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Description

The invention pertains to a rotor blade for a wind power system and to a corresponding wind power system.

With respect to the pertinent state of the art, we refer to the book "Windkraftanlagen" [Wind power systems] by Erich Hau, 1996. This book contains a few examples of wind power systems, rotor blades for such wind power systems as well as cross sections through rotor blades according to the state of the art. The geometric profile parameters of aerodynamic profiles according to NACA are illustrated in Figure 5.34 on page 102. According to this illustration, the rotor blade is described by a profile depth that corresponds to the length of the chord, a maximum camber (or camber ratio) that defines the maximum height of the skeleton line above the chord, a position of maximum camber, i.e., the location of the maximum camber within the cross section of the rotor blade relative to the profile depth, the maximum profile thickness that defines the maximum diameter of an inscribed circle, the center of which lies on the skeleton line, and the position of maximum thickness, i.e., the location at which the cross section of the rotor blade assumes its maximum profile thickness relative to the profile depth. In addition, the leading edge radius as well as the profile coordinates of the lower and upper side are used for describing the cross section of the rotor blade. The nomenclature from the book by Erich Hau, *inter alia*, is also used for the description of the cross section of a rotor blade according to the present invention.

Other rotor blades according to the state of the art are disclosed in DE 103 07 682, US 5,474,425, US 6,068,446 and DE 694 15 292. A rotor blade realized in two-parts is known from WO 02/051730 (Wobben, Aloys).

The optimization of rotor blades can be realized in terms of several different aspects. The rotor blades should not only operate quietly, but also have a maximum dynamic performance in order to initiate the rotation of the wind power system at relatively low wind velocities and to reach nominal velocity, i.e., the velocity at which the nominal power of the wind power system is reached for the first time, at the lowest wind strength possible. If the wind velocity subsequently increases, it is now common practice to increase the adjustment of the rotor blades of pitch-regulated wind power systems into the wind such that nominal power is maintained while the surface area of the rotor blade exposed to the wind decreases in order to protect the entire wind power system and its parts from mechanical damage. In any case, the aerodynamic properties of the rotor blade profiles of the rotor blade of a wind power system are of the utmost importance.

The present invention is based on the objective of disclosing a rotor blade with a rotor blade profile and a corresponding wind power system that make it possible to improve the efficiency in comparison with rotor blades known thus far.

According to the invention, this objective is realized with a rotor blade that has a rotor blade profile according to the characteristics of the independent claim. Advantageous additional developments are defined in the dependent claims.

The concrete coordinates of a rotor blade profile according to the invention are listed in Table 1.

The invention is described below with reference to several figures. The individual figures show:

Figure 1, a view of a wind power system according to the invention from a front perspective;

Figure 2, a view of a wind power system according to the invention from a rear side perspective;

Figure 3, a side view of a wind power system according to the invention;

Figures 4-8, views of a rotor blade according to the invention from different directions;

Figure 9, an enlarged view of a wind power system according to the invention;

Figure 10, a view of a rotor blade according to the invention;

Figures 11-17, 19, different views of a wind power system according to the invention, and

Figure 18, a cross section through a rotor blade according to the invention (in the region near the hub).

The rotor blade profile described in the present application is situated, in particular, in the region of the rotor blade that lies adjacent to the rotor blade mount (the connection to the hub). The profile described in the present application is preferably located in the first third of the rotor blade relative to its total length. Depending on the nominal power of the wind power system, these blades have a total length between 10 m and 70 m. For example, a wind power system of the Enercon E-112 type (diameter approximately 112 m) has a nominal power of 4.5 MW while a wind power system of the Enercon E-30 type has a nominal power of 300 kW.

One particular characteristic of the profile of the rotor blade according to the invention is that the maximum profile thickness is approximately 25%-40% of the rotor blade chord length, preferably 32%-36%. In Figure 18, the maximum profile thickness is approximately 34.6% of the rotor blade chord length. The chord 1 shown in Figure 1 extends from the center 2 of the trailing rotor blade edge 3 to the extreme point 4 of the rotor blade tip 5. The position of maximum thickness, i.e., the location of the maximum profile thickness relative to the blade length, is approximately 20%-30% of the chord length, preferably 23%-28%. In the embodiment shown, the position of maximum thickness is 25.9%. The maximum thickness was determined perpendicular to the chord, and the maximum position is relative to the rotor blade tip.

Figure 18 also shows a so-called skeleton line 7. This skeleton line respectively defines half the thickness of the rotor blade 8 at any given point. Accordingly, this skeleton line is not straight, but rather positioned exactly between opposite points on the pressure side 9 of the rotor blade 7 and the suction side 10 of the rotor blade 7. The skeleton line intersects the chord at the trailing rotor blade edge and the rotor blade tip.

The position of maximum camber in the cross section of the rotor blade according to the invention is approximately 55%-70% of the chord length, preferably 59%-63%. The position of maximum camber in the embodiment shown is approximately 61.9%. The maximum camber in this case is approximately 4%-8% of the chord length, preferably 5%-7% of the chord length. In the embodiment shown, the camber is approximately 5.87% of the chord length.

Another obvious peculiarity of the profile of the rotor blade according to the invention is that the pressure side of the rotor blade "intersects" the chord twice. Therefore, the pressure side of the profile is realized concavely in this region while the pressure side is realized convexly in the front profile region. In the concave region of the pressure side, the suction side is limited by a nearly straight line in the correspondingly opposite region on the suction side.

It may well have been known to realize the pressure side with a concave camber or to realize the suction side with a straight boundary. However, the combination of both measures, in particular, is of the utmost importance for the profile of a rotor blade according to the invention and characteristic for the rotor blade profile according to the invention.

The trailing rotor blade edge of the profile shown is also conspicuously thick. However, this not problematic with respect to the development of noise on the trailing rotor blade edge because the profile shown is arranged within the inner third of the circle defined by the rotor blade tip and the path velocity is not very high at this location.

The x-y coordinates of the profile illustrated in the figures are listed in Table 1 and exactly describe the profile of the rotor blade according to the invention.

The aerodynamic shape of the rotor blade can be improved by designing the region of the rotor blade root in such a way that the rotor blade has here its maximum thickness and thus the rotor blade is approximately trapezoidal (in a plan view) that more or less resembles the optimal aerodynamic shape. In the region of its root, the rotor blade is preferably realized in such a way that the edge of the rotor blade root which faces the nacelle of the wind power system is adapted to the outside contour of the nacelle in at least one angular position, for example, adapted such that a very small gap with a width of approximately 5 mm-100 mm is formed between the edge of the rotor blade root that faces the wind power system and the outside contours of the nacelle when the rotor blade is in its nominal wind position.

It was determined that a rotor blade with the aforementioned characteristics makes it possible to significantly increase the power, namely, by up to 10% in certain cases. Due to this unforeseen increase in power, the power output of a wind power system according to the invention is increased at any given wind velocity below the nominal wind velocity. In addition, the wind power system reaches its nominal power more quickly than before. This means that the rotor blades can also be turned (pitched) earlier in order to reduce the sound emission as well as the mechanical stress on the system.

The invention is based on the idea that the conventional rotor blade shape in use today is tested in the wind tunnel at different wind velocities but with a uniform air flow. However, since natural wind rarely blows so uniformly and is subject to stochastic laws, wind gusts may cause separation of the flow in conventional rotor blades, particularly in the inner blade region near the rotor hub where the blade is no longer realized in an aerodynamically clean and optimal fashion. The flow separation continues over a certain distance in the direction of the outer rotor blade region (rotor blade tip). This may lead to flow separation in a bubble-shaped region and a consequent loss of power. Due to the clean design of the rotor blade, the invention also makes it possible to increase the power significantly in the inner rotor blade region in the case of the above-described type.

If a conventional standard profile were used instead of the empirically determined profile proposed by the present application, an aerodynamically clean design of the rotor blade would require approximately twice the profile depth (that corresponds to the chord length of the rotor blade) in the lower rotor blade region (the region near the hub). The significant profile thickness in the front region, however, is required for a safe load transfer and for reaching a lift coefficient C_A greater than 2.

State-of-the-art rotor blades are now routinely manufactured in such a way that a maximum material savings is achieved in the inner region. Typical examples of such state-of-the-art rotor blades are shown on pages 114 and 115 in the above-cited "Windkraftanlagen" by Erich Hau, 1996. According to these examples, the maximum profile depth is always reached a certain distance from the rotor blade mount, i.e., near the rotor blade mounting region, wherein material is saved in these rotor blades according to the state of the art. However, when using an optimal shape that resembles a trapezoid in a plan view, the maximum width of the rotor blade is not located a certain distance from the rotor blade mount, but exactly in the region of the rotor blade mount itself. Consequently, here a maximum material saving cannot be achieved in the inner region of the rotor blades.

The reason for the material savings can be seen in the (above-described) static consideration of the flow conditions in the calculation/development of the rotor blades. In addition, popular calculation programs for rotor blades divide the rotor blade into individual sections and calculate each rotor blade section individually in order to derive the evaluation of the entire rotor blade.

However, the actual conditions are quite different. First, the wind does not blow in a uniform and static fashion within a certain surface area, but rather exhibits a distinct stochastic behavior. Second, the wind velocity is a significant factor due to the slow peripheral velocity of the rotor blade in the inner region (i.e., in the region near the rotor hub) such that the change in the angle of attack is highly dependent on the instantaneous wind velocity in this region. Consequently, boundary layer separations also occur with a corresponding frequency in the inner region of the rotor blade.

Hysteresis is effective in such cases. Once the wind calms to the prior wind velocity, e.g., after a wind gust, the boundary layer on the rotor blade is not only not immediately restored, but the wind velocity must initially decrease further (i.e., the angle of attack needs to be further adjusted) until the boundary layer on the rotor blade surface is restored. However, if the wind velocity does not decrease further, it may very well be that a certain force is exerted on the rotor blade for an extended period of time despite the incident wind because the boundary layer on the rotor blade surface is not yet restored.

The design of the rotor blade in accordance with the invention significantly reduces the risk of a boundary layer separation. This risk of separation is also reduced with the aid of the relatively thick profile. Another explanation for the substantial increase in efficiency is that the hysteresis effect causes the decreased power output to persist for a significant period of time (when state-of-the-art rotor blades are used) once a boundary layer separation has occurred.

The increased efficiency can also be partly explained in that the wind utilizes the path of least resistance. A very thin design of the rotor blade in the inner region near the hub (significant material savings) is equivalent to a "slip hole" in the rotor circle harvesting area swept out by the rotor blade, whereby the air prefers to flow through this slip hole. This is another indicator of a weakness of popular calculation programs that always base calculations on a uniform distribution over the circular area swept out by the rotor blades.

If this "slip hole" is "closed" by utilizing a rotor blade of trapezoidal design in the region near the hub, the distribution of the air flow is improved over the entire circular area and the effect on the outer region of the motor blade is somewhat intensified. Consequently, the "closing" of this "slip hole" contributes to the improved power coefficient of the rotor blade according to the invention.

This also indicates yet another weakness of popular calculation programs because they also consider the rotor blade section located directly adjacent to the "slip hole" as a fully functional rotor blade section. However, this cannot be the case due to the special flow conditions (frequent boundary layer separations followed by the restoration of the intended flow conditions).

Figures 11-17 respectively show a front view and a side view of a wind power system according to the invention. In these figures, the three rotor blades transition into the outside contours of the nacelle nearly seamlessly in the region near the hub. However, this only applies to the position of the rotor blades that corresponds to the nominal wind position.

Once the wind increases beyond the nominal wind, the rotor blades are slowly adjusted out of the wind in conventional fashion by means of pitching (pitch regulation), wherein Figure 15 shows that this can very well result in a gap of greater width being formed between the lower edge of the rotor blade in its inner region and the nacelle. However, Figure 4 also shows that the outside of the nacelle contains a structure whose cross section largely corresponds to the profile of the rotor blade in the region near the hub. This structure lies directly underneath the rotor blade at the nominal velocity when the rotor blade is adjusted to a the corresponding angle of attack such that only a narrow gap is formed between the structure and the rotor blade in the region near the hub.

Consequently, the outside contours of the nacelle also contains a section of the rotor blade that does not form an integral part with it.

In the rotor blade profile shown in Figure 18, the tip radius is approximately 0.146 of the profile depth.

According to Figure 18, the suction side contains a longer region that is nearly straight. For example, this region can be described as follows: in the region between 38% and 100% of the profile depth, the radius is 1.19-times the length of the profile depth. In the region between 40% and 85% of the profile depth (see Figure 18), the radius is approximately 2.44 multiplied by the profile depth. In the region between 42 and 45% of the profile depth, the radius is approximately 5.56-times the profile depth.

In the region between 36% and 100% of the profile depth, the maximum deviation from an ideal straight line is approximately 0.012 of the profile length. This value is definitive because the radius of curvature varies and the maximum radius of curvature in the respective regions is already defined.

In the example shown, the length of the suction side is approximately 1.124-times the length of the profile depth, and the length of the pressure side is 1.112-times the length of the profile depth. This means that the suction side is only insignificantly longer than the pressure side. Consequently, it is very advantageous if the ratio between the length of the suction side and the length of the pressure side is smaller than 1.2, preferably smaller than 1.1, or lies in the range between 1 and 1.03.

The figures indicate that the rotor blade has its maximum profile depth directly at the spinner, i.e., on the outside of the nacelle of the wind power system. In a wind power system with a rotor diameter of 30 m, the profile depth at the spinner may be, for example, approximately 1.8 to 1.9, preferably 1.84 m. If the spinner has a diameter of approximately 3.2 m, the ratio between the profile depth of the rotor blade at the spinner and the spinner diameter is approximately 0.575. Therefore, it is highly advantageous if the ratio between the profile depth and the spinner diameter is higher than 0.4 or lies in the range between 0.5 and 1. In this respect, any value within the aforementioned range of values may be chosen. In the aforementioned example, the ratio between the profile depth and the rotor diameter is approximately 0.061. It is quite obvious that the resulting "slip hole" is minimized if the ratio between the profile depth and the rotor diameter is higher than a value between 0.05 and 0.01 [sic], where the example value proved highly advantageous with respect to the efficiency of the rotor blade.

