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(54) WIND TURBINE WITH SLENDER BLADE

WINDTURBINE MIT SCHLANKER SCHAUFEL

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Description

Introduction & Definitions

[0001] The wind turbine can be a horizontal axis wind turbine or a vertical axis wind turbine comprising a rotor with rotor blades, with N the number of rotor blades and R the blade radius. Due to rotation, the blade tip at radius R obtains a tip speed v_{tip} equal to the product of the rotor speed ω and the rotor radius R : $v_{tip} = \omega R$. The undisturbed wind speed V is the wind speed at the locus of the axis of the rotor when the wind turbine does not disturb the flow. The ratio between the v_{tip} and V is the tip speed ratio $\lambda = \omega R/V$. An airfoil is a for the aerodynamics optimized profile which is round at the leading edge and sharp or cut off at the trailing edge. One side of the airfoil is the upper side or suction side, the other side is the lower side or the pressure side.

[0002] The curve through the centres of circles within the airfoil touching both the lower side and the upper side is called the camber line. At the leading edge this line continues to the airfoil contour. The line part which connects the most forward and the most backward part of the camber line is the chord c or the local chord c_r at radial position r . A rotor blade may exist of several airfoils at the same radial position. In such a case the sum of the chords of the airfoils should be taken as the locale chord c_r .

[0003] The leading edge of the airfoil is located at 0% of the chord (0%c) and the trailing edge at 100%c. The largest distance between the camber line and the chord is the camber.

[0004] The ratio between the diameter of the largest circle in the airfoil and the chord is the thickness t of the airfoil. Flexible or in position controllable parts of the aft part of the airfoil, which can move more than 2.5%c with respect to the leading edge are not part of the chord. The lift $L = \frac{1}{2}\rho U^2 c C_l$ and drag $D = \frac{1}{2}\rho U^2 c C_d$ of an airfoil are both proportional to the chord c and respectively to the lift coefficient C_l and the drag coefficient C_d .

[0005] The chord follows from the equation $C = M$. Here in M is a dimensionless momentum loss. C is the chord number which is $Nrc_r c_l \lambda^2 / (2\pi R^2)$ for a horizontal axis turbine and $Nrc_r c_l \lambda^2 / R^2$ for a vertical axis turbine. This number prescribes how the parameters N , c_r , c_l , r , R and λ should be chosen in order to realise a certain dimensionless momentum loss in the flow. Close to the axis of rotation, the chord number does not provide good values and therefore this number is primary useful in the range starting at $0.3R$ - $0.6R$ and ending at $0.9R$ - $1.0R$. Example for a horizontal axis wind turbine with $M=4$. When the designer chooses $R = 50m$, $\lambda = 8$, $N = 3$ and $c_l = 0.9$ then it follows that $c_r = 68.2m^2$, so at $25m$ radial position the chord should be about $2.73m$. The average chord number in e.g. the range of $0.5R$ to $0.9R$ is:

$$\bar{C} = \frac{1}{0.4R} \int_{r=0.5R}^{r=0.9R} \frac{Nrc_r c_l \lambda^2}{2\pi R^2} dr.$$

[0006] The chord of a wind turbine blade can be calculated also with the equation $Nc_r \lambda^2 / R^2 = 8\pi a(1-a)/c_l$, in which a is the axial induction according to the Lanchester-Betz theory. The term on the left hand side of the equation is the chord number D , of which the average in e.g. the range of $0.4R$ to $0.95R$ is:

$$\bar{D} = \frac{1}{0.55R} \int_{r=0.4R}^{r=0.95R} \frac{Nrc_r \lambda^2}{R^2} dr.$$

[0007] The power coefficient $C_p = P/(\frac{1}{2}\rho A V^3)$, in which P is the power extracted from the flow according to the Lanchester-Betz theory, ρ is the air density and A the swept area πR^2 . The extracted power P will be higher than the electric power P_e due to transfer losses. For values of P_e between $0.5P_{nom}$ and P_{nom} , in which P_{nom} is the nominal or rated power, it is assumed that $P = 1.2P_e$. The pitch angle is 0° when the local chord at $0.99R$ is located in the plane in which the blade is rotating. The angle becomes more positive when the blade pitches towards vane position. The angle of attack is the angle between the chord and the undisturbed inflow in a 2D situation. The angle of attack at which the blade develops zero lift is the 0-lift angle. The lift (coefficient) increases approximately linear with the angle of attack for small angles of attack (e.g. between -8° and $+8^\circ$). Most pitch regulated variable speed turbines operate essentially at or near constant tip speed ratio λ below rated wind speed. The turbine may deviate from this constant λ operation e.g. to avoid certain eigenfrequencies or to decrease sound emission. Still it is optimised for a certain λ_{design} and the airfoils operate on average at the angle of attack α_{design} which gives optimum performance. At α_{design} the airfoil develops a lift coefficient $C_{l,design}$ and has a lift over drag ratio L/D_{design} . When actual turbines produce power under non-extreme conditions and below rated wind speed, the mean value of the angle of attack and also of the lift coefficient approach the design value. The momentary realisations of those parameters behave stochastic due to turbulence, yaw, shear etc. A common method to characterise a wind turbine is to bin parameters like the 10-minute averaged power or angle of attack or lift coefficient as a function of the 10 minute averaged wind speed. When many data points are collected in each bin and averaged a more or less accurate estimate of the averages of those parameters is obtained. The so obtained value of for example a lift coefficient at a certain wind speed is the mean lift coefficient or the 10 minute averaged lift coefficient. If the turbine is produced conform the design, those mean or 10 minute averaged values correspond to the design values. So essentially the

design value, the 10 minute averaged value and the mean value of a parameter such as the lift coefficient or angle of attack are equivalent. The angle at which the airfoil stalls or the flow separates from the surface is airfoil dependent. A typical stall angle is $+10^\circ$, at which the lift coefficient is about 1.0 to 1.6. At larger angles c_l increases slightly or even decreases and simultaneously c_d increases, so that the efficiency of the rotor blades drops.

[0008] Flow separation can be avoided with lift enhancing means, such as known in literature. Examples of such lift enhancing means are vortex generators (VGs), gurney flaps, lengthening of the chord, increase of camber, suction of the boundary layer, flaps near the leading edge or near the trailing edge, deformation of a flexible part at the trailing edge of the airfoil, application of the Magnus effect, FCS such as described in Sinha, S.K., WO03067169, synthetic jets which feed energy into the boundary layer such as is known by e.g. Gerhard, L., US4674717 and MEM translational tabs. Most of those options can be applied in a passive and an active sense, in said active case the control can be by pneumatics, hydraulics, electromagnetics, piezo electrics, by MEM translational tabs or any other control method known from literature. All those lift enhancing means can principally be attached as separate elements to the blade or can be integrated with the blade.

[0009] VGs are elements which generate vortices which feed energy into the boundary layer. VGs can be elements which are more or less submerged in the surface and are known in many different shapes. Examples are a special curvature of the airfoil surface itself (e.g. cavities) or surfaces which extend from the airfoil surface into the flow. Possible connection parts such as a base which is connected to the VG, is not counted as part as the VG. The chord position of the VG is related to the part of the VG at the smallest chord position. The base can be essentially flat or following the local airfoil shape. Known shapes of VGs can be found in Waring, J., US5734990; Kuethe, A.M., US3578264; Kabushiki, K.T., EP0845580; Grabau, P., WO00/15961; Corten, G.P., NL1012949, Gyatt, G.W., DOE/NASA/0367-1 etc. VGs may have a length of about 3% of the chord, a height of about 1% of the chord and a mutual distance of about 5% of the chord. VGs postpone stall to larger angles of attack. Airfoils with VGs reach typical lift coefficients of 1.5-2.5 at angles of attack of e.g. $+12^\circ$ tot $+25^\circ$. Three or more VGs at regular spacing attached essentially in a line biased less than 30° from the line perpendicular to the flow direction is defined as a basis line of VGs. Tangentials are circles around the centre of rotation in the plane of rotation of the applicable airfoils.

Disadvantages

[0010] Wind turbine costs are high because of the loads which require much material. Therefore turbine designers aim at high electricity production at low loads. A disadvantage of the present wind turbines is that the

loads by the wind vary and that this variation leads to additional costs. An extreme case of a disadvantageous load variation is that wherein a blade bends so much that it hits the tower. At wind speeds above $V_{cut-out}$ the turbine has to be stopped to avoid overloading, which reduces production and adds uncertainty to the predicted production. Another disadvantage is relevant at high wind speeds when turbines are usually halted. The wind pressure on the blades causes high loads because the required chord of the turbine blades is large. A further disadvantage is that the loads increase when turbines are operated in the wake of other turbines and need to be placed far apart which costs space and additional cable length.

