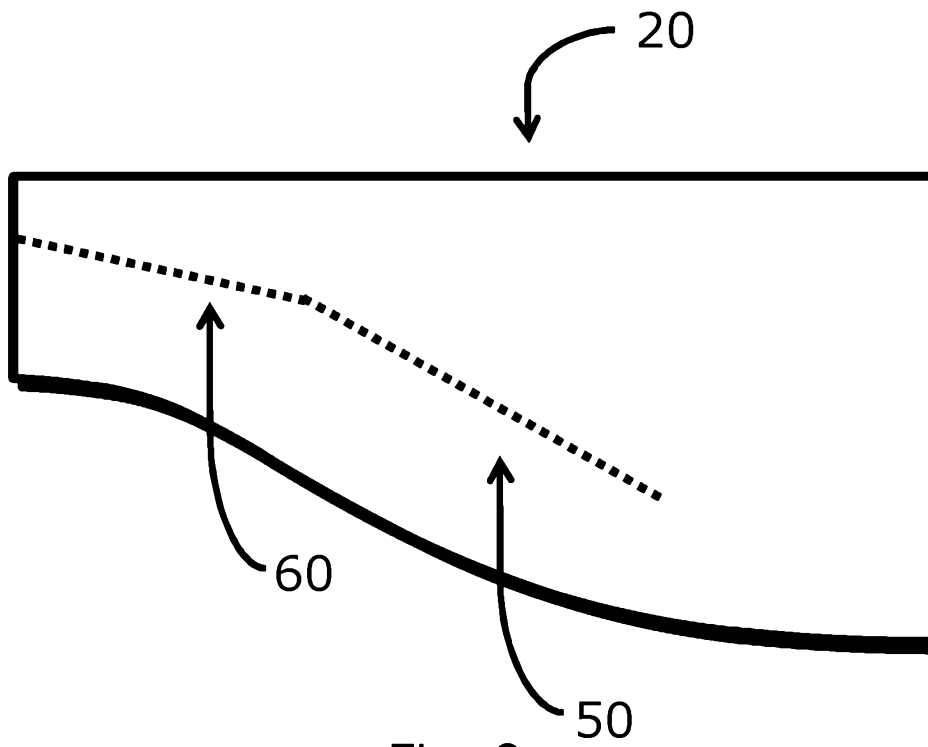


Fig. 9

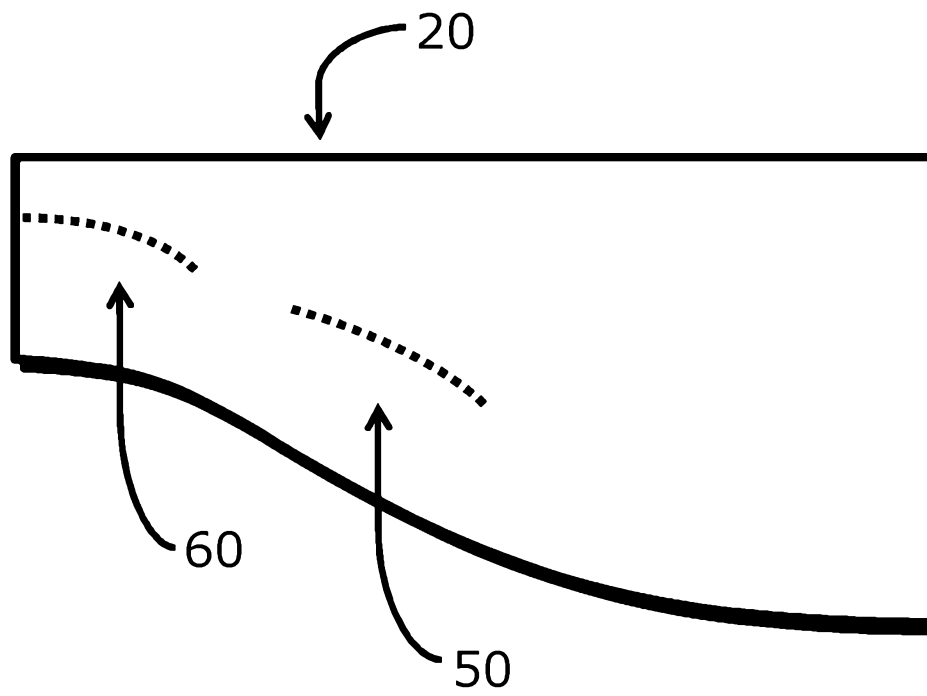


Fig. 10

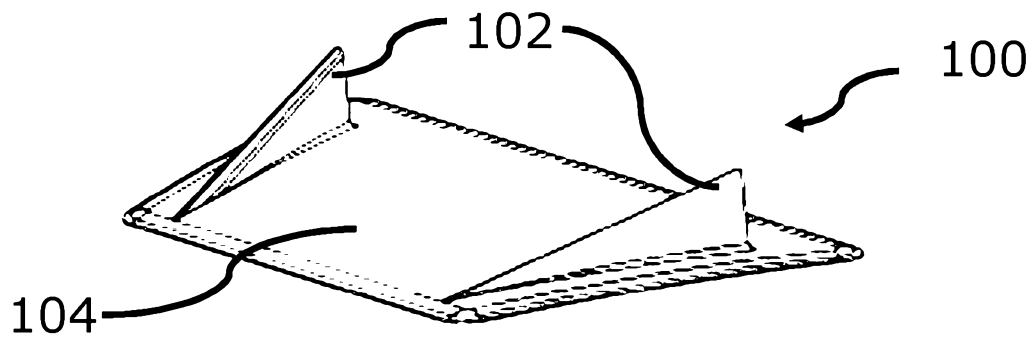


Fig. 11