In another example, the first third of a rotor blade has the profile cross section shown in Figure 18, where the profile depth at the spinner lies at approximately 4.35 m, the spinner has a diameter of approximately 5.4 m and the rotor has an overall diameter of 71 m. In this case, the ratio between the profile depth and the spinner diameter is 0.806 and the ratio between the profile depth and the rotor diameter once again is 0.061. The above-cited values refer to a three-blade rotor with pitch regulation.

As mentioned above, the widest point of the rotor (the point of the rotor with the maximum profile depth) may be realized directly in the region of the blade mount. The term blade mount refers to the region in which the rotor blade is connected (joined, screwed, etc.) to the hub of the wind power system. In addition, the lower edge of the rotor blade, i.e., the edge that faces the nacelle of the wind power system, is adapted or largely follows the outside contours of the nacelle in the longitudinal direction. Consequently, a rotor blade in the feathered pitch position (practically no surface any longer aligned into the wind) lies parallel to the lower edge facing the nacelle and the distance between the lower edge and the outside contours of the nacelle is minimal, preferably less than 50 cm, particularly less than 20 cm.

If this rotor blade is now adjusted into the wind, it also has a surface of maximum size in the innermost region of the rotor blade (the slip hole is very small). The aforementioned citation by Erich Hau shows that the rotor blade according to the state of the art continuously decreases in the region near the hub (the rotor blades are narrower at this location than at their widest point). The widest point of the rotor blade according to the invention, in contrast, specifically lies in the region near the hub such that the wind potential can also be the fully utilized at this location.

It is well known that very large rotor blades, in particular, have a very large rotor blade width in the region near the hub. The rotor blade may also be composed of two parts in order to realize the transport of such rotor blades (the width of large rotor blades, i.e., rotor blades with a length in excess of 30 m, may very well lie between 5 m and 8 m in the region near the hub). The two parts are separated during transport and can be assembled after the rotor blade arrives at the installation site. The two parts are interconnected when the rotor blade is installed on the wind power system, for example, by means of screw connections or inseparable connections (bonding). This does not pose a problem, particularly with large rotor blades, because the interior of such rotor blades is also accessible during the assembly process. The outside of the rotor blade has a uniform appearance and separating lines between the assembled parts are barely visible or not visible at all.

Initial measurements demonstrated that the rotor blade design according to the invention makes it possible to significantly increase the efficiency in comparison with conventional rotor blades known thus far.

According to Figures 1-17, the rotor blades of a wind power system 1 according to the invention are realized such that they have their maximum profile depth in the region near the hub, and the rotor blades extend to location in the immediate vicinity of the nacelle fairing (spinner) of the power house of the wind power system along their entire profile in the region near the hub. This results in a very narrow gap between the rotor blade and the nacelle fairing, at least for the position in which the rotor blade is adjusted to an angle that corresponds to wind velocities up to the nominal wind range. In Figures 1, 2 and 3, for example, the rotor blades also extend to a location in the immediate vicinity of the outer nacelle fairing with the rear profile depth region. In an alternative variant that is illustrated, for example, in Figures

11-17, the outside nacelle fairing itself is provided with a rotor blade section 30 that, however, does not form an integral part of the entire rotor blade. Figures 15 and 17, in particular, show that the rotor blade part realized on the outside of the nacelle is fixed at this location and arranged at an angle that corresponds to the angular position of a rotor blade up to the nominal wind velocity. This means that only a minimal gap is also formed between the lower edge of the rotor blade and the nacelle in the rear profile depth region, at least at wind velocities up to the nominal wind.

Figure 19 also shows quite clearly that the design of the rotor blades in accordance with the invention results in a very small "slip hole" for the wind in the center of the rotor.

Figure 18 shows a cross section through the rotor blade according to the invention along line A-A in Figure 17, i.e., the profile of the rotor blade in the region near the hub.

Figure 17 also contains an indication that refers to the diameter D of the spinner.

The rotor diameter is described by the diameter of the circular area swept by the rotor during its rotation.

According to Figure 15 and other figures, the part 30 of the rotor blade does not form an integral part of the rotatable rotor blade, but rather an integral part of the outer nacelle fairing. The corresponding part may be screwed to the nacelle or be integrally connected or bonded to it.

In instances in which the rotor blade according to the present application has a significant length and a corresponding rotor blade depth, i.e., blade chord, in the region near the hub, it may be practical to divide the blade into two (or more) parts in this region in order to simplify the transport of the rotor blade. In this case, the rotor blade is not reassembled until it reaches the installation site, at which the entire rotor blade is mounted on the hub. In such cases, part of the rotor blade may be realized, for example, as illustrated in Figure 20. According to this figure, a section is missing in the rear blade edge region. The profile illustrated in Figure 18 can be restored in this region by attaching the missing section.

The two parts can be interconnected by means of screws, bonding or other fastening methods.

It would also be conceivable to provide means for varying the size of the rotor blade surface in this region of the rotor blade. Corresponding variants are illustrated in Figures 21-33, where it should be noted that the rotor blade cross section illustrated in these figures should only be understood symbolically (the profile of the rotor blade essentially corresponds to the profile shown in Figure 18).

The variants shown in Figures 21-33 provide the advantage that the overall rotor blade surface can be reduced, if so required. This is practical in extreme wind conditions as well as during the transport of the rotor blade because it allows or at least simplifies the transport of the rotor blade and protects the wind power system from overloads during extreme wind conditions.

In one particularly preferred variant of the invention, part of the surface consists of a deformable material that forms part of a closed receptacle (forming the rear profile box). This closed receptacle may be filled, for example, with a gaseous medium that is subjected to a predetermined pressure. This results in a partially inflatable surface of the rotor blade that can be evacuated during transport of the rotor blade or extreme wind conditions and therefore requires less space and yields to the wind pressure. This reduces the effective surface area of the rotor blade and therefore the surface of attack for the wind. The load on the downstream components including the tower is simultaneously reduced.

In another variant of the invention, the rotor blade contains a second airfoil structure in the region of the rear box (that is not illustrated in Figure 20), wherein said airfoil structure can be moved on and/or in itself. The deformable material can be fixed at predetermined locations of this second airfoil structure, and one side of the deformable material can be fixed on a rotatable winding element.

The second airfoil structure can be extended in the normal operating mode of the wind power system, i.e., unfolding arms can be completely unfolded or telescopic arms can be completely extended. The deformable material may be fixed on a rotatable winding element with one side. If the surface area of the rotor blade surface must be reduced, the winding element is turned--analogous to an awning--such that the deformable material is wound up. The folding arms are simultaneously folded and reduce the size of the second airfoil structure in the region of the reducible surface such that the surface area of the rotor blade is reduced accordingly.

In an alternative variant of the invention, part of the rotor blade surface consists of lamellar strips that are respectively arranged on a support rail pivotable about its own longitudinal axis. In the normal operating mode, these lamellae are aligned such that they increase the aerodynamically effective surface area of the rotor blade. During transport of the rotor blade and/or under extreme loads, the support rails can be pivoted in such a way that the corresponding lamellae are moved, for example, into the wind shadow of the remaining rotor blade and the surface area of the rotor blade is reduced accordingly.

In one particularly preferred additional development of the invention, the movable part of the aerodynamically effective rotor blade surface consists of a separate planar element that can be displaced in the direction of the rotor blade depth. In normal operating mode, this planar element increases the surface area of the rotor blade, preferably on the suction side, in order to create a large aerodynamically effective surface area.

In order to reduce the surface area, this planar element can be displaced similar to the flap system of an aircraft wing, so that it is either displaced into the rotor blade and covered by the remaining surface of the rotor blade or displaced onto the rotor blade and covers its surface. In any case, this results in a reduction of the rotor blade surface area.

In an alternative variant of the invention, one side of this planar element is coupled to the first airfoil structure or the trailing edge of the rotor blade in a pivoted fashion. The surface area of the rotor blade can be varied by pivoting this element about its axis either toward the suction side or toward the pressure side of the rotor blade.

If this planar element is pivoted by approximately 90°, it stands essentially perpendicular to the direction of the air flow on the rotor blade and creates a corresponding deceleration effect because it forms an obstacle for the air flowing along the surface of the rotor blade.

Several variants of the invention are described in greater detail below with reference to the enclosed drawings. They show:

Figure 20, a top view of a rotor blade according to the invention;

Figure 21, a top view of the front section of a rotor blade according to the invention;

Figure 22, a schematic cross section through a first variant of a rotor blade according to the invention;

Figure 23, a schematic cross section through a second variant of the rotor blade according to the invention;

Figures 24a, 24b, schematic cross sections through a third variant of the rotor blade according to the invention;

Figure 25, a schematic cross section through a fourth variant of a rotor blade according to the invention;

Figure 26, a schematic cross section through a fifth variant of a rotor blade according to the invention;

Figures 27a, 27b, simplified cross sections through a sixth variant of a rotor blade according to the invention;

Figure 28, a top view of one constructive variant of a rotor blade according to the invention, and

Figures 29-33, the other advantageous examples of the invention.

Figure 20 shows a schematic top view of a complete rotor blade according to the invention. The rotor blade 100 is divided into two parts. With respect to its essential components, the rotor blade 100 is designed conventionally. However, a partition is visible in the region located adjacent to the rotor blade root 120, i.e., the region with the maximum blade depth. This partition marks the region of the rotor blade 140, the surface area of which can be reduced, if so required, such that it is no longer subjected to the effect of the wind.

Figure 21 shows the rigid part of the rotor blade 100, the surface area of which remains unchanged. This figure clearly shows that the aerodynamically effective surface area of the rotor blade 100 is significantly reduced such that the load, particularly in extreme wind situations, is much lower than that of a conventionally designed rotor blade.

Figure 22 shows a schematic cross section through a first variant of the invention. In this case, the rotor blade 100 is divided into a front region 110 and a rear box 140. This rear box 140 consists of two strips of a deformable material 180 that form a closed receptacle 160 together with the rear wall of the front region 110. If this closed receptacle 160 is now filled with a pressurized gaseous medium, the deformable material 180 forms part of the surface area of the rotor blade 100 according to the invention that is aerodynamically effective in the normal operating mode (and identified by the reference symbol 140 in Figure 20).

This section of the rotor blade 100 can be realized with such a stability that its normal effect becomes evident under normal wind conditions. However, the wind pressure exerted upon this part of the rotor blade 100 is higher in extreme wind situation such that the external pressure is higher than the internal pressure, whereby the rotor blade is deformed in the region of the rear box 140 in such instances and the rotor blade ultimately yields to the external wind pressure. This not only reduces the surface of attack for this extreme wind, but also the loads on the downstream structure.

It should also be noted that this part of the rear box (in which the filling medium is accommodated) can be actively evacuated in order to reduce the surface area of the rotor blade, for example, when a predetermined wind velocity is exceeded. This active evacuation provides the advantage that the shape of the rotor blade is defined at all times while uncertain situations may arise if the rear box yields to the external pressure.

In order to prevent damage to the receptacle 160, it would be possible, for example, to provide a (not-shown) pressure relief valve that allows excess pressure being built up in the receptacle 160 to escape.

The pressure required for the normal operating mode can be restored by utilizing a compressor 170. If (not-shown) control valves and/or pressure sensors are provided, the pressure in the receptacle 160 can also be adjusted if the wind pressure fluctuates such that optimal operating conditions are always maintained.

Figure 23 shows a second variant of the present invention, in which the surface on the suction side of the rotor blade 100 is extended rather than utilizing a complete rear box 140. This extension consists of a planar element 240 that lies adjacent to the surface of the front region 110.

This planar element 240 can be displaced in the direction indicated by the arrow in order to reduce the aerodynamically effective surface area. This displacement can be realized, for example, hydraulically with corresponding hydraulic cylinders, pneumatically with pneumatic cylinders, with electric drive systems or the like. Naturally, corresponding pumps, compressors or drives (actuators) must be provided for this purpose (but are not illustrated in the figure in order to provide a better overview).

The planar element may be displaced into the front region such that the surface of the front region 110 covers the planar element 240. Alternatively, the planar element may also be displaced onto the surface of the front region 110 such that the surface element 240 covers the corresponding surface area of the front region 110. The aerodynamically effective surface area of the rotor blade 100 is reduced in the both instances.

Figures 24a and 24b show a third variant of the present invention. Figure 24a shows a reel 200 of a deformable material, and the reference symbol 300 designates folding arms that are illustrated in the folded state. This mechanism may be realized similarly to that of an awning.

Figure 24b shows this variant in normal operating mode. The folding arms 300 are extended and the deformable material 180 fixed thereon was unwound from the reel 200 during the extension of the folding arms 300. Consequently, the reel 210 no longer carries the entire wound-up material.

In this unwound state, the deformable material 180 is fixed on the reel 210 with one side and on the ends of the folding arms 300 that point toward the right in the figure with the other side. The ends of the folding arms 300 may be connected to a not-shown web in order to increase the rigidity of the construction and to fix the deformable material in position.

In order to prevent the deformable material 180 from becoming slack between the reel 210 and the outer ends of the folding arms 300, a (not-shown) device similar to an adjustable grate may be provided underneath the deformable material 180, which grate is actuated synchronously with the folding arms 30 and supports the deformable material 180 in the extended state.

The effective surface area is reduced by reversing this sequence; the folding arms 300 and the (not-shown) adjustable grate a retracted (folded) and the deformable material 180 is simultaneously wound on the reel core 210. This ultimately results in the reel 200 illustrated in Figure 24a and a reduced effective surface area of the rotor blade 100.

In the fourth variant of the invention shown in Figure 25, the planar element 240 is coupled in a pivoted fashion to the rear side of the front region 110 such that it forms an extension of the suction side of this front region 110.

In this case, the planar element 240 is supported by a compression spring 280 that is arranged between the planar element 240 and the supporting structure of the front region 110.

In the normal operating mode, this compression spring 280 supports the planar element 240 in such a way that it maintains the desired position. If an abnormal wind pressure acts upon the upper side of the rotor blade 100, the pressure exerted upon the surface of the planar element 240 increases and overcomes the force of the spring 280 such that the planar element 240 shown in Figure 25 is pressed downward and yields to the wind pressure. This results in a corresponding reduction of the aerodynamically effective surface area.