[0011] Another disadvantage of the present turbines is that the aerodynamic characteristics of the rotor blades are hard to predict and therefore new prototypes often undergo a long and costly phase of testing and adaptation before they fulfil.

[0012] Furthermore when a turbine is operated at a reduced tip speed ratio to meet a certain sound emission level, the efficiency drops rather much, since in fact the blades need adaptation for such situations.

[0013] A further disadvantage is that the high moments require much and strong material in the case of slender blades. Overcoming this disadvantage by the application of thick airfoils may lead to flow separation thus more drag and less lift. Another disadvantage of actual wind turbines is that the induction near the centre of a wind turbine rotor is less than further outside. This 'leak' in the rotor centre reduces the pressure difference over the rotor and therefore reduces the power.

[0014] A further disadvantage of present rotors is that the blade performance degrades substantially by contamination.

Aim of the Invention

[0015] The aim of the invention is to reduce the ratio between the variation of the lift force and the average lift force of wind turbine blades and more in general to overcome the mentioned disadvantages. This aim is reached by replacing the state of the art airfoils by airfoils with a 10 minute averaged lift coefficient of more than 1.1, particularly more than 1.2 and more particularly more than 1.4 and preferably about 1.6 in the range between 0.5R and 0.95R. Special benefit is obtained by using airfoils between 0.4R and 0.95R with a mean lift coefficient which is higher than 1.5 and in particular higher than 1.75 and more particularly higher than 2.0 in a part of the operating range excluding extreme conditions.

[0016] Since the lift of an airfoil is essentially proportional to both c_l and c , the product cc_l should have a minimum value to reach the required lift. The designer can freely choose c and c_l as long as the product cc_l is larger than this minimum. Without notice the designer applies the same argument to lift variations, which is not correct. Surprisingly the lift variations are unlike the lift essentially

independent of the lift coefficient c_l . When the designer uses this new insight, he would reduce c and increase c_l , so that the lift variations become less. This is especially relevant in the outer part ($r > 0.5R$) of the rotor.

[0017] This way the variation of the lift force due to turbulence, wind shear, turbine misalignment, blade motions, control errors etc. may reduce by more than 30%. This mitigates both the fatigue and extreme loads, which is beneficial for the entire wind turbine structure including the foundation. It enables commissioning of turbines on high turbulence sites. In wind farms one can choose a smaller spacing between the turbines.

[0018] The text below describes the background of many preferred embodiments of the invention for which also reference is made to the sub claims.

[0019] Further benefit is obtained when airfoils are applied which operate on 10 minute averaged angles of attack which deviate from the 0-lift angle by more than 10° , and particularly more than 12° and more particularly more than 14° and preferably about 16° .

[0020] For wind turbines with a power coefficient C_p between $\frac{1}{3}$ and $\frac{16}{27}$, the dimensionless momentum loss M can be determined in many ways. One method of special benefit is $M = -1.19 + 9.74C_p - 21.01C_p^2 + 17.50C_p^3$. By setting the so obtained M equal to the chord number C and by substitution of N , r , c_l , λ , R , the local chord c_l can be determined. Further advantage is obtained when c_l is chosen smaller than the value which follows assuming $c_l = 1.1$ and particularly 1.3 and more particularly 1.5 and even more particularly preferably 1.7 .

[0021] Example: A classic horizontal axis turbine has an airfoil near the tip with a 0-lift angle of -3° , a maximum lift coefficient of 1.3 at 10° angle of attack and a lift coefficient which is linear by 0.1 per degree between those angles. Above 10° angle of attack the airfoil stalls and the efficiency drops much. Assume the average angle of attack is 7° and due to turbulence it varies by $\pm 3^\circ$, then the lift coefficient varies from 0.7 to 1.3 and its average is 1.0 . The lift variation is $0.6/1.0 = 60\%$ of the average. This is a measure for the load variation on in the blades, the transmission, the bearings, the tower, the foundation etc, and everywhere increases costs. According to an example of the invention we choose airfoils with VGs so that stalling is postponed to a larger angle of attack. The maximum lift coefficient is now e.g. 1.8 at an angle of attack of 15° . The rotor is designed so that the average angle of attack is 12° and the average lift coefficient is 1.5 . Since the lift is proportional to the product of chord and lift coefficient for small α , we choose the chord smaller by a factor of 1.5 , so that the lift and thus the yield are equal. Due to turbulence the angle of attack varies in this case between 9° and 15° without stalling. With furthermore the same assumptions it follows that the lift coefficient varies between 1.2 and 1.8 . Surprisingly the variation is only $0.6/1.5 = 40\%$ of the average, or $2/3$ of the load variation without the invention. Also load variations due to yawed inflow or wind shear are less. By parking the blades above $V_{cut-out}$ so that the maximum positive

lift is not reached and the lift preferably is negative, the loads on the blades will be less by about the same factor as the chord reduction. A parking position of particular benefit is when the pitch angle is set outside the range of $30^\circ - 100^\circ$.

[0022] Further advantage of the load mitigation according to the invention is that less (expensive) turbine control options are required. The common active controlled options are pitch control (to vane or to stall) and variable rotation speed. A preferred embodiment of the invention considers a wind turbine with 2 and particularly 1 or more particularly 0 active control options selected from the said active control options.

[0023] Further advantage is obtained when lift enhancing means such as VGs are applied on a rotor blade on which those means are attached as separate members or when those means are integrated with the rotor blade. It is state of the art to correct rotors with bad performance by the application of VGs. Such a case is described in Corten, G.P., "Flow Separation on Wind Turbine Blades", ISBN 90-393-2582-0. In the case of newly designed rotors the expert advises against the application of VGs, since the prejudice is that they will add noise and drag, without further advantage. It is commonly known from wind tunnel experiments that, for small angles of attack, the drag of an airfoil without VGs is less than the drag of the same airfoil with VGs. Surprisingly this advice is not correct and is based on an incorrect experiment. An airfoil without VGs should be compared to an airfoil with VGs with a reduced chord which reaches the same lift.

[0024] Example: Assume the airfoil without VGs has $c_l = 1.0$, $c_d = 0.01$ and $c = 1$ m and the airfoil with VGs has $c_l = 1.5$, $c_d = 0.012$ en $c = 2/3$ m. Both airfoils develop the same lift since the product cc_l is constant. The drag of the airfoil without VGs is proportional to $cc_d = 0.01 \times 1 = 0.01$ and that of the airfoil with VGs is $cc_d = 0.012 \times 2/3 = 0.008$. So with VGs the drag is less, even while the drag coefficient is higher. Apart from that the drag coefficient can also decrease by attaching VGs. Further advantage is obtained because the VGs condition the boundary layer much and therefore the effects of contamination are relatively less important. This leads to less production losses in case of contamination.

[0025] Further advantage is obtained because the application of lift enhancing means essentially at the suction side increases the maximum lift for the positive angles while the maximum lift for negative angles of attack essentially is unchanged. Preferred embodiments of the invention have a ratio $c_{l,max}/c_{l,min}$ less than $-1.2 - 0.2\%cam$ and in particular less than $-1.4 - 0.2\%cam$, wherein $c_{l,max}$ is the maximum lift at positive angle of attack, $c_{l,min}$ is the maximum lift at negative angles of attack and $\%cam$ is the camber in percent of the chord, so when the camber is 6% said ratio is preferably larger than 2.2 and in particular 2.4 . Therefore less measures (addition of foam or application of a higher percentage second type fibres) are required at the aerodynamic suction side to avoid buckling.

[0026] Further advantage is obtained by the application of carbon fibres, which are suitable to add stiffness and to take up tensile loads, at the aerodynamic suction side. This leads to a mass reduction and less tip deflection, which will reduce costs in the entire turbine. For the definition of first type and second type fibres reference is made to Bech, A. e.a., WO 2004/078465. In this patent an asymmetric laminated part is already noted. However it was not clarified what specifically is asymmetric and also not what the arguments are for an asymmetric structure while those arguments (asymmetric aerodynamic behaviour) does not turn up until blades according to the present invention are used.

[0027] Further advantage is obtained by the application of air inlets such as slits in the airfoil at the suction side between 5%c and 60%c. Those inlets are preferably located in the radial range of 0.05R to 0.5R. These inlets are connected to channels in the blade which run to larger radial positions and which have an opening at the trailing edge of the blade. The centrifugal force on the air in the channel provides a natural suction. Further advantage is obtained by connecting inlets of more than 10% difference in radial position to different channels. Further advantage is obtained when the inlets can be opened or closed actively by using MEM tabs or piezoelectrics.