Instead of using a spring 280, it would also be possible to provide corresponding telescopic elements for actively adjusting the planar element, e.g., hydraulic or pneumatic devices or mechanical devices. It would also be possible, for example, to utilize threaded rods and worm drives or the like in order to hold the planar element 240 in a first predetermined position or to displace the planar element into a second predetermined position. Naturally, corresponding pumps, compressors or drives that are not illustrated in this figure in order to provide a better overview also must be provided in order to operate these actuators.

The wind load acting upon the planar element 240 can also be determined in this case, where the planar element 240 is pivoted about the pivoting axis as a function of the measured wind load in order to optimally adjust the planar element in accordance with the instantaneous operating conditions.

Figure 26 shows a fifth variant of the invention. In this fifth variant, the planar element 240 is not coupled in pivoted fashion to the rear side of the front region 110, but rather is arranged on a hinge pin 220 that can be turned about its own longitudinal axis. In the position shown in Figure 26, the planar element 24 forms an extension of the aerodynamically effective surface area of the rotor blade 100.

In order to reduce this surface area, the hinge pin 220 with the planar element 240 fixed thereon is turned about its longitudinal axis in such a way that the outer end of the planar element 240 moves in one of the two directions indicated by the double arrow. This also leads to a reduction of the aerodynamically effective surface area of the rotor blade 100 and therefore to a change of the wind load acting upon the rotor blade 100 and all downstream components of the wind power system.

Figures 27a and 27b show a modification of the embodiment shown in Figure 26. The planar element identified by the reference symbol 240 in Figure 26 is divided into three lamellar elements 260 in Figure 27a. These lamellar elements are intentionally spaced apart in Figure 27a in order to elucidate this division. Naturally, these three elements are actually arranged in such a way that they form a largely closed surface that transitions into the front region 110 of the rotor blade 100 as smoothly as possible.

Each lamella 260 is arranged on its own hinge pin. Each hinge pin 280 can be turned about its own longitudinal axis, whereby the respective lamellae 260 are pivoted by turning the hinge pin 280 about the longitudinal axis.

Figure 27b shows a device according to the invention in a situation in which these lamellae are pivoted into such a position that they reduce the aerodynamically effective surface area of the rotor blade 100. The lamellae 260 are pivoted into the wind shadow of the front region 110 in this case. Thus, the lamellae no longer form part of the rotor blade surface area such that they are no longer subjected to the wind and therefore any elevated loads.

Such an arrangement is realized in that the distance between the left hinge pin 280 in the figure and the front region 110 of the rotor blade 100 and the mutual distances between the hinge pins 280 are reduced in addition to the turning of the hinge pins 280 about their longitudinal axes.

Although only an extension of the surface area on the suction side is illustrated in the figures, it would naturally also be possible to alternatively or additionally vary the size of the surface area on the pressure side.

If a wind power system is equipped with the above-described rotor blades and an extreme wind situation occurs, it is possible not only to determine the high wind force with the aid of wind velocity indicators, but also to reduce significantly the size of the rotor blade surface area with the aid of a corresponding control arrangement. According to Figures 20 and 21, the surface area of the rotor blade shown in Figure 20 is larger than the surface area of the rotor blade shown in Figure 21 by more than 10%. The rotor blade is adjusted to its normal size when the wind power system operates in normal mode, for example, at wind velocities between 2-20 m/s. Once the wind velocity increases to a value above 20 m/s, the surface area can be reduced such that its size decreases significantly--as shown in Figure 21.

The control arrangement is preferably realized in a computer-assisted fashion and ensures that the respectively optimal size of the rotor blade surface area is adjusted, if so required.

Figure 33 shows another variant of a rotor blade according to the invention. In this case, the structure is composed of pivoted hoops 320 that are covered with a deformable film and pivotally supported in bearing points 340. During a movement in the direction of the rotor blade tip (arrow), these hoops are pivoted, for example, about the bearing points 340 such that the rear box profile is changed.

Figures 28-33 show other alternative and supplementary variants of Figures 22-27b.

Figure 30b (Figure 30a essentially corresponds to Figure 25) shows a modification of Figure 25 that is provided with a supplementary element 250 on the pressure side. Since the point of contact of the spring 280 was not changed in relation to Figures 25 and 30a, respectively, the elements 240 and 250 must be connected on the trailing blade edge such that they can be pivoted about a coupling point 260. Under certain circumstances, it would be possible to realize the rotor blade box 110 so that it overlaps the element 250 along the length of the rotor blade in this variant.

Figure 31b (an expanded variant of Figures 26 and 31a, respectively) also shows an element 250 on the pressure side that is connected to the same shaft 120 as the element 240 on the suction side via a mechanical connection.

Figures 32a and 32b show an additional development of the variant according to Figures 27a and 27b. In this case, separate shafts 280 are provided for corresponding elements on the pressure side. Analogous to Figure 27a, Figure 32a shows a rotor blade in normal operating mode. Figure 32b shows a situation in which the rear box is rendered ineffective by rotating or displacing the shaft 280 accordingly.

Patentkrav

1. Vindenergianlæg med mindst en rotorvinge (100), som er anbragt på et rotornav, og med en navbeklædning, **kendetegnet ved, at** der på den udvendige side af navbeklædningen er udformet en rotorvingedel (30), som er fast forbundet med navbeklædningen, men ikke er en integreret bestanddel af vindenergianlæggets rotorvinge, og at rotorvingen i rodområdet, altså området i nærheden af navet, har sin største profildybde og er todelt udformet, hvor der er udformet en skillelinje, som er orienteret i rotorvingens langsgående retning, og at rotorvingedelens (30) profil, som er udformet på navbeklædningen, svarer i det væsentlige til rotorvingens profil i området i nærheden af navet.

2. Vindenergianlæg ifølge krav 1, **kendetegnet ved, at** rotorvingens tværsnit er beskrevet af en skeletlinje, hvis største krumning ligger i et område fra 50° til 70°, fortrinsvis ca. i området fra 60° til 65°.

3. Vindenergianlæg ifølge krav 2, **kendetegnet ved, at** den største krumning er ca. 3 % til 10 %, fortrinsvis ca. 4 % til 7 %.

4. Vindenergianlæg ifølge et af de foregående krav, **kendetegnet ved, at** dette tværsnit er udformet fortrinsvis i den nederste tredjedel af rotorvingen, der slutter sig til rotorvingetilslutningen.

5. Vindenergianlæg ifølge et af de foregående krav, **kendetegnet ved, at** rotorvingen har en trykside og en sugeside, hvor tryksiden har en del med en konkav krumning, og at der på sugesiden er udformet et næsten lige afsnit.

6. Vindenergianlæg ifølge krav 5, **kendetegnet ved, at** rotorvingens del, som er udformet på navbeklædningen, er faststående og er i det væsentlige orienteret således, at den ligger direkte under området i nærheden af navet af vindenergianlæggets rotorvinge ved rotorvingens stilling ved nominel vindhastighed under den nominelle vindhastighed.

7. Vindenergianlæg ifølge krav 6, hvor vindenergianlægget har en rotor, som optager mindst en rotorvinge, som i området af rotorvingenavet har sin største profildybde, hvor forholdet mellem profildybde og rotordiameter antager værdien, som ligger i området fra ca. 0,04 til 0,1, fortrinsvis har ca. en værdi fra 0,055 til 0,7, f.eks. 0,061.

8. Vindenergianlæg ifølge krav 7, med et maskinhus, som optager en generator og en rotor, der er forbundet med generatoren, hvor rotoren indeholder mindst to rotorvinger, hvor rotoren har et nav, som er forsynet med en beklædning (spinner), hvor forholdet mellem profildybden af en rotorvinge og spinnerens diameter har en værdi, som er større end 0,4, fortrinsvis ligger i et værdiområde mellem 0,5 og 1.

9. Vindenergianlæg ifølge et af de foregående krav, med en rotor, som fortrinsvis har mere end en rotorvinge, hvor rotorvingen har en trapezform, som mere eller mindre er tilnærmet den aerodynamiske optimalform, og rotorvingen i området af rotorvingeroden har sin største bredde, og rotorvingerodens kant, der vender mod vindenergianlæggets nacelle, er udformet på en sådan måde, at kantens forløb er tilpasset i det væsentlige til nacellens udvendige kontur (i den langsgående retning).

10. Vindenergianlæg ifølge krav 9, **kendetegnet ved, at** rotorvingens nedre kant, som vender mod nacellen, ligger næsten parallelt med nacellens udvendige kontur i rodområdet ved drejning af rotorvingen til fanestilling.

11. Vindenergianlæg ifølge krav 10, **kendetegnet ved, at** afstanden mellem rotorvingens nedre kant, som vender mod nacellen, og nacellens udvendige kontur er mindre end 50 cm, fortrinsvis mindre end 20 cm, i fanestilling.

12. Vindenergianlæg ifølge et af de foregående krav, **kendetegnet ved, at** rotorvingen i rodområdet er vippet ud af hovedvingeplanet.

13. Vindenergianlæg ifølge et af de foregående krav, **kendetegnet ved, at** rotorvingen er todelt udformet i rodområdet, hvor der er udformet en skillelinje, som er orienteret i rotorvingens langsgående retning.

14. Vindenergianlæg ifølge krav 13, **kendetegnet ved, at** begge dele af rotorvingen først sættes sammen kort før installation af rotorvingen i vindenergianlægget.

15. Vindenergianlæg ifølge kravene 13 og 14, **kendetegnet ved, at** rotorvingens dele er adskilt under transporten af rotorvingen.

16. Vindenergianlæg ifølge et af de foregående krav, **kendetegnet ved, at** vindenergianlægget har mindst en rotorvinge, som er kendetegnet ved en sugeside og en trykside, hvor forholdet mellem sugesidens længde og tryksidens længde er mindre end en værdi på 1,2, fortrinsvis er mindre end 1,1 og især ligger i et værdiområde mellem 1 og 1,03.