[0028] Further advantage is obtained by application of the blades up side down: the suction side as pressure side and the pressure side as suction side, in particular at wind speeds above 12 m/s and more particularly above 14 m/s. In operational terms this means that the turbine pitches the blades by about 150° and that the turbine stops and starts up again in the other rotational direction. Alternatively the nacelle is yawed over 180° so that the rotor changes from upwind to downwind operation. In this case the direction of rotation of the rotor remains the same. With the blades up side down, the variation of the lift force developed by the entire blade is less, the extreme lift force is less and the lift force acts on a smaller radial position, so that yaw and blade root moments are less. Those are reasons to increase the $V_{cut-out}$ from the classical value of 25 m/s to 30 m/s or to 35 m/s or to higher values.

[0029] With increasing turbine size the material usage increases faster than the yield, therefore saving material is of more importance for larger turbines. Therefore the invention is particularly relevant for turbines with a rotor diameter larger than 60m, particularly larger than 80m and more particularly larger than 100m.

[0030] At constant relative thickness, the reduced chord according to the invention may require more material to carry the loads. To carry the loads with little material and to add stiffness the blades can be split in an upper blade and a lower blade at e.g. 0.2R-0.7R. Further advantage is obtained when the first type fibres at the pressure side continue from the non-divided outer part of the blade in the upper blade. Optionally the first type fibres at the suction side of the non-divided outer part of the blade continue in the lower blade. Further advantage

is obtained when the upper and the lower blade reach a mutual distance of at least 5%R and particularly at least 10%R. The asymmetric aerodynamic behaviour of the blades leads to the situation that the upper blades take mainly pressure loads and the lower blades take mainly tensile loads. According to an example of the invention the lower blade preferably has a 20% and particularly 40% and more particularly a 60% shorter chord than the upper blade at equal radial positions. A further advantage is that the addition of the chords of the lower and the upper blades increases the yield because 'leakage' from pressure side to the suction side is avoided.

[0031] Further advantage is obtained by the application of relatively thick airfoils to carry the loads with little material and to add stiffness. The reason is that with VGs, possibly attached on both sides, flow separation can be avoided, so that thick airfoil can have high efficiency in a large angle of attack range. Airfoils of at least $t = 25\%c$ are applicable at radial positions $> 0.55R$ and particularly at radial positions $> 0.65R$ and more particularly at radial position $> 0.75R$.

[0032] Further advantage is obtained by application of VGs at the pressure side to avoid flow separation. Doing this the maximum negative lift does not or slightly increase because the VGs are preferably placed close to the trailing edge at chord positions larger than 30%c, particularly larger than 50%c and more particularly larger than 70%c.

[0033] Further advantage can be obtained by using airfoil with a camber of more than 6%c and particularly of more than 8%c and more particularly of more than 10%c. The additional camber avoids a deep suction peak at large angles of attack, which reduces sensitivity to contamination. Furthermore airfoils with high camber often have a high L/D ratio at large angles of attack.

[0034] When multiple VGs or basis line of VGs are located behind each other in flow direction, one can speak about front, middle and rear VGs. The front VGs correspond to the VGs at the smallest chord position, the rear VGs to those at the largest chord position and those in between are the middle VGs. Further advantage is obtained when the VGs in the middle are larger than the front ones and particularly when they are also larger than the rear ones.

[0035] Further advantage is obtained by placement of some additional VGs upstream with respect to the basis line of VGs. The additional VGs keep the flow longer attached up to the basis line downstream. Those additional VGs reduce hysteresis of the c/α relation when α passes the stall angle. Those VGs can be located between 3%c at the pressure side and 10%c at the suction side and more particularly between 0%c and 5%c at the suction side. It is beneficial when VGs which are located behind each other in flow direction generate vortices of the same rotational direction.

[0036] Further advantage is obtained by attachment of VGs on the airfoil between the position of the stagnation point and that of the suction peak at an angle of attack

of 5°. In this range the advantage is that the VGs are located in a low speed area at small angles of attack. When the angle of attack increases then the suction peak (the locus of maximum flow speed) shifts towards the VGs which therefore become more effective. So the VGs have low activity at small angles (thus little drag increase) and high activity when it is necessary at large angles.

[0037] To reduce said c_l/α hysteresis, one can also apply long VGs which extend e.g. more than 10%c or even more than 30%c in chord direction. In this design the blade surface is provided with ribs under an angle with the flow, of which the upflow part preferably is located at a smaller radial position than the downflow part.

[0038] In the case of a vertical axis turbine the angles of attack also vary without turbulence. The angle of attack variation is inversely proportional to the tip speed ratio λ . To keep the angle of attack variation in the range of -10° to +10°, λ should not become less than about 4½. For lower λ values the airfoils stall. Application of airfoils with VGs on both sides delays stall to larger angles of attack so that a λ of 4, 3½, 3 or even 2½ can be used without stalling. A further advantage for the VAT turbine (when used in air or in water) is that it becomes self starting by attachment of VGs at less than 20%c, particularly less than 15%c and more in particular at less than 10%c on both the suction and pressure side of an airfoil or hydrofoil.

[0039] Further advantage is obtained by using the high lift coefficients since it enables operations at lower tip speed ratios which reduces noise.

[0040] Preferably several VGs (1, 2, 4 or another number) and the ground plate are manufactured as one piece or even as a tape of a flexible material such as rubber, polyurethane or an elastomer possibly with additives to block UV-radiation. This is called a VG-element and is favourably manufactured of plastics of the families PVDF, FEP, PEEK, PI, PEI, PES and PFTE.

[0041] The VG-element can be attached to the rotor blade with any known technique. It is of particular advantage to provide the ground plate partly of double sided adhesive and partly with fluid adhesive such as a cyanoacrylate. The double sided adhesive provides direct fixation after which the fluid glue has time to harden. The VGs can be attached with a hinge and only fold out after the blades are installed to the turbine. The side of the ground plate which will be attached to the blade can be slightly concave with a radius of curvature which is smaller than the radius of curvature of the blade at the position of attachment.

[0042] Further advantage is realised when the VGs have curvature in flow direction so that the angle between the flow without VG disturbance and the VG increases by preferably 5° to 15° in flow direction and particularly increases in the range of 2° to 30° are effective. This curvature avoids Kelvin-Helmholtz instability of the VGs and so increases durability.

[0043] Further advantage is obtained by the application of airfoils of which the lift is less dependent on the

angle of attack in other words which have a $dc_l/d\alpha$ smaller than 1.1, and particularly smaller than 1.05 and more particularly smaller than 1.0 in the angle of attack range of 4° to 7°.

[0044] Further advantage is obtained by replacing the old rotor of an existing wind turbine by a new rotor according to the invention. This new rotor can be larger at the same load level and therefore can increase production. The old rotor is preferably replaced by a new rotor which has in the range of 0.6R to 0.95R a chord which is at least 10% less and preferably at least 20% at equal radial positions and more particularly is provided with VGs in that range.

[0045] Further advantage of the invention is that the properties of the produced blades according to the invention can be changed by adaptation of the lift enhancing means and in particular the VG-pattern regarding position, type, mutual spacing, size etc. When a further delay of stall is preferred possible VG-pattern adaptations are: Increasing the size of VGs (e.g. 25%), reducing the spacing in between VGs (e.g. 25%), placing more VGs (e.g. an additional basis line), increasing the angle between the flow and VGs (e.g. by 5°), changing the position of the VGs (e.g. 5%c), etc. In particular when the sound emission of a turbine is too high, the tip speed ratio may be reduced. Then adaptation of the blades to more optimal operation at higher angles of attack is preferred. Other cases wherein adaptability is also relevant are when blades of about the same design are used for different wind climates or on different turbines.

[0046] Further advantage is obtained by the application of controllable VGs. This can be used to decrease the maximum lift above rated wind speed, which may be reason to increase the cut out wind speed. It also can be used as a method to decrease the torque of the rotor in case of a failure, emergency stop or manual stop, which lowers the cost of other brake systems. The VGs can be switched to an effective state when a delay of low separation is preferred and to ineffective states when not. According to a preferred embodiment of the invention the VGs are controlled by piezoelectrics or by MEM tabs and in particular by cylindrical MEM devices or piezoelectrics which enable a direct rotation of the vortex generator over e.g. 15°. The VG can be attached to this piezoelectric or MEM device so that its orientation to the flow can change from non-effective to effective. The effectiveness may be controlled by changing the angle between the VG and the flow, by folding it in or by retracting it more or less in the airfoil surface. Controllable VGs have the advantage of a faster response compared to pitching a blade. A preferred embodiment of the invention concerns a wind turbine with fixed rotor blades and controllable vortex generators.

[0047] Further advantage is obtained by providing a rotor blade according to the invention of at least one strengthened point such as a hoisting point which is suitable for lifting the blade where by this point preferably is located at less than 1 chord length of the centre of mass

of the blade. This avoids damage to the VGs since a hoisting band around the blade is not needed during the installation of the blade.

[0048] Further advantage is obtained by alignment of the VGs parallel to the local undisturbed (by the VGs) flow at about the 0-lift angle $\pm 3^\circ$ or parallel to the tangentials. With increasing angle of attack the flow on the suction side will bend radially outward, so that the angle between the VG and the flow increases and a stronger vortex is generated. This way the VGs become active at high angles of attack when they are needed and hardly add drag at small angles of attack when they are not needed.

[0049] Further advantage is obtained when the upstream side of the VGs is located at a smaller radial position than the downstream side so that the VGs force the flow towards larger radial position so that the natural radial flow component in the boundary layer is increased.

Figures

[0050] The figures below show preferred embodiments according to the inventions.

- Fig. 1 lift versus angle of attack;
- Fig. 2 horizontal axis turbine with upwind rotor;
- Fig. 3 airfoil cross section;
- Fig. 4 airfoil cross section;
- Fig. 5 airfoil cross section;
- Fig. 6 airfoil cross section;
- Fig. 7 airfoil cross section;
- Fig. 8 horizontal axis turbine of fig. 3 with blades up side down;
- Fig. 9 wind turbine with a 2-bladed rotor;
- Fig. 10 blade of a wind turbine;
- Fig. 11 blade of a wind turbine.

[0051] Figure 1 shows a plot of the lift L versus the angle of attack α . Curve 3 shows the relation for a classical airfoil without lift enhancing means. To reach a given lift 4 the flow should enter the airfoil under an angle of attack 5. Due to e.g. turbulence in the wind the angle of attack varies in range 6 and therefore the lift will vary in range 7. An airfoil according to the invention with a higher lift coefficient and a shorter chord behaving like curve 8 should reach the same lift 4. This is realised at a larger angle of attack 9. Assuming the same turbulence in the wind, the angle of attack varies in range 10 which is as wide as range 6. Now the surprising element: The lift variation 11 of the airfoil with the higher lift coefficient is less than the lift variation 7 of the classical airfoil.

[0052] Figure 2 shows as example of the invention an upwind turbine 13 with tower 14 and nacelle 15. The turbine rotor of radius R comprises a hub 16 and blades 18 with tip 19 and root 17. On the rear side of the blade VGs are installed which are not visible in the figure. The blades are rotating in the direction of tangential 20 and comprise a leading edge 21 and a trailing edge 22. Figures 3 to 7

show airfoil cross sections I-I indicated in figure 2. The cross sections show the suction sides 34 and the pressure sides 35. Figure 3 shows the angle of attack α 27 the extended chord 25 and the undisturbed flow 26. The line through the centres of the circles 36 is the camber line 37. This line intersects with the chord 38 of length 39. The leading edge of the airfoil is shown by 21 and the trailing edge by 22. On the suction side, front 42, middle 43 and rear 44 VGs are applied and on the pressure side also VGs 41 are applied. Figure 4 shows another realisation of VGs 45 on small chord position and VGs 44 on a larger chord position. The flexible trailing edge 49 shown in two positions in range 50 is not counted as part of the chord 29 if range 50 is more than 2.5% c with respect to the leading edge. The blade comprises first type fibres at the suction side 46 and at the pressure side 47 which extend perpendicular to the cross sections. The shear web 48 is located in between the suction side and pressure side.

[0053] Figure 5 shows two oblique rows of VGs of which the front VG 61 of the upper line in the figure is located upstream relative to the most rear VG 62 of the lower line. Preferably VGs 61 and 62 generate vortices of the same direction of rotation. Figure 6 shows the front base line with VGs 63 and the rear base line with VGs 64. Figure 7 shows VGs 65 which extend over a relatively large part of the chord. Figure 8 shows turbine 15 of figure 2 directly after the blades 18 with VGs 68 were turned around to the up side down position which is illustrated by arrows 68. In this up side down application of the blades the function of the aerodynamic pressure and suction sides are exchanged and the rotor rotates in opposite direction. The actual VGs are smaller and are applied in greater numbers than shown in the figure. Figure 9 shows turbine 15 with a 2-bladed rotor of which the blades 18 split at division 75 in an upper blade 77 and a lower blade 76 which are connected at the extension of the main shaft 78. In both figures 9 and 10 air can flow through the free spaces 79 between the upper blade and the lower blade, which upper blade and lower blade reach a distance 74 at the same radial position. The local chord is the sum of the chord of the upper blade and the chord of the lower blade at equal radial position. Figure 10 shows a blade 18 with tip 19 and root 17. The substantially first type fibres 81 on the structural pressure side run from the blade root via the upper blade 76 and the division 75 towards the tip 19. The first type fibres 80 at the structural tensile side run from the root 17 via the lower blade 77 and the division 75 towards the blade tip 19. Spacer 82 is located between the upper and lower blade. Figure 11 shows a blade 18 of a wind turbine with an inlet 85 at radial position r_1 which sucks in boundary layer air which suction is driven by the centrifugal force on the air in channel 87 which runs to the outlet 86 at radial position r_{11} . Inlet 88 is located relative to inlet 85 at the larger radial position r_2 and preferably has a stronger suction than inlet 85 and therefore this inlet has a separate channel 90 which preferably extends further in radial direction

than channel 87. Channel 90 ducts the suck air to outlet 89 at radial position r_{22} .

[0054] Numerical values are given for parameters like wind speed (variation), drag and lift coefficient, nominal wind speed, angle of attack variation etc. The expert understands that those values are only indicative and actually are dependent on airfoil, design of the rotor and wind turbine and on the operational conditions. The expert will also understand that a turbine in this text refers to both vertical axis and horizontal axis turbines which are only type denotations which do not prescribe the orientation of the axis. He will also immediately understand that the invention is beneficial for all known types of wind turbines which operation is based on lift forces: constant and variable speed turbines, pitch to vane and pitch to stall controlled turbines, and all known types of flying turbines such as auto gyro type turbines and ladder turbines, said ladder turbines being a special kind of vertical axis turbine (US6072245) of which the entire blades should be regarded to operate at radial position R . The above text comprises physical explanations for the flow phenomena. It should be understood that the validity of those explanations is not related to the validity of the enclosed claims. It will be obvious for the expert that advantage is also obtained when the invention is combined with other wind turbine concepts such as e.g. cyclic pitching, controlling wind (US2006131889) and heat and flux (US2006232073).

Claims

1. A pitch controlled wind turbine (13) comprising a rotor of at least 60m diameter, the rotor comprising a blade (18) with an aerodynamic profile **characterised in that** said profile has in the range of $0.5R$ to $0.95R$ a design lift coefficient c_l larger than 1.1, particularly larger than 1.2 and more particularly larger than 1.4 and more particularly preferably about 1.6 and wherein the blade comprises vortex generators (42, 43, 44, 45, 61, 62, 63, 64, 65).
2. A wind turbine according to claim 1 **characterised in that** the blade comprises profiles of at least 25% thickness which are used at radial positions larger than $0.55R$, and particularly larger than $0.65R$ and more particularly larger than $0.75R$, wherein R represents the radius of the rotor of the wind turbine and wherein the thickness is the ratio between the diameter of the largest circle in the airfoil and the chord.
3. The wind turbine according to claim 1 or 2 wherein within the range from $0.4R$ to $0.95R$, and particularly from $0.5R$ to $0.8R$ a lift increasing means is integrated with said blade (18) or is attached to it as a separate element and in particular that said lift increasing means comprises vortex generators (42, 43, 44, 45, 61, 62, 63, 64, 65).
4. The wind turbine according to any of the preceding claims, comprising first type fibres which are located between 5%c and 70%c on both the aerodynamic pressure side and the aerodynamic suction side, wherein the cross section of the first type fibres at the suction side compared to the cross section of the first type fibres at the pressure side in the radial range between $0.3R$ and $0.7R$ is at least 20% larger and particularly at least 30% larger and more particularly at least 40% larger, wherein c represents the local chord of the blade (18).
5. The wind turbine according to any of the preceding claims comprising first type unidirectional fibres which are located between 5%c and 70%c wherein within a cross section in the radial range between $0.3R$ and $0.7R$ said unidirectional fibres at the aerodynamic pressure side consist of at least 25% carbon fibres and particularly that said unidirectional fibres at the aerodynamic suction side comprise for at least 25% glass fibres.
6. Wind turbine according to any of the preceding claims of the horizontal axis type wherein said blade in the direction from the tip (19) towards the root (17) at a radial position between $0.7R$ and $0.2R$ splits at division (75) in an upper blade (76) and a lower blade (77) with in between a free space (79) and that both the upper blade and the lower blade contribute to the aerodynamic lift and in particular that at a certain radial position the distance (74) between the lower and the upper blade is larger than $5\%R$ and more in particular is larger than $10\%R$.
7. Wind turbine according to any of the preceding claims wherein said blade comprises vortex generators (41) located at the pressure side of a profile, wherein said vortex generators are preferably placed at chord positions larger than 30%c, particularly larger than 50%c and more particularly larger than 70%c.
8. Wind turbine according to any of the preceding claims wherein said blade (18) comprises an airfoil with camber of more than 6%c particularly more than 8%c and more particularly more than 10%c.
9. Wind turbine according to any of the preceding claims wherein said blade (18) comprises vortex generators (42, 43, 44, 45, 61, 62, 63, 64, 65) comprising a surface of the plastic PVDF and particularly that said vortex generators entirely consist of said plastic.
10. Wind turbine according to any of the preceding claims, wherein said blade (18) comprises a vortex generator (42, 43, 44, 45, 61, 62, 63, 64, 65) comprising a ground plate which is partly of double sided adhesive tape and partly with fluid adhesive so that

the double sided adhesive provides direct fixation after which the fluid glue has time to harden.