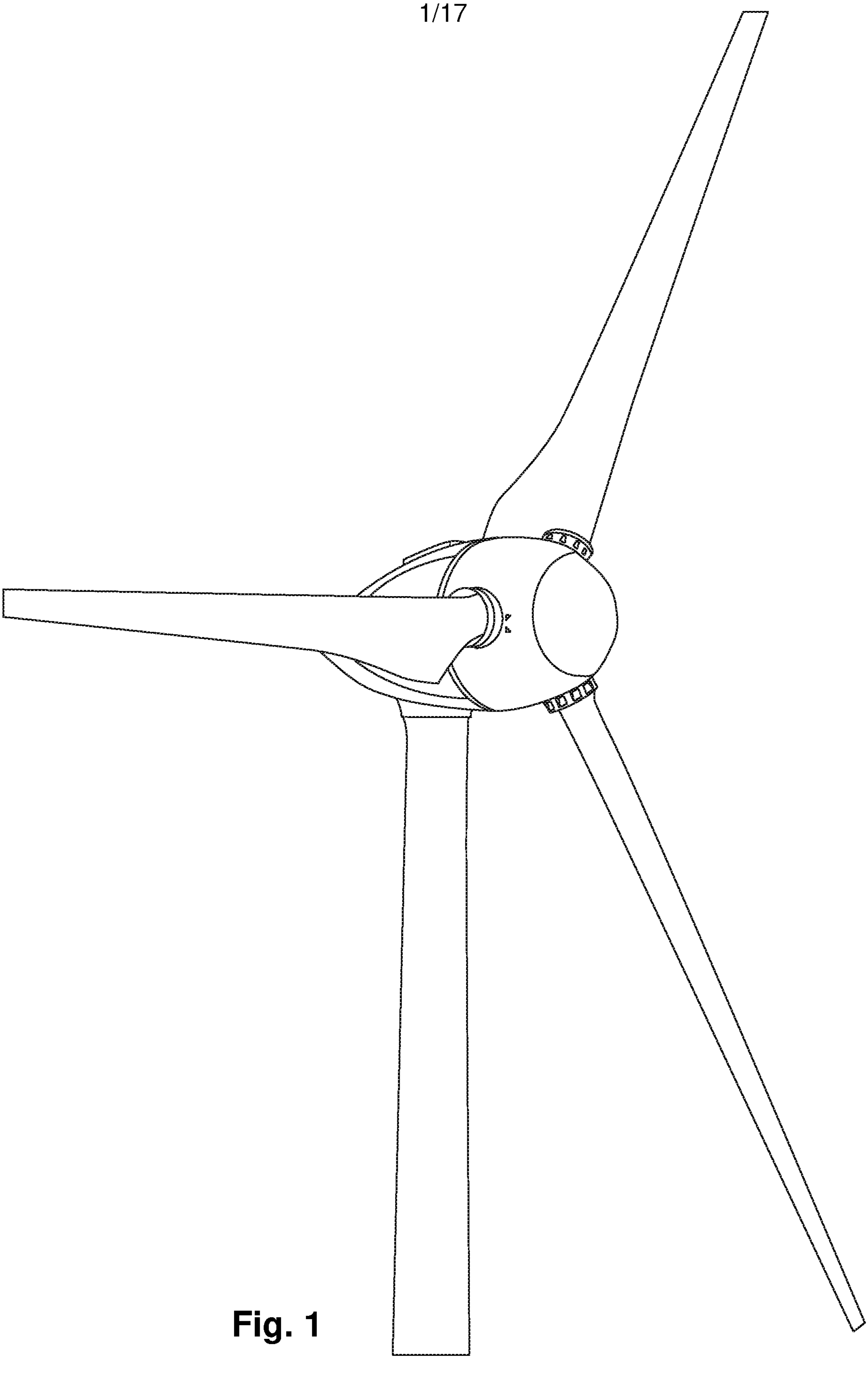

Fig. 1

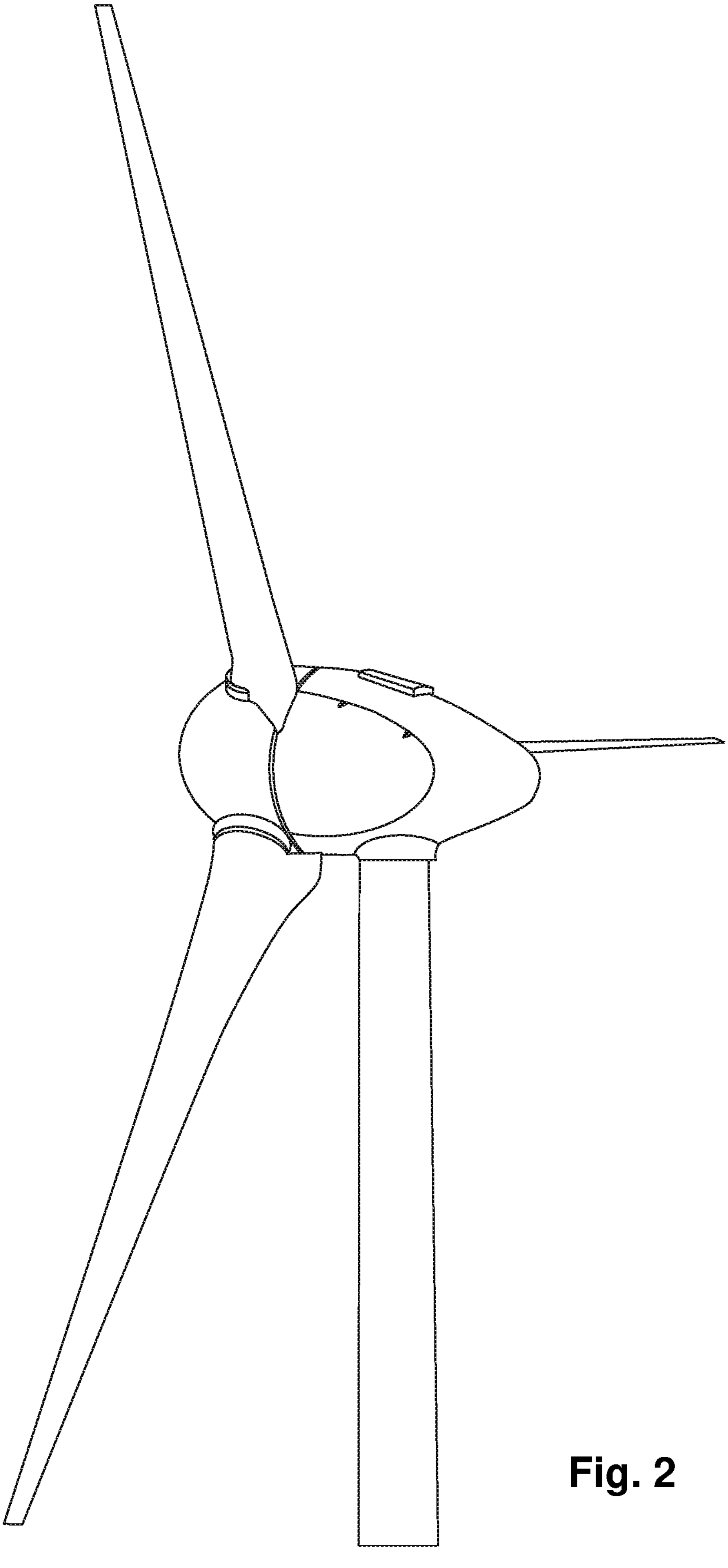

Fig. 2

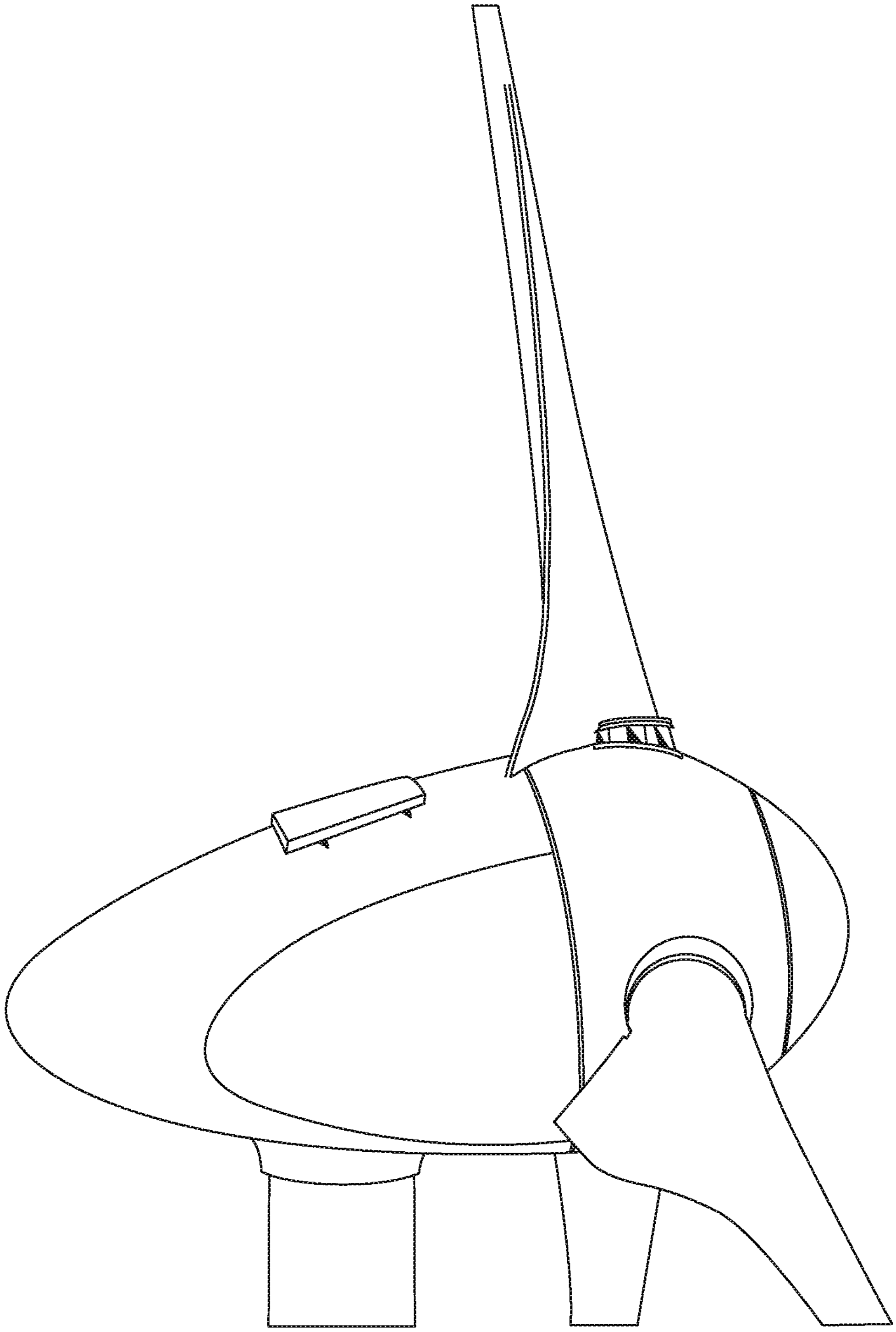

Fig.3

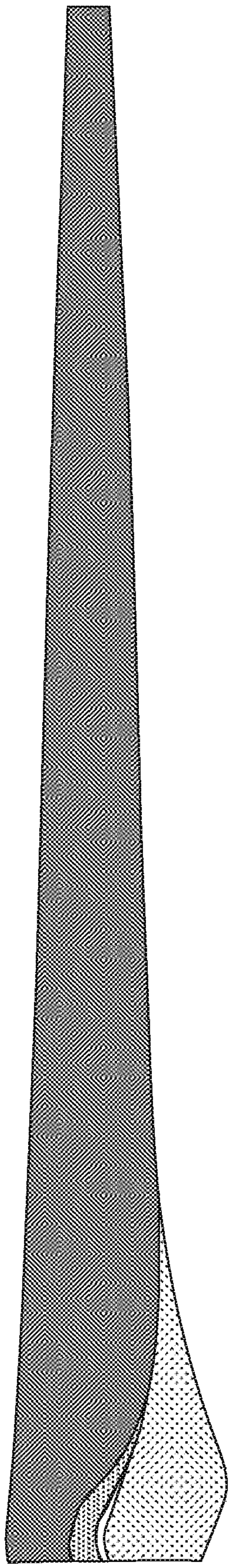

Fig.4

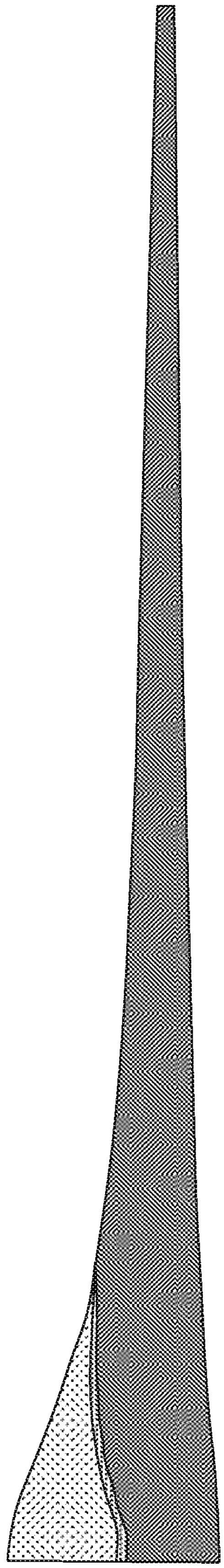

Fig.5

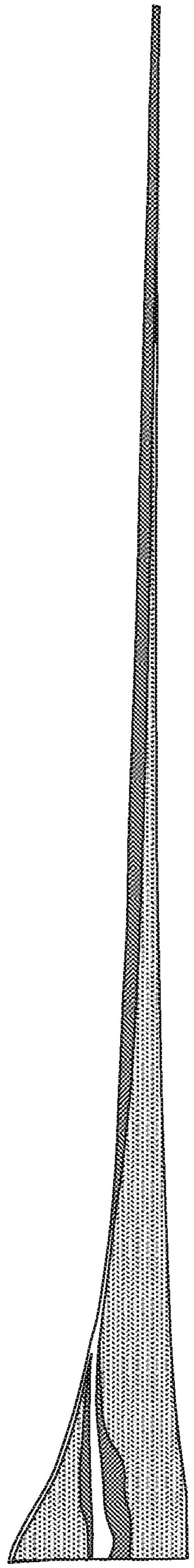

Fig.6

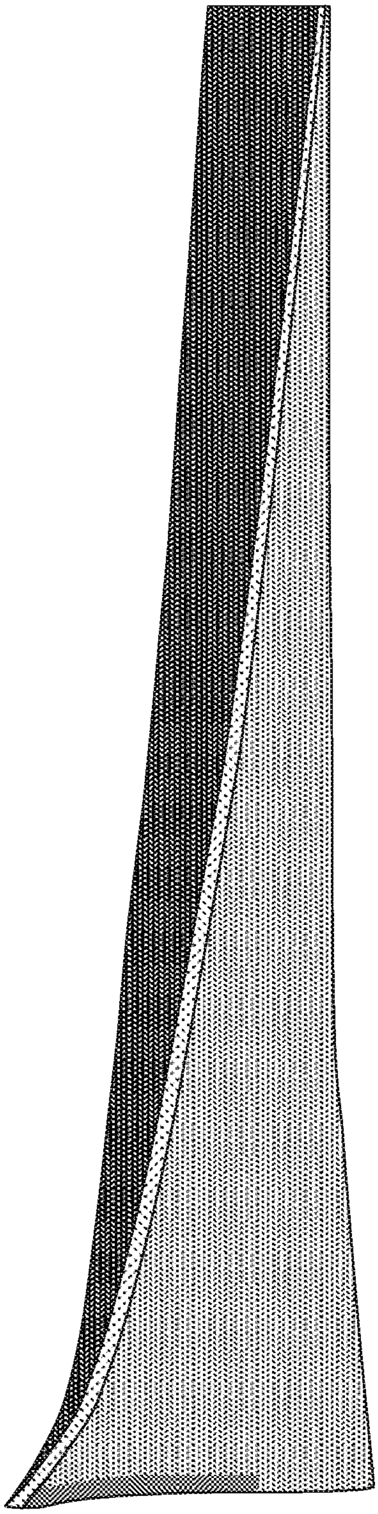

Fig.7

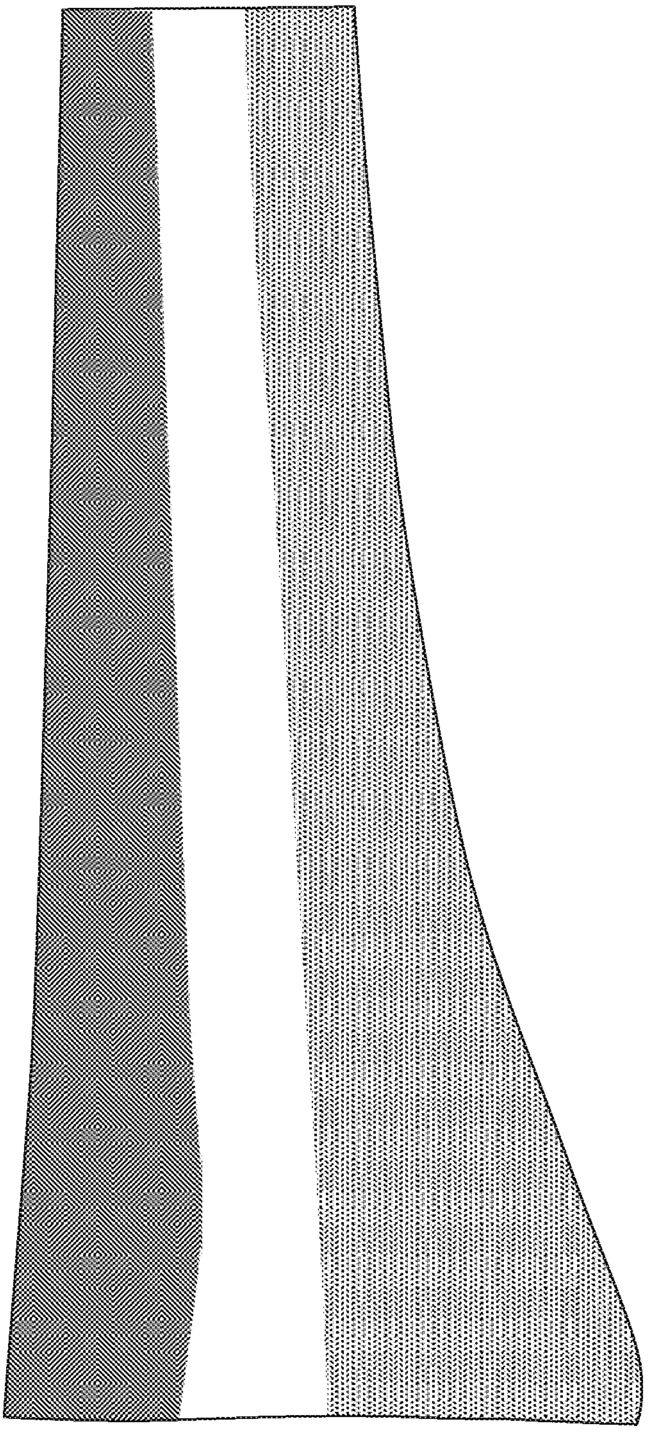

Fig. 8