11. Wind turbine according to any of the preceding claims, wherein said blade (18) comprises a vortex generator (42, 43, 44, 45, 61, 62, 63, 64, 65) that is arranged parallel to the tangentials or parallel to the local undisturbed flow at about the 0-lift angle.
12. Wind turbine according to any of the preceding claims, wherein said blade (18) comprises vortex generators (42, 43, 44, 45, 61, 62, 63, 64, 65) that are arranged at an angle of less than 10° , and particularly less than 5° , to the tangentials related to the centre of rotation.
13. Wind turbine according to any of the preceding claims, wherein said blade (18) comprises vortex generators (42, 43, 44, 45, 61, 62, 63, 64, 65) wherein the upstream side of more than 70% of said vortex generators has a shorter distance to the centre of rotation than the downstream side.
14. Wind turbine according to any of the preceding claims, wherein vortex generators (42, 43, 44, 45, 61, 62, 63, 64, 65) are installed in a pattern which increases in chord position at least once, and particularly at least twice, in the longitudinal direction of the blade.
15. Wind turbine according to any of the preceding claims wherein the diameter of the rotor is larger than 80m and particularly larger than 100m.
16. Wind turbine according to any of the preceding claims comprising a blade (18) with a basis line of vortex generators wherein upstream with respect to the basis line additional vortex generators are installed.
17. Wind turbine according to any of the preceding claims, wherein said blade (18) comprises vortex generators (42, 43, 44, 45, 61, 62, 63, 64, 65) wherein the effectiveness of the vortex generators can be regulated by changing the position, or opening them out to a greater or lesser degree, or submerging them partly in the blade surface and in particular by activating the vortex generators by MEM tabs or piezo-electrics.
18. Wind turbine according to any of the preceding claims wherein the turbine is operated at a reduced tip speed ratio to reduce noise or sound emission by the wind turbine and in particular wherein the lift enhancing means are adapted to more optimal operation at higher angles of attack.
19. Wind turbine according to any of the preceding

claims wherein said turbine has variable rotation speed control.

20. Wind turbine according to any of the preceding claims wherein said profile within the range of $0.5R$ to $0.95R$ is operated at a 10 minute averaged angle of attack which differs of the 0-lift angle of said profile by more than 10° , particularly more than 12° and more particularly more than 14° and more particularly preferably by about 16° .
21. Wind turbine according to any of the preceding claims, wherein for tip speed ratios λ pertaining to the undisturbed wind speeds between 8 and 10 m/s, the chord number $D (= Nc_r \lambda^2 / R^2)$ for said blade between $0.5R$ and $0.8R$ and or the chord number D_{avg} averaged over the range between $0.5R$ and $0.8R$ is less than 3.00, and particularly less than 2.75, and more particularly less than 2.50.
22. Method where by a first blade of an existing turbine is removed and is replaced by an other blade wherein said existing turbine with said other blade is according to any of the preceding claims and particularly that said other blade in the range of $0.7R$ to $0.95R$ comprises a local chord c_r which is at least 10% and more particularly at least 20% smaller than the local chord c_r of said first blade.

Patentansprüche

1. Pitchgeregelte Windenergieanlage (13), die einen Rotor mit wenigstens 60m Durchmesser aufweist, wobei der Rotor ein Rotorblatt (18) mit einem aerodynamischen Profil aufweist, **dadurch gekennzeichnet, dass** das Profil in dem Bereich von $0,5R$ bis $0,95R$ einen Designauftriebskoeffizienten c_l größer als 1,1, insbesondere größer als 1,2 und weiter insbesondere größer als 1,4 und weiter insbesondere bevorzugt etwa 1,6 aufweist und wobei das Rotorblatt Vortexgeneratoren (42, 43, 44, 45, 61, 62, 63, 64, 65) aufweist.
2. Windenergieanlage nach Anspruch 1, **dadurch gekennzeichnet, dass** das Rotorblatt Profile von wenigstens 25% Dicke aufweist, die an Radiuspositionen größer als $0,55R$, insbesondere größer als $0,65R$ und weiter insbesondere größer als $0,75R$, verwendet werden, wobei R den Radius des Rotors der Windenergieanlage angibt und wobei die Dicke das Verhältnis zwischen dem Durchmesser des größten Kreises in dem Strömungsprofil und der Profiltiefe ist.
3. Windenergieanlage nach Anspruch 1 oder 2, wobei innerhalb des Bereiches von $0,4R$ bis $0,95R$ und insbesondere von $0,5R$ bis $0,8R$ ein Auftriebserhö-

- hungsmittel in dem Rotorblatt (18) integriert ist oder als separates Element daran befestigt ist und wobei das Auftriebserhöhungsmittel insbesondere Vortexgeneratoren (42, 43, 44, 45, 61, 62, 63, 64, 65) aufweist.
4. Windenergieanlage nach einem der vorstehenden Ansprüche, die eine erste Art Fasern, die zwischen 5%c und 70%c auf beiden der aerodynamischen Druckseite und der aerodynamischen Saugseite angeordnet sind, aufweist, wobei der Querschnitt der ersten Art Fasern auf der Saugseite verglichen mit dem Querschnitt der ersten Art Fasern auf der Druckseite in dem Radiusbereich zwischen $0,3R$ und $0,7R$ wenigstens 20% größer und insbesondere wenigstens 30% größer und weiter insbesondere wenigstens 40% größer ist, wobei c die lokale Profiltiefe des Rotorblattes (18) repräsentiert.
 5. Windenergieanlage nach einem der vorstehenden Ansprüche, die eine erste Art unidirektionaler Fasern aufweist, die zwischen 5%c und 70%c angeordnet sind, wobei die unidirektionalen Fasern innerhalb eines Querschnittes in dem Radiusbereich zwischen $0,3R$ und $0,7R$ der aerodynamischen Druckseite aus wenigstens 25% Kohlenstofffasern bestehen, wobei insbesondere die unidirektionalen Fasern an der aerodynamischen Saugseite wenigstens 25% Glasfasern aufweisen.
 6. Windenergieanlage nach einem der vorstehenden Ansprüche der Horizontalachsenart, wobei das Rotorblatt in der Richtung von der Spitze (19) zu der Wurzel (17) an einer Radiusposition zwischen $0,7R$ und $0,2R$ sich an einer Teilung (75) in ein oberes Blatt (76) und ein unteres Blatt (77) mit einem freien Raum (79) dazwischen aufspaltet, wobei sowohl das obere Blatt und das untere Blatt zu dem aerodynamischen Auftrieb beitragen, wobei insbesondere der Abstand (74) zwischen dem unteren und dem oberen Blatt an einer bestimmten Radiusposition größer als $5\%R$ und weiter insbesondere größer als $10\%R$ ist.
 7. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Rotorblatt Vortexgeneratoren (41) aufweist, die an der Druckseite eines Profils angeordnet sind, wobei die Vortexgeneratoren vorzugsweise an Sehnenpositionen größer als 30%, insbesondere größer als 50%c und weiter insbesondere größer als 70%c angeordnet sind.
 8. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Rotorblatt (18) ein Strömungsprofil mit einer Wölbung von mehr als 6%c insbesondere mehr als 8%c und weiter insbesondere mehr als 10%c aufweist.
 9. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Rotorblatt (18) Vortexgeneratoren (42, 43, 44, 45, 61, 62, 63, 64, 65) aufweist, die eine Oberfläche des Kunststoffes PVDF aufweisen, und wobei die Vortexgeneratoren insbesondere vollständig aus dem Kunststoff bestehen.
 10. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Rotorblatt (18) einen Vortexgenerator (42, 43, 44, 45, 61, 62, 63, 64, 65) aufweist, der eine Grundplatte aufweist, die teilweise aus doppelseitigem Klebeband und teilweise mit Fluidklebstoff ist, so dass das doppelseitige Klebeband eine direkte Fixierung bereitstellt, nach der der Flüssigklebstoff Zeit zum Aushärten hat.
 11. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Rotorblatt (18) einen Vortexgenerator (42, 43, 44, 45, 61, 62, 63, 64, 65) aufweist, der parallel zu den tangentialen oder parallel zu dem lokalen ungestörten Fluss bei etwa dem 0-Auftriebs-Winkel angeordnet ist.
 12. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Rotorblatt (18) Vortexgeneratoren (42, 43, 44, 45, 61, 62, 63, 64, 65) aufweist, die an einem Winkel von weniger als 10° und insbesondere weniger als 5° zu den Tangentialen bezogen auf den Drehmittelpunkt angeordnet sind.
 13. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Rotorblatt (18) Vortexgeneratoren (42, 43, 44, 45, 61, 62, 63, 64, 65) aufweist, wobei die stromaufwärtige Seite von über 70% der Vortexgeneratoren einen kürzeren Abstand zu dem Drehmittelpunkt als die stromabwärtige Seite aufweist.
 14. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei Vortexgeneratoren (42, 43, 44, 45, 61, 62, 63, 64, 65) gemäß einem Muster installiert sind, das sich in der Längsrichtung des Rotorblattes in der Position in Profiltiefenrichtung wenigstens einmal und insbesondere wenigstens zweimal erhöht.
 15. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei der Durchmesser des Rotors größer als 80 m und insbesondere größer als 100 m beträgt.
 16. Windenergieanlage nach einem der vorstehenden Ansprüche, umfassend ein Rotorblatt (18) mit einer Basislinie von Vortexgeneratoren, wobei zusätzliche Vortexgeneratoren stromaufwärts bezogen auf die Basislinie installiert sind.
 17. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Rotorblatt (18) Vortexgene-

ratoren (42, 43, 44, 45, 61, 62, 63, 64, 65) aufweist, wobei die Wirksamkeit der Vortexgeneratoren durch Verändern der Position, durch Öffnen zu einem höheren oder niedrigeren Grad oder durch teilweises Versenken in der Rotorblattoberfläche und insbesondere durch Aktivieren der Vortexgeneratoren durch MEM-Tabs oder Piezoelektrik reguliert werden kann.

18. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei die Anlage mit einer reduzierten Schnelllaufzahl betrieben wird, um Geräusch- oder Schallemissionen durch die Windenergieanlage zu reduzieren, wobei insbesondere die auftriebssteigernden Elemente zum optimierten Betrieb bei höheren Anstellwinkeln angepasst sind.
19. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei die Windenergieanlage eine variabel geregelte Drehgeschwindigkeit aufweist.
20. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei das Profil innerhalb des Bereiches von $0,5R$ bis $0,95R$ bei einem über 10 Minuten gemittelten Anstellwinkel betrieben wird, der sich von dem 0-Auftriebs-Winkel des Profils um mehr als 10° , insbesondere um mehr als 12° , weiter insbesondere um mehr als 14° und weiter insbesondere bevorzugt um etwa 16° unterscheidet.
21. Windenergieanlage nach einem der vorstehenden Ansprüche, wobei für Schnelllaufzahlen λ , die zu ungestörten Windgeschwindigkeiten zwischen 8 und 10 m/s gehören, die Profiltiefenzahl $D (= Nc_r \lambda^2 / R^2)$ für das Rotorblatt zwischen $0,5R$ und $0,8R$ und/oder die Profiltiefenzahl D_{avg} , die über den Bereich zwischen $0,5R$ und $0,8R$ gemittelt ist, niedriger als 3,00 und insbesondere niedriger als 2,75 und weiter insbesondere niedriger als 2,50 ist.
22. Verfahren bei dem ein erstes Rotorblatt einer bestehenden Anlage entfernt und durch ein anderes Rotorblatt ersetzt wird, wobei die bestehende Anlage mit dem anderen Rotorblatt gemäß einem der vorstehenden Ansprüche ist und wobei das andere Rotorblatt insbesondere in dem Bereich von $0,7R$ bis $0,95R$ eine lokale Profiltiefe c_r aufweist, die wenigstens 10% und insbesondere wenigstens 20% kleiner als die lokale Profiltiefe c_r des ersten Rotorblattes ist.

Revendications

1. Eolienne à pas variable (13) comprenant un rotor d'au moins 60 m de diamètre, le rotor comprenant une pale (18) avec un profil aérodynamique **caractérisée en ce que** ledit profil présente dans la plage de $0,5R$ à $0,95R$ un coefficient de portance de con-

ception C_l supérieur à 1,1, en particulier supérieur à 1,2 et plus particulièrement supérieur à 1,4 et plus particulièrement de préférence environ 1,6 et dans laquelle la pale comprend des générateurs de vortex (42, 43, 44, 45, 61, 62 63, 64, 65).

2. Eolienne selon la revendication 1 **caractérisée en ce que** la pale comprend des profils d'au moins 25 % d'épaisseur qui sont utilisés à des positions radiales supérieures à $0,55R$, et en particulier supérieures à $0,65R$ et plus particulièrement supérieures à $0,75R$, dans laquelle R représente le rayon du rotor de l'éolienne et dans laquelle l'épaisseur est le rapport entre le diamètre du plus grand cercle dans le profil d'aile portante et la corde.
3. Eolienne selon la revendication 1 ou 2 dans laquelle dans la plage de $0,4R$ à $0,95R$, et en particulier de $0,5R$ à $0,8R$ un moyen d'augmentation de la portance est intégré à ladite pale (18) ou est attaché à elle en tant qu'élément distinct et en particulier ledit moyen d'augmentation de la portance comprend des générateurs de vortex (42, 43, 44, 45, 61, 62, 63, 64, 65).
4. Eolienne selon l'une quelconque des revendications précédentes, comprenant des fibres d'un premier type qui sont situées entre 5 %c et 70 %c à la fois sur le côté de pression aérodynamique et le côté d'aspiration aérodynamique, dans laquelle la section transversale des fibres d'un premier type du côté aspiration comparée à la section transversale des fibres d'un premier type du côté pression dans la plage radiale entre $0,3R$ et $0,7R$ est au moins 20 % supérieure et en particulier au moins 30 % supérieure et plus particulièrement au moins 40 % supérieure, dans laquelle c représente la corde locale de la pale (18).
5. Eolienne selon l'une quelconque des revendications précédentes comprenant des fibres unidirectionnelles d'un premier type qui sont situées entre 5 %c et 70 %c dans laquelle dans une section transversale dans la plage radiale entre $0,3R$ et $0,7R$ lesdites fibres unidirectionnelles du côté de la pression aérodynamique sont constituées d'au moins 25 % de fibres de carbone et en particulier lesdites fibres unidirectionnelles du côté de l'aspiration aérodynamique comprennent au moins 25 % de fibres de verre.
6. Eolienne selon l'une quelconque des revendications précédentes du type à axe horizontal dans laquelle ladite pale dans la direction depuis la pointe (19) vers le pied (17) à une position radiale entre $0,7R$ et $0,2R$ se divise à la division (75) en une pale supérieure (76) et une pale inférieure (77) avec entre elles un espace libre (79) et à la fois la pale supérieure et la pale inférieure contribuent à la portance aérodyna-

mique et en particulier à une certaine position radiale la distance (74) entre la pale inférieure et la pale supérieure est supérieure à 5 %R et plus particulièrement supérieure à 10 %R.

7. Eolienne selon l'une quelconque des revendications précédentes dans laquelle ladite pale comprend des générateurs de vortex (41) situés du côté pression d'un profil, dans laquelle lesdits générateurs de vortex sont de préférence placés à des positions de corde supérieures à 30 %c, en particulier supérieures à 50 %c et plus particulièrement supérieures à 70 %c.
8. Eolienne selon l'une quelconque des revendications précédentes dans laquelle ladite pale (18) comprend un profil d'aile portante avec une cambrure de plus de 6 %c en particulier plus de 8 %c et plus particulièrement plus de 10 %c.
9. Eolienne selon l'une quelconque des revendications précédentes dans laquelle ladite pale (18) comprend des générateurs de vortex (42, 43, 44, 45, 61, 62, 63, 64, 65) comprenant une surface en plastique PVDF et plus particulièrement lesdits générateurs de vortex sont constitués entièrement dudit plastique.
10. Eolienne selon l'une quelconque des revendications précédentes, dans laquelle ladite pale (18) comprend un générateur de vortex (42, 43, 44, 45, 61, 62, 63, 64, 65) comprenant une plaque de base qui est partiellement en ruban adhésif double face et partiellement avec un adhésif liquide de sorte que l'adhésif double face fournisse une fixation directe après laquelle la colle liquide a le temps de durcir.
11. Eolienne selon l'une quelconque des revendications précédentes, dans laquelle ladite pale (18) comprend un générateur de vortex (42, 43, 44, 45, 61, 62, 63, 64, 65) qui est agencé parallèle aux tangentes ou parallèle à l'écoulement local non perturbé à environ l'angle de portance 0.
12. Eolienne selon l'une quelconque des revendications précédentes, dans laquelle ladite pale (18) comprend des générateurs de vortex (42, 43, 44, 45, 61, 62, 63, 64, 65) qui sont agencés à un angle de moins de 10°, et en particulier moins de 5°, par rapport aux tangentes associées au centre de rotation.
13. Eolienne selon l'une quelconque des revendications précédentes, dans laquelle ladite pale (18) comprend des générateurs de vortex (42, 43, 44, 45, 61, 62, 63, 64, 65) dans laquelle le côté amont de plus de 70 % desdits générateurs de vortex présente une distance plus courte au centre de rotation que le côté aval.