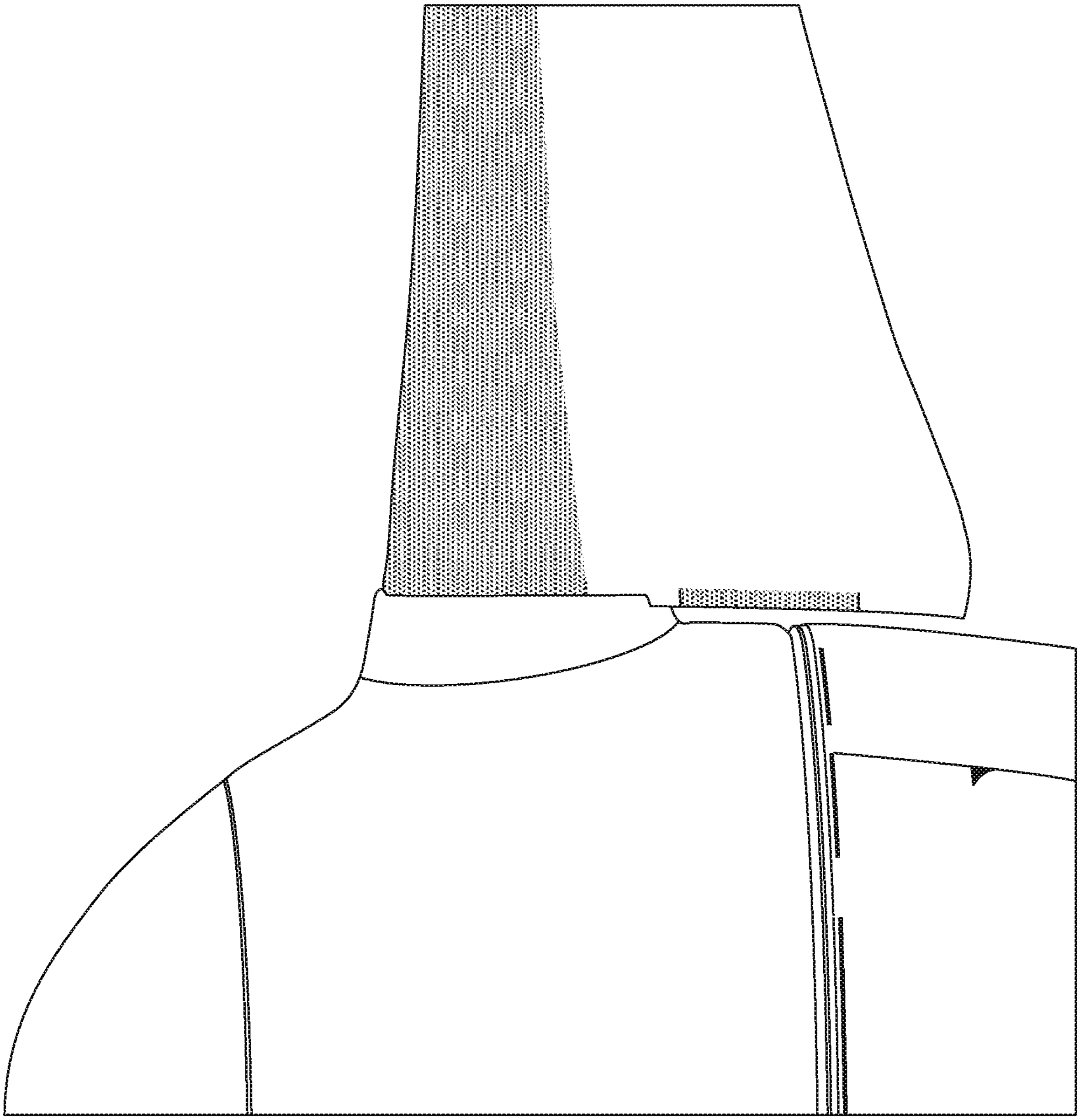

Fig. 9

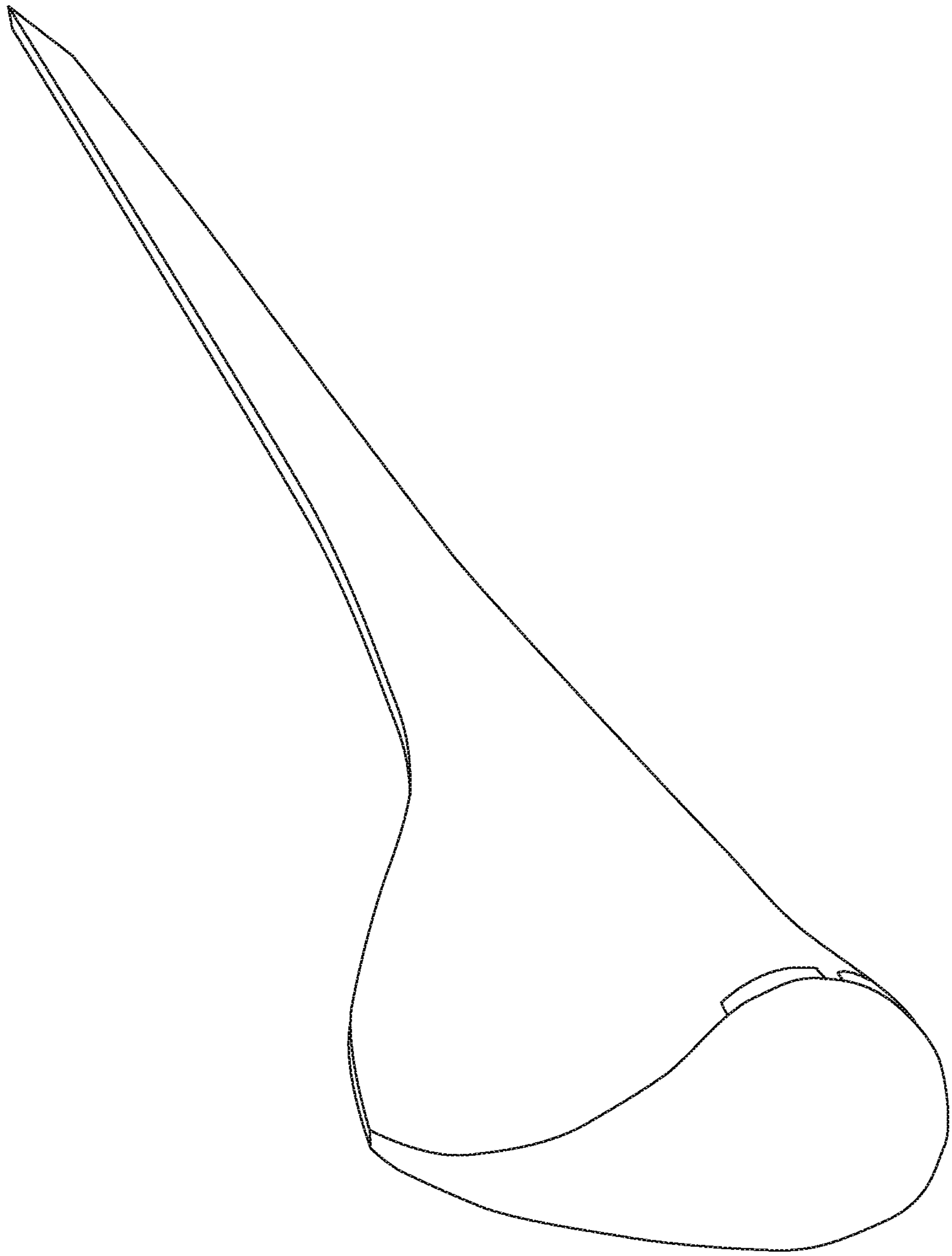

Fig.10

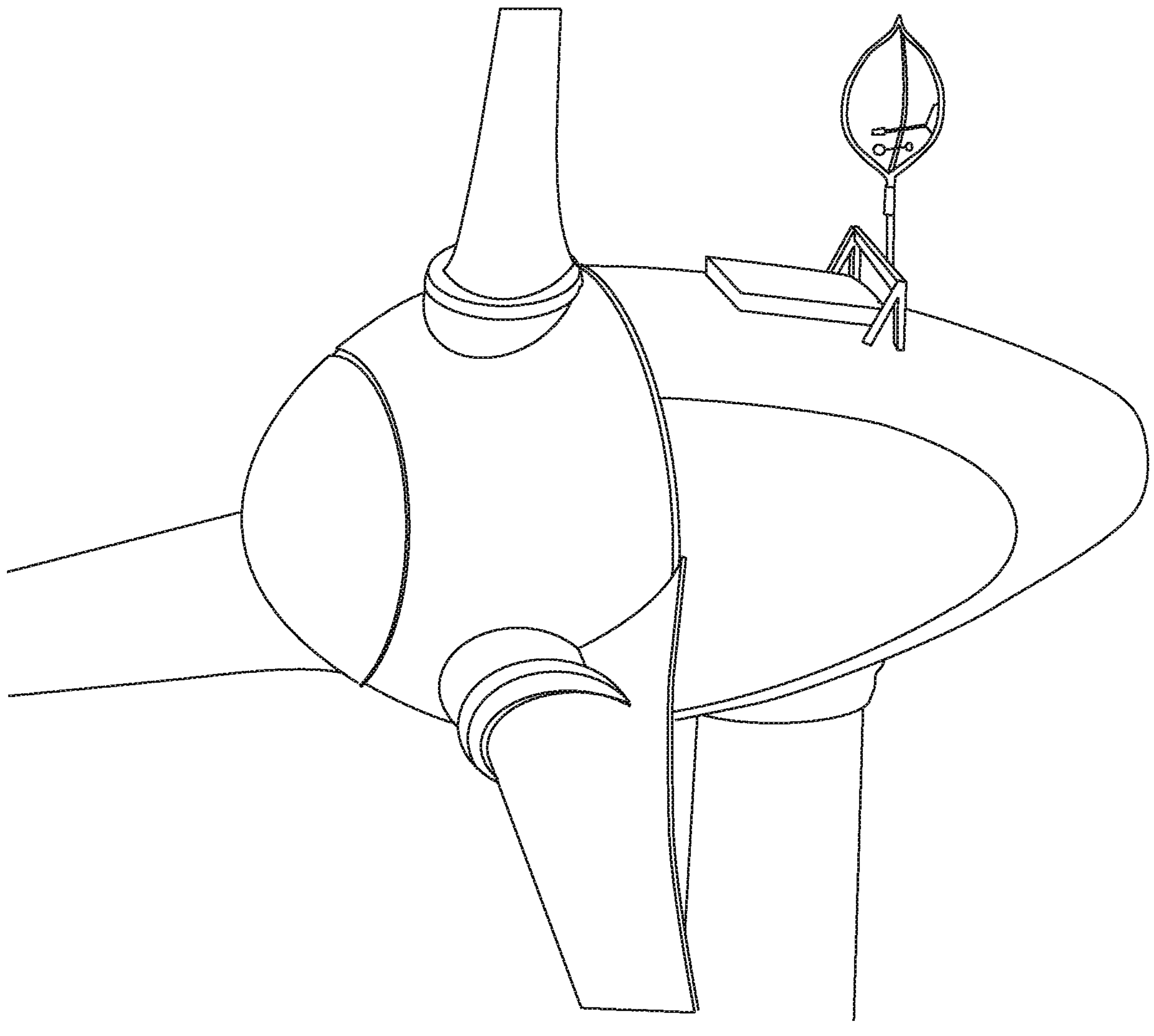

Fig.11

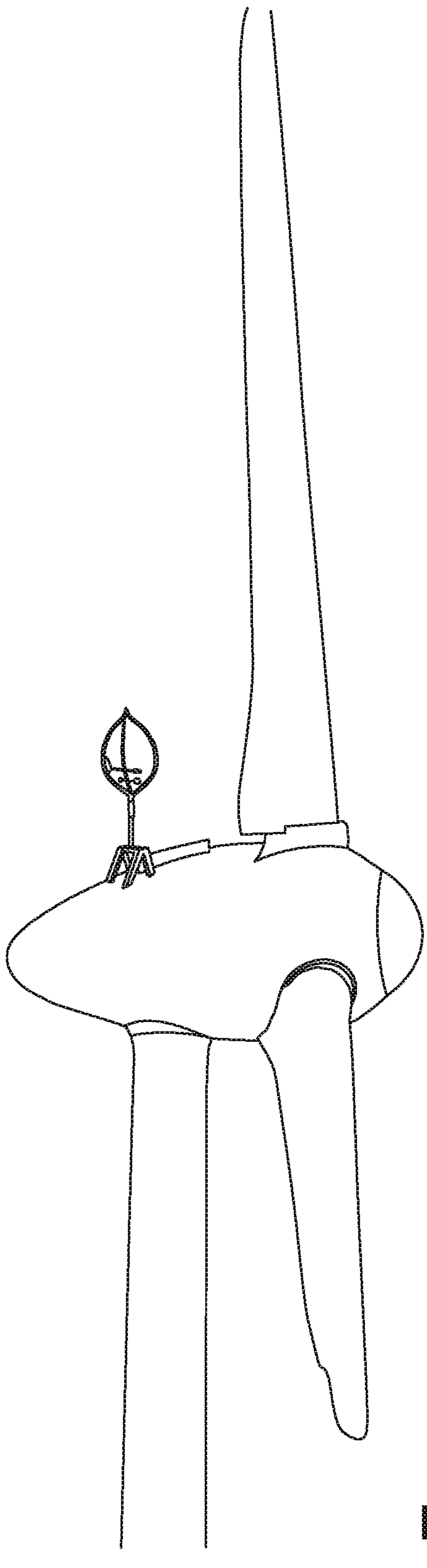

Fig.12

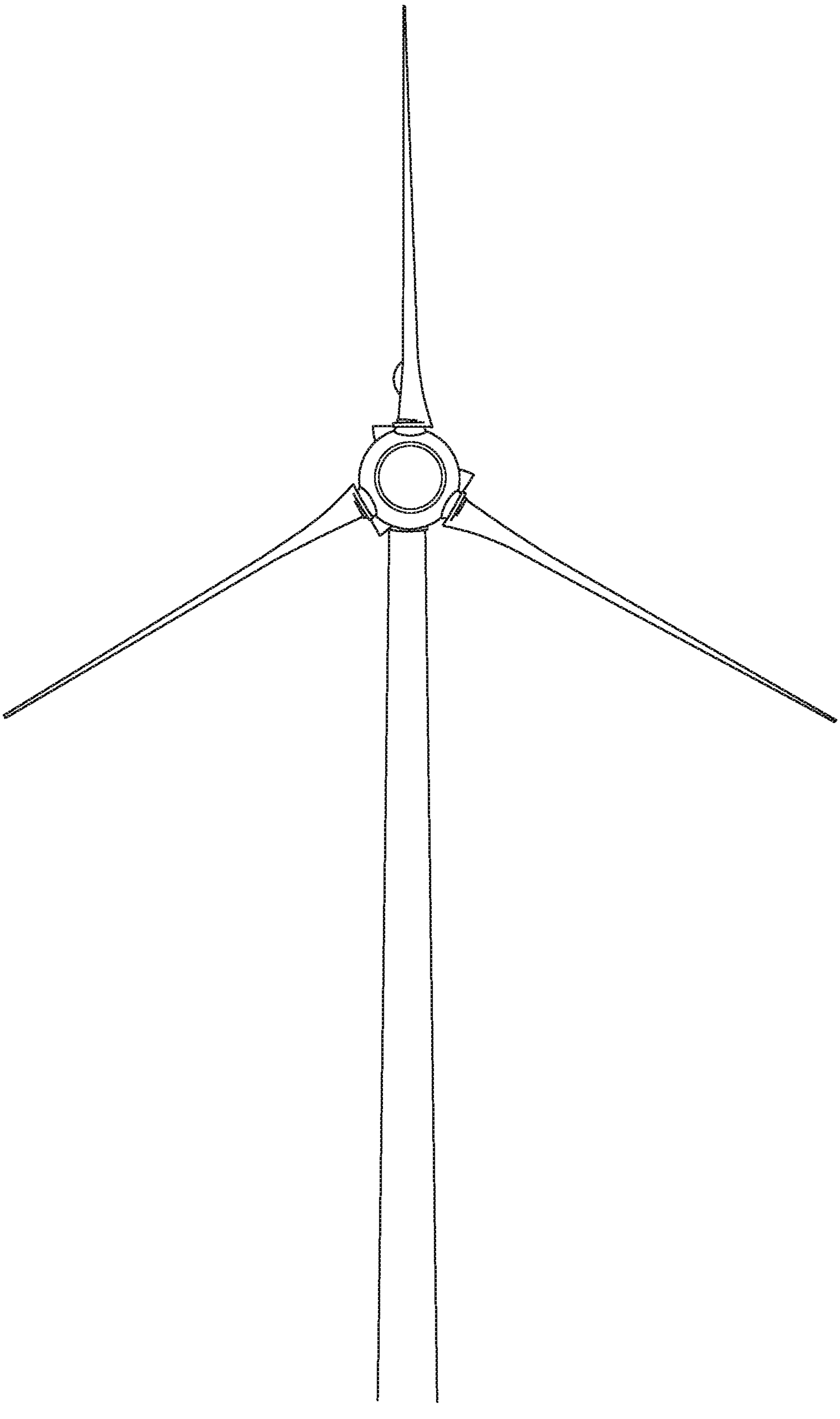

Fig. 13

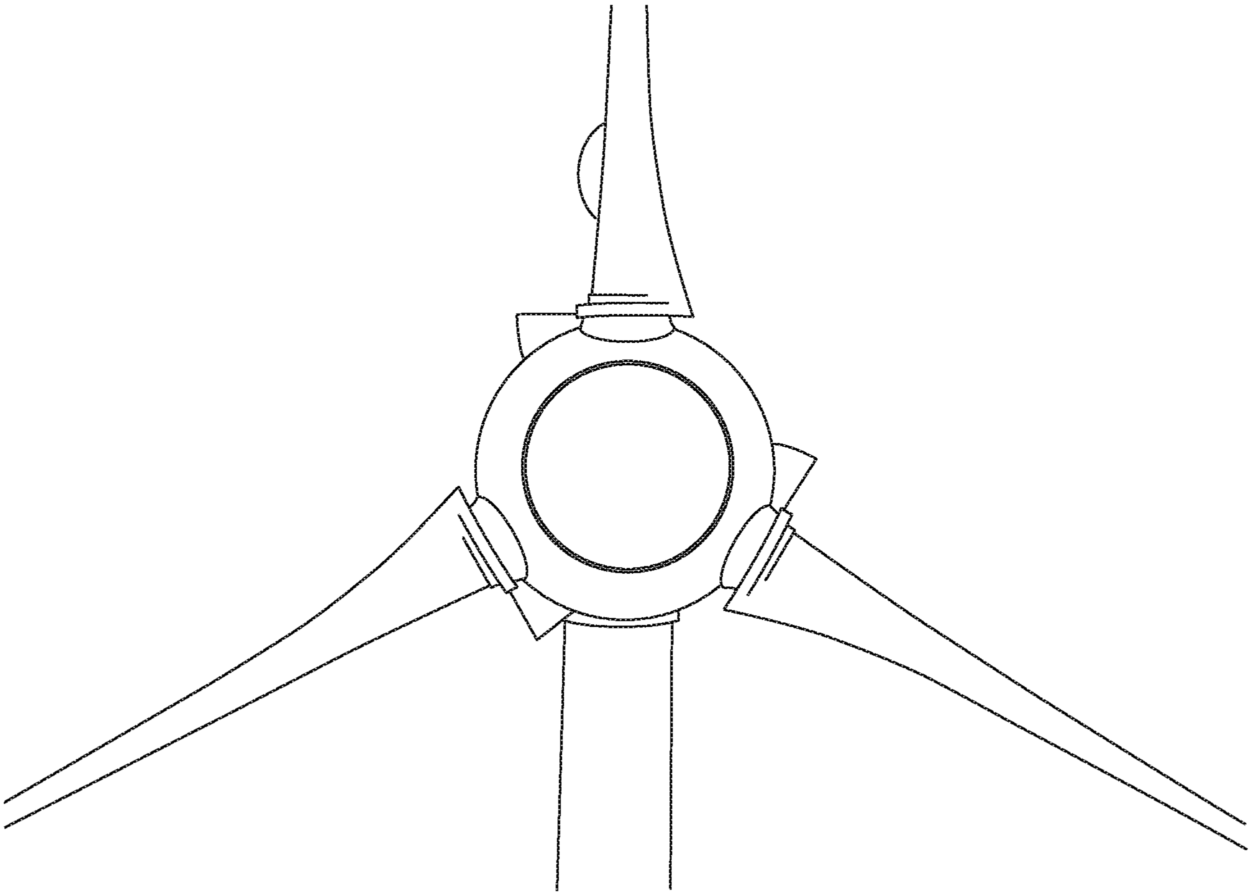

Fig.14

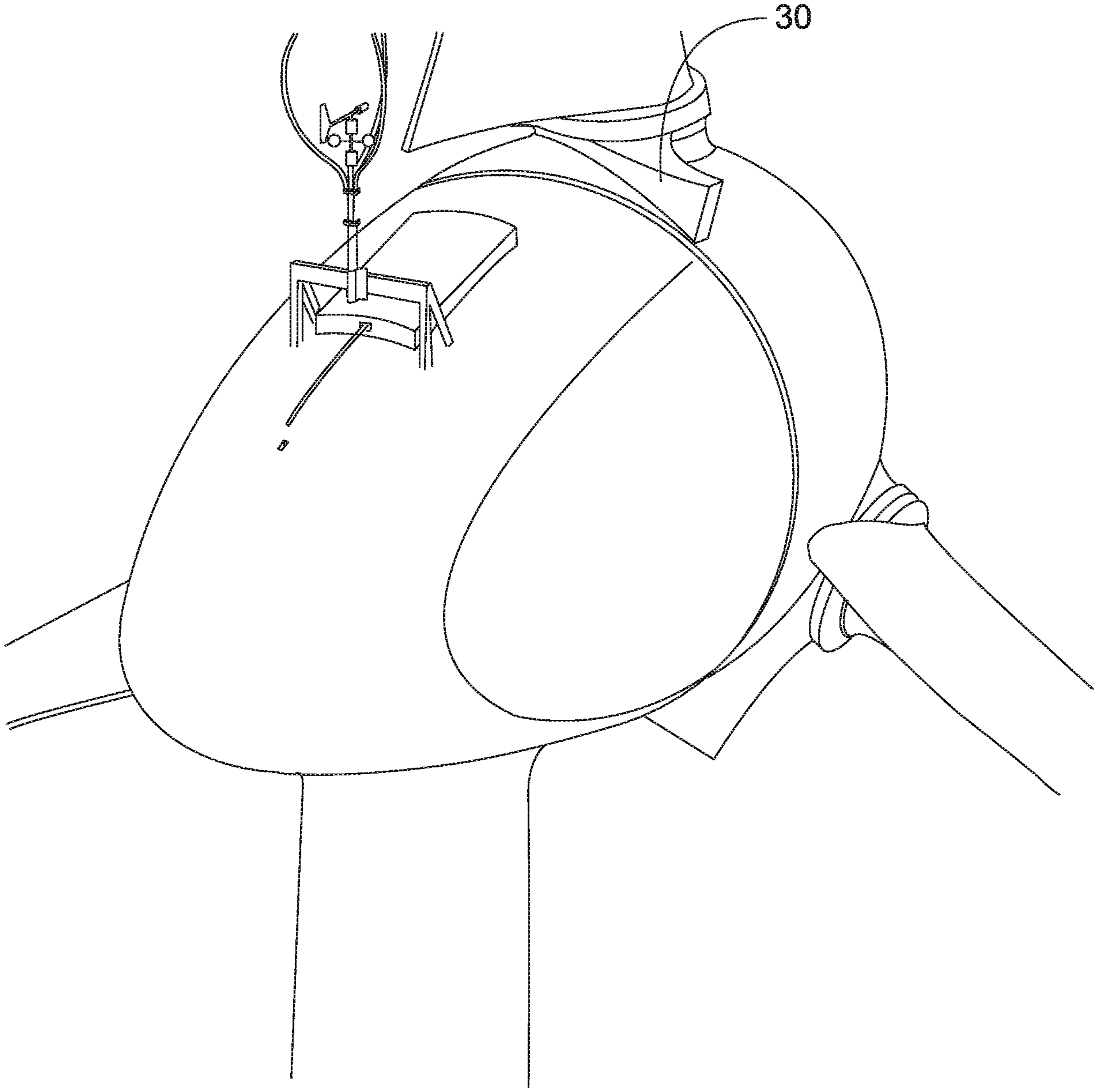

Fig. 15

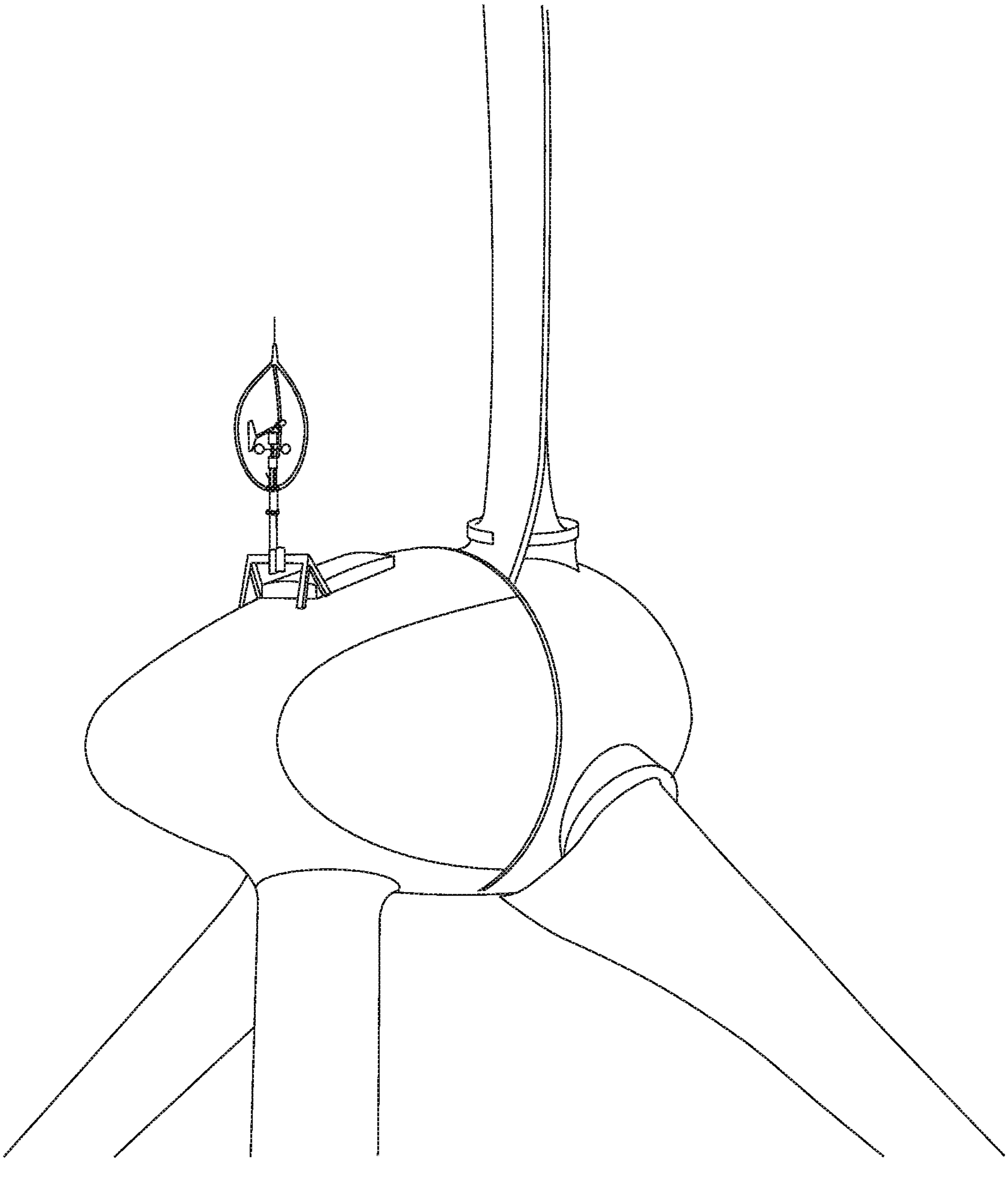

Fig.16

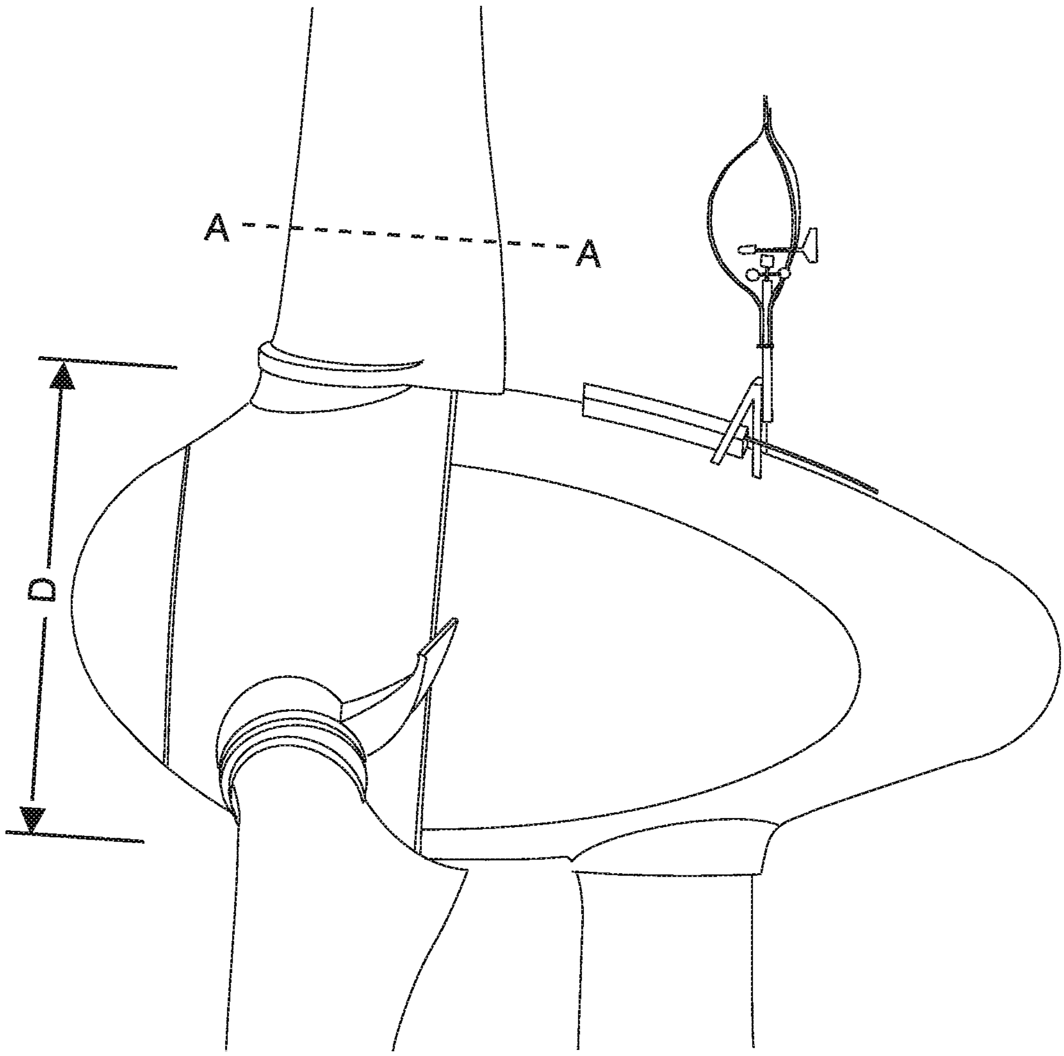

Fig. 17

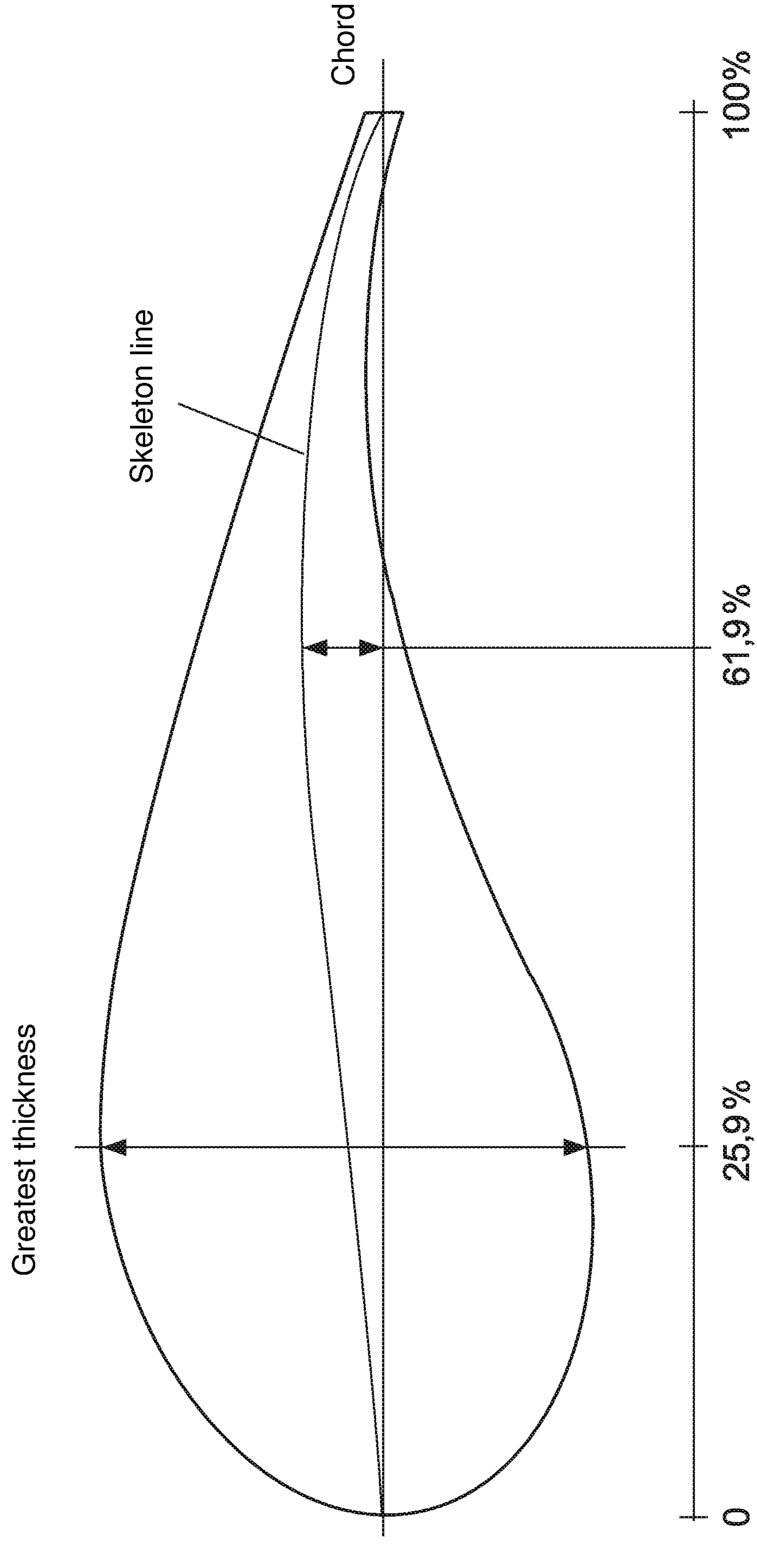

Fig. 18

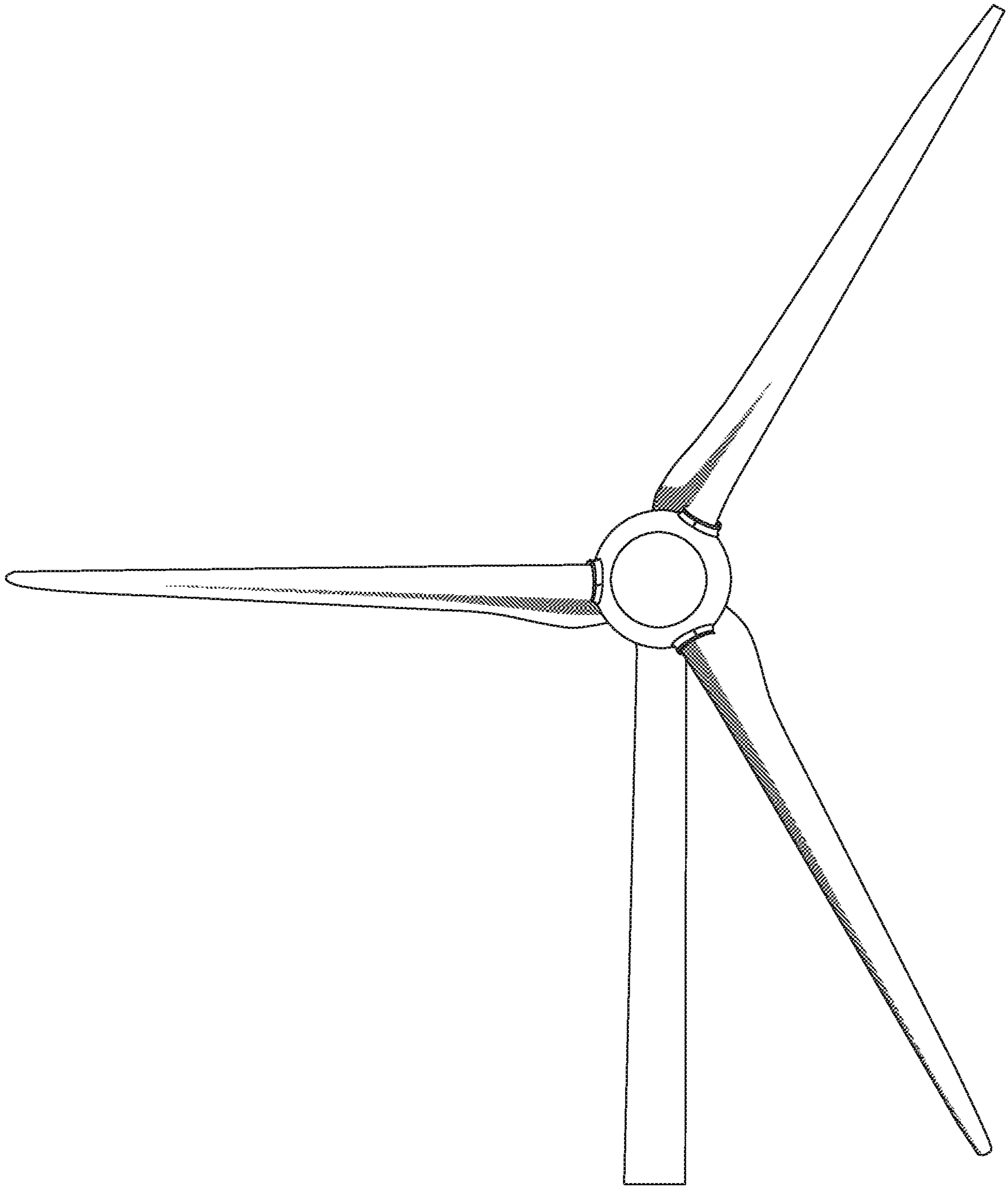

Fig.19

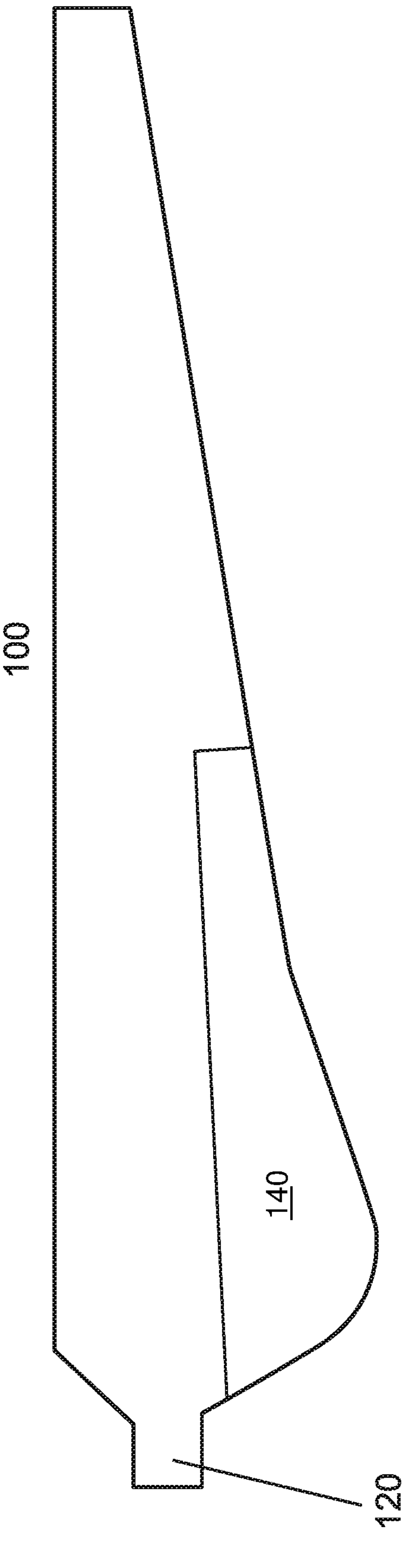

Fig. 20

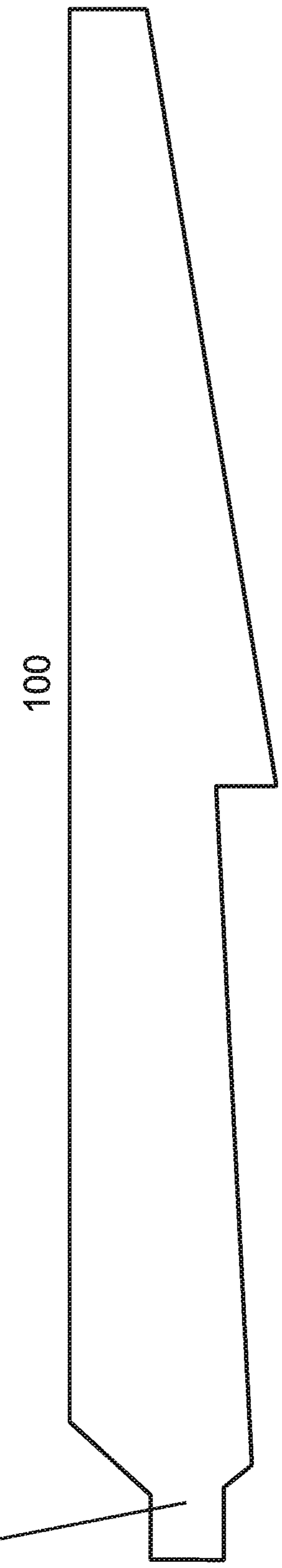

Fig.21

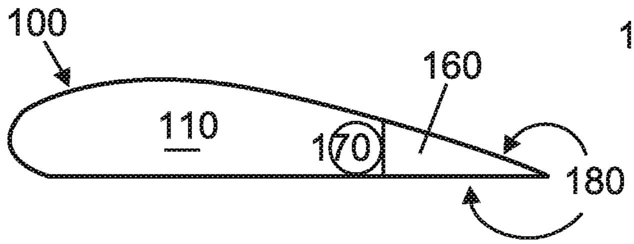

Fig. 22

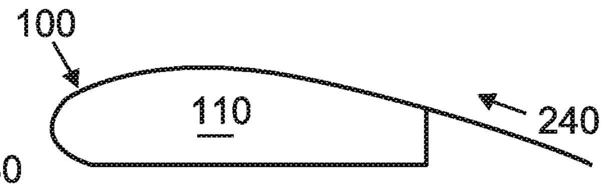

Fig. 23

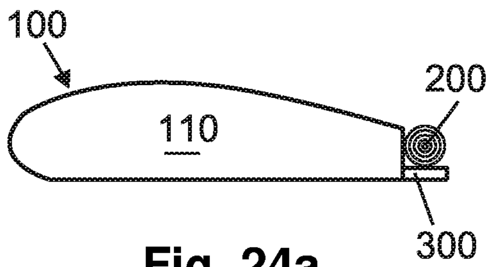

Fig. 24a