14. Eolienne selon l'une quelconque des revendications précédentes, dans laquelle des générateurs de vortex (42, 43, 44, 45, 61, 62, 63, 64, 65) sont installés dans un schéma qui augmente de position de corde au moins une fois, et particulièrement au moins deux fois, dans la direction longitudinale de la pale.

15. Eolienne selon l'une quelconque des revendications précédentes dans laquelle le diamètre du rotor est supérieur à 80 m et en particulier supérieur à 100 m.

16. Eolienne selon l'une quelconque des revendications précédentes comprenant une pale (18) avec une ligne de base de générateurs de vortex dans laquelle, en amont par rapport à la ligne de base, des générateurs de vortex supplémentaires sont installés.

17. Eolienne selon l'une quelconque des revendications précédentes, dans laquelle ladite pale (18) comprend des générateurs de vortex (42, 43, 44, 45, 61, 62, 63, 64, 65) dans laquelle l'efficacité des générateurs de vortex peut être réglée en changeant la position, ou en les ouvrant dans un plus grand ou dans un moindre degré, ou en les immergeant partiellement dans la surface de la pale et en particulier en activant les générateurs de vortex par des ongles MEM ou des éléments piézoélectriques.

18. Eolienne selon l'une quelconque des revendications précédentes dans laquelle la turbine est utilisée à un rapport de vitesse de pointe réduit pour réduire l'émission de bruit ou de son par l'éolienne et en particulier dans laquelle le moyen d'augmentation de la portance est adapté pour une utilisation plus optimale à des angles d'attaque supérieurs.

19. Eolienne selon l'une quelconque des revendications précédentes dans laquelle ladite turbine présente une commande de vitesse de rotation variable.

20. Eolienne selon l'une quelconque des revendications précédentes dans laquelle ledit profil dans la plage de 0,5 R à 0,95 R est utilisé à un angle d'attaque moyenné de 10 minutes qui diffère de l'angle de portance 0 dudit profil de plus de 10°, en particulier plus de 12° et plus particulièrement plus de 14° et plus particulièrement de préférence d'environ 16°.

21. Eolienne selon l'une quelconque des revendications précédentes, dans laquelle pour les rapports de vitesse de pointe λ relatifs aux vitesses de vent non perturbées entre 8 et 10 m/s, le nombre de cordes $D (= Nc \cdot r \lambda^2 / R^2)$ pour ladite pale entre 0,5 R et 0,8 R et ou le nombre de cordes D_{avg} moyenné sur la plage entre 0,5 R et 0,8 R est inférieur à 3,00, et particulièrement inférieur à 2,75, et plus particulièrement inférieur à 2,50.

22. Procédé selon lequel une première pale d'une turbine existante est retirée et est remplacée par une autre pale dans lequel ladite turbine existante avec ladite autre pale est selon l'une quelconque des revendications précédentes et particulièrement ladite autre pale dans la plage de $0,7 R$ à $0,95 R$ comprend une corde locale c_r qui est au moins 10 % et plus particulièrement au moins 20 % plus petite que la corde locale c_r de ladite première pale.

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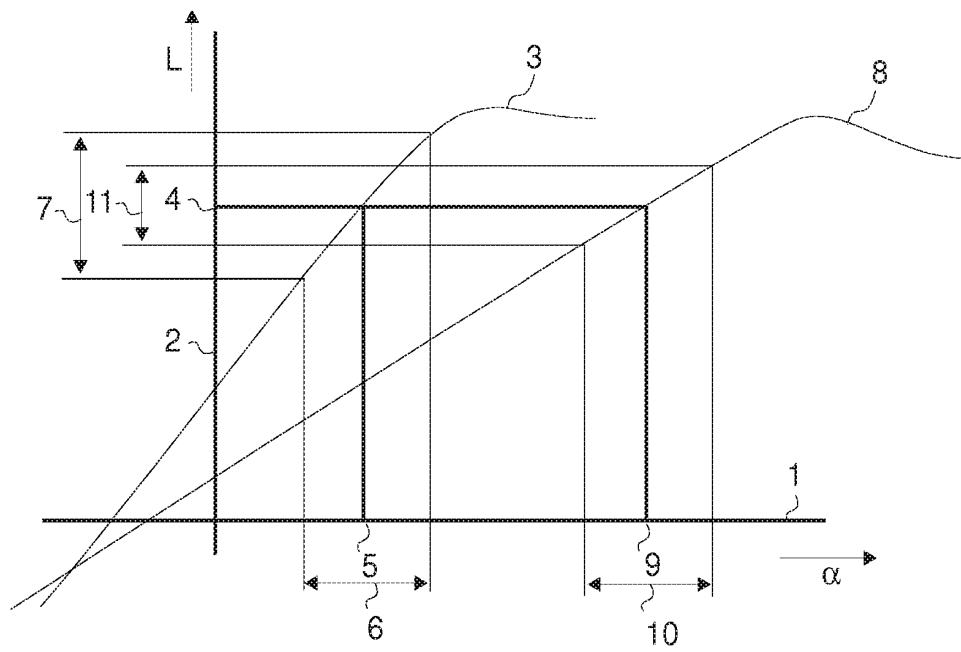
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Fig. 1