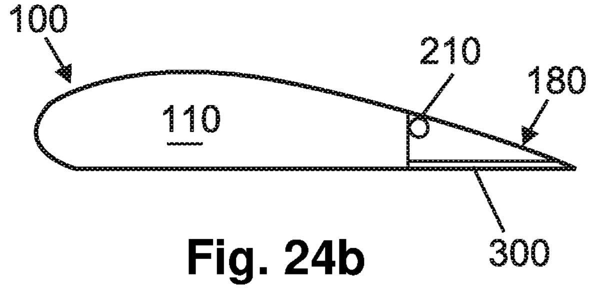

Fig. 24b

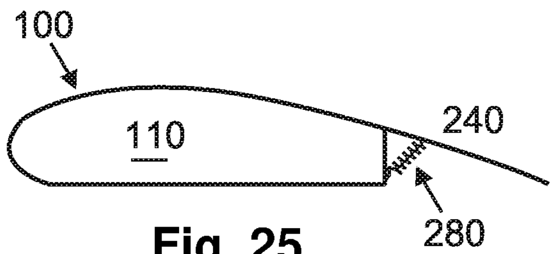

Fig. 25

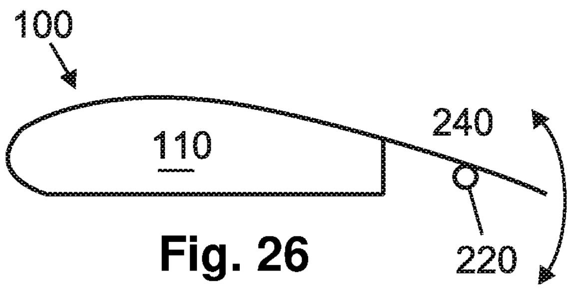

Fig. 26

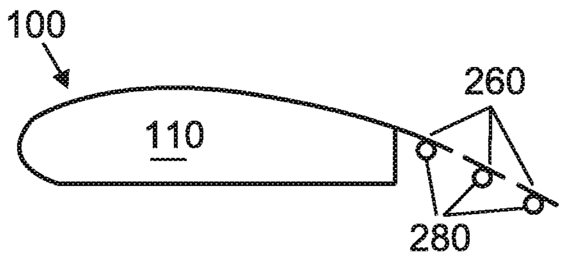

Fig. 27a

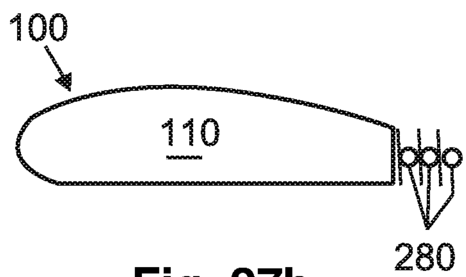

Fig. 27b

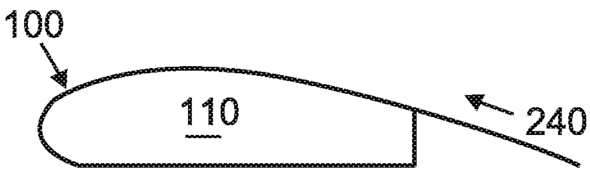

Fig. 28a

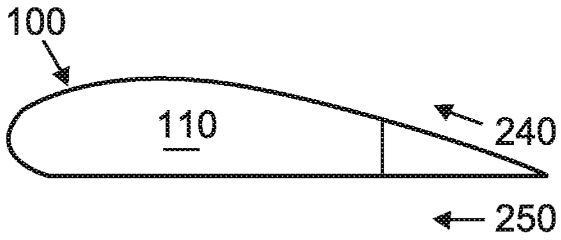

Fig. 28b

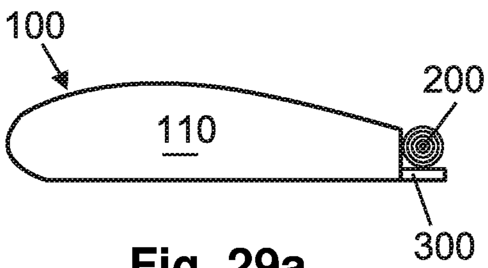

Fig. 29a

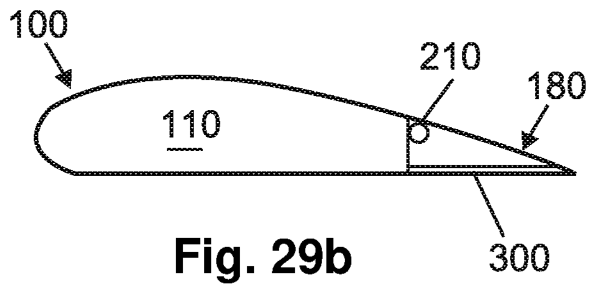

Fig. 29b

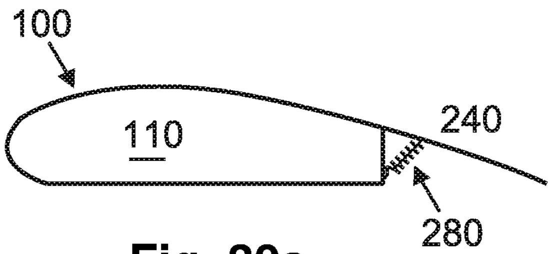

Fig. 30a

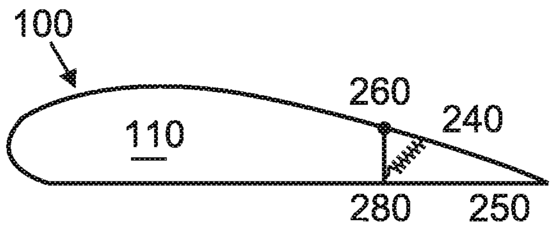

Fig. 30b

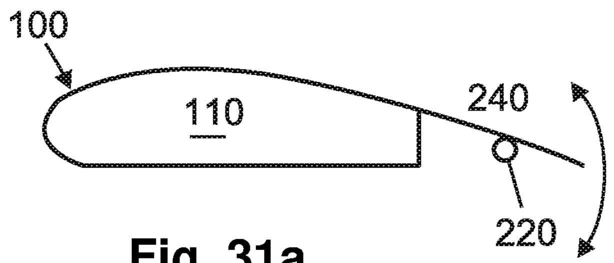

Fig. 31a

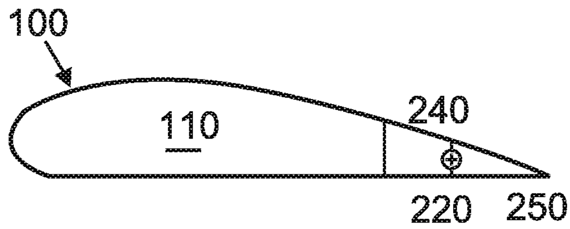

Fig. 31b

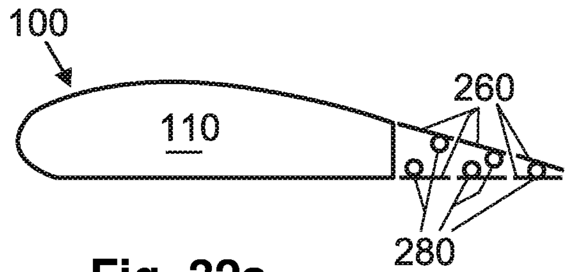

Fig. 32a

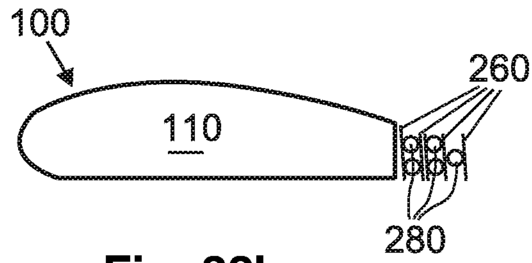

Fig. 32b

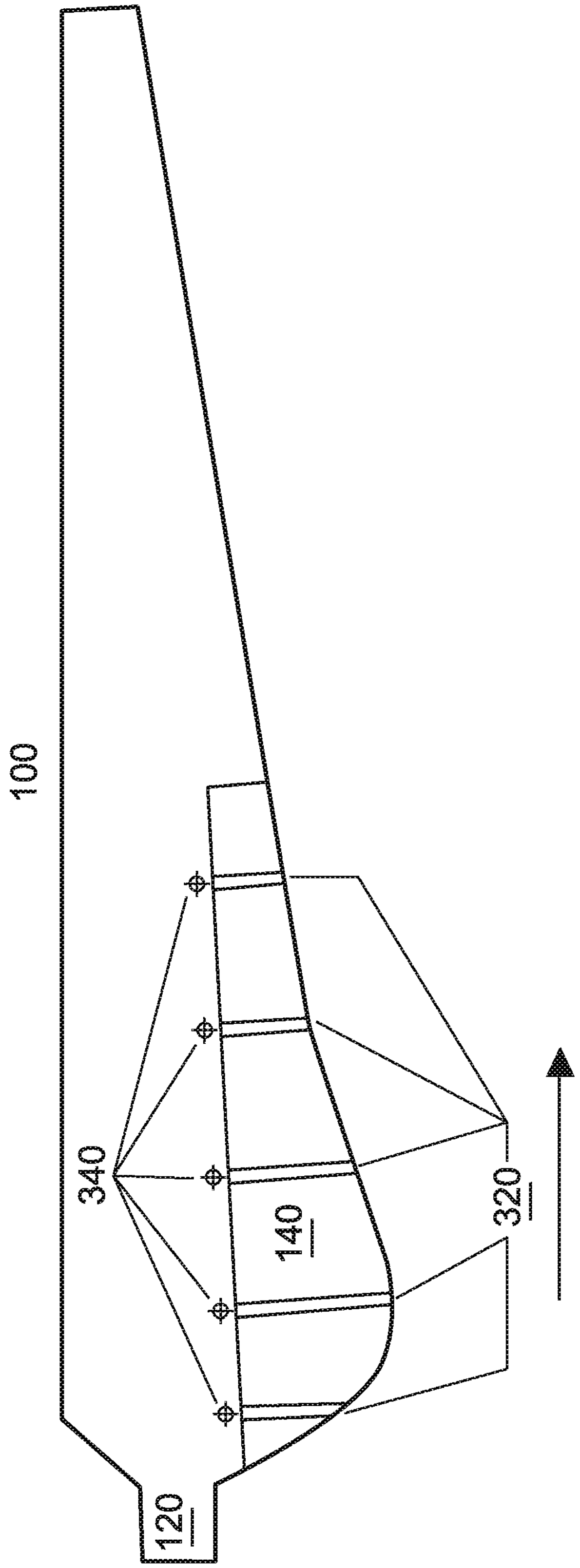

Fig. 33