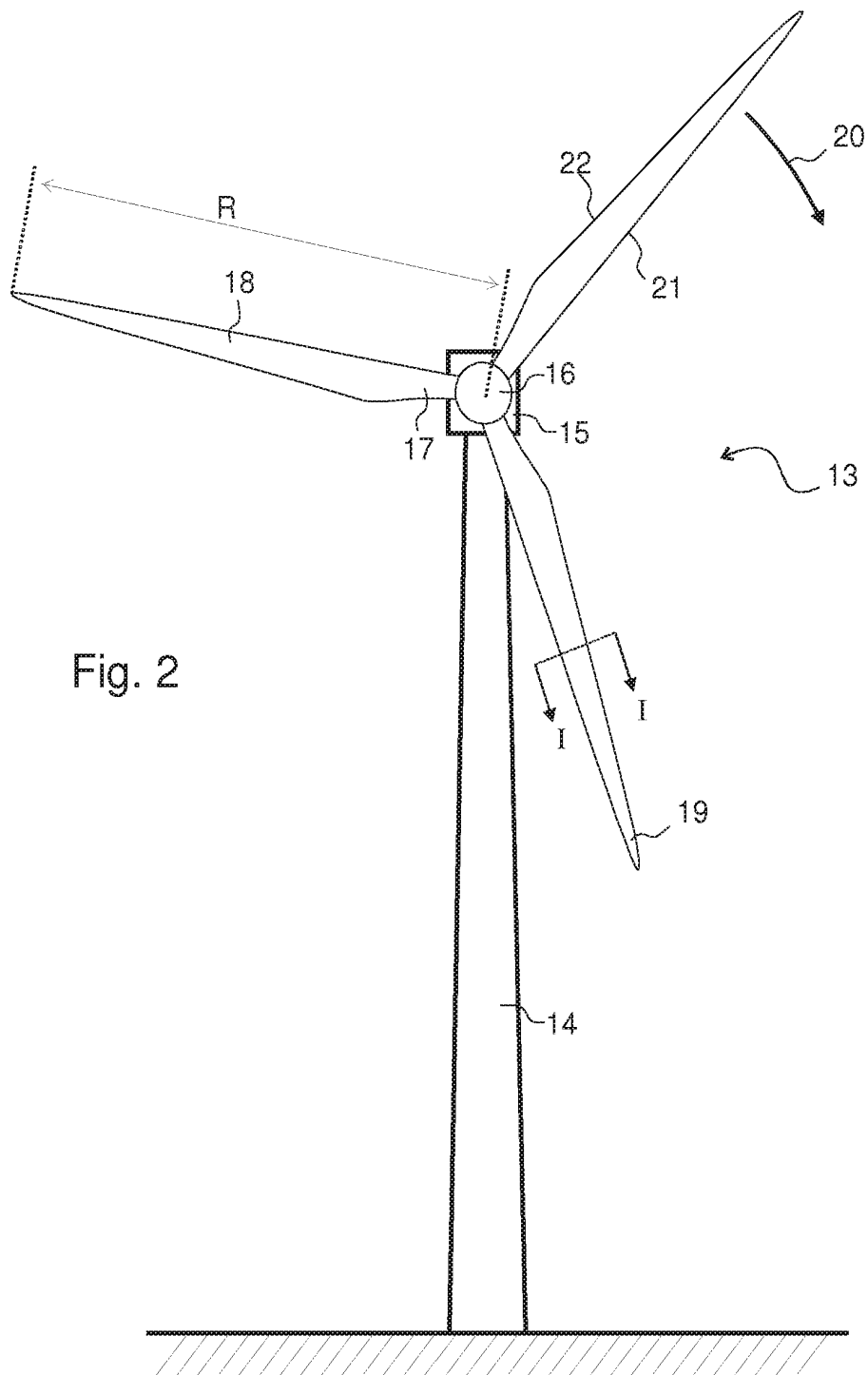


Fig. 3

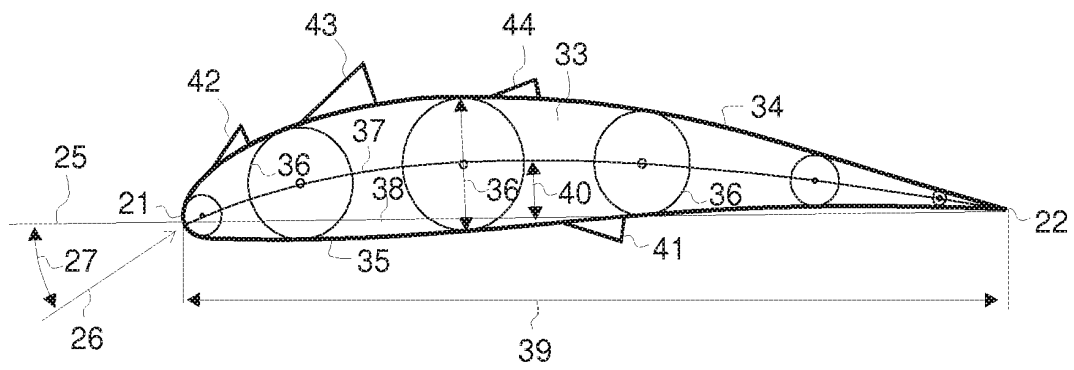
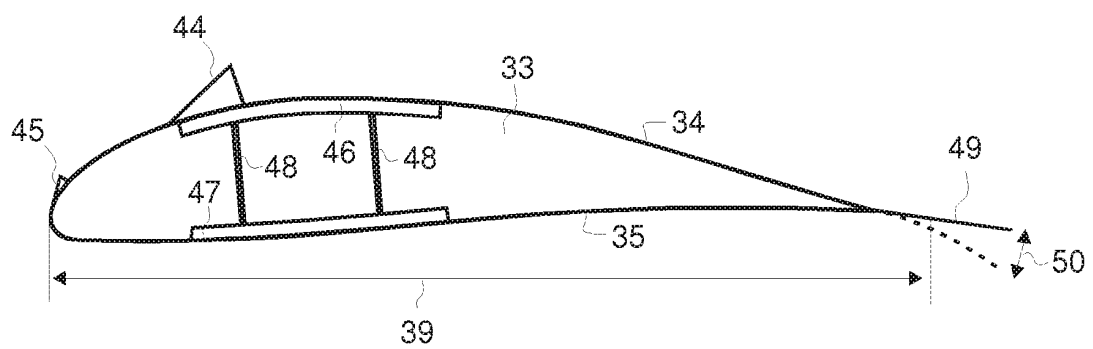
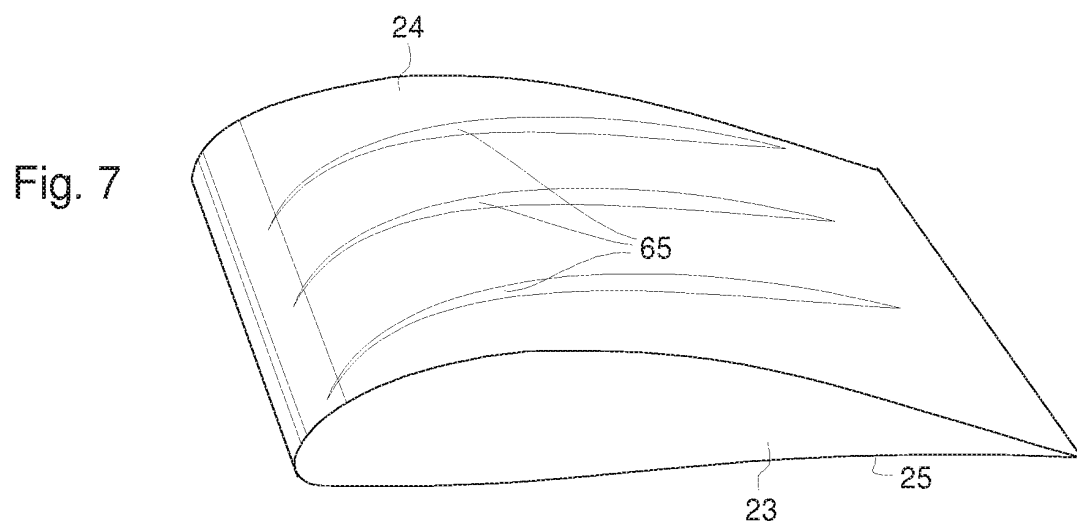
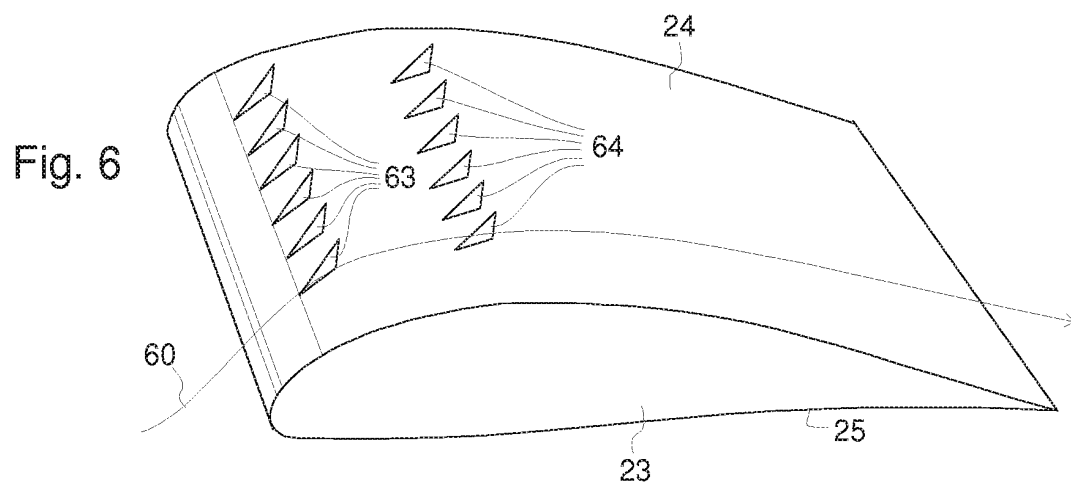
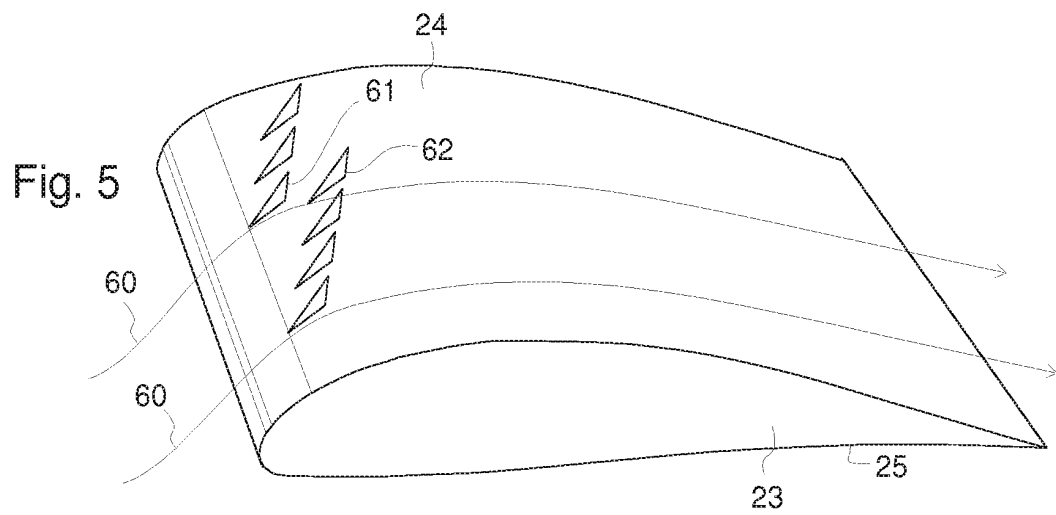


Fig. 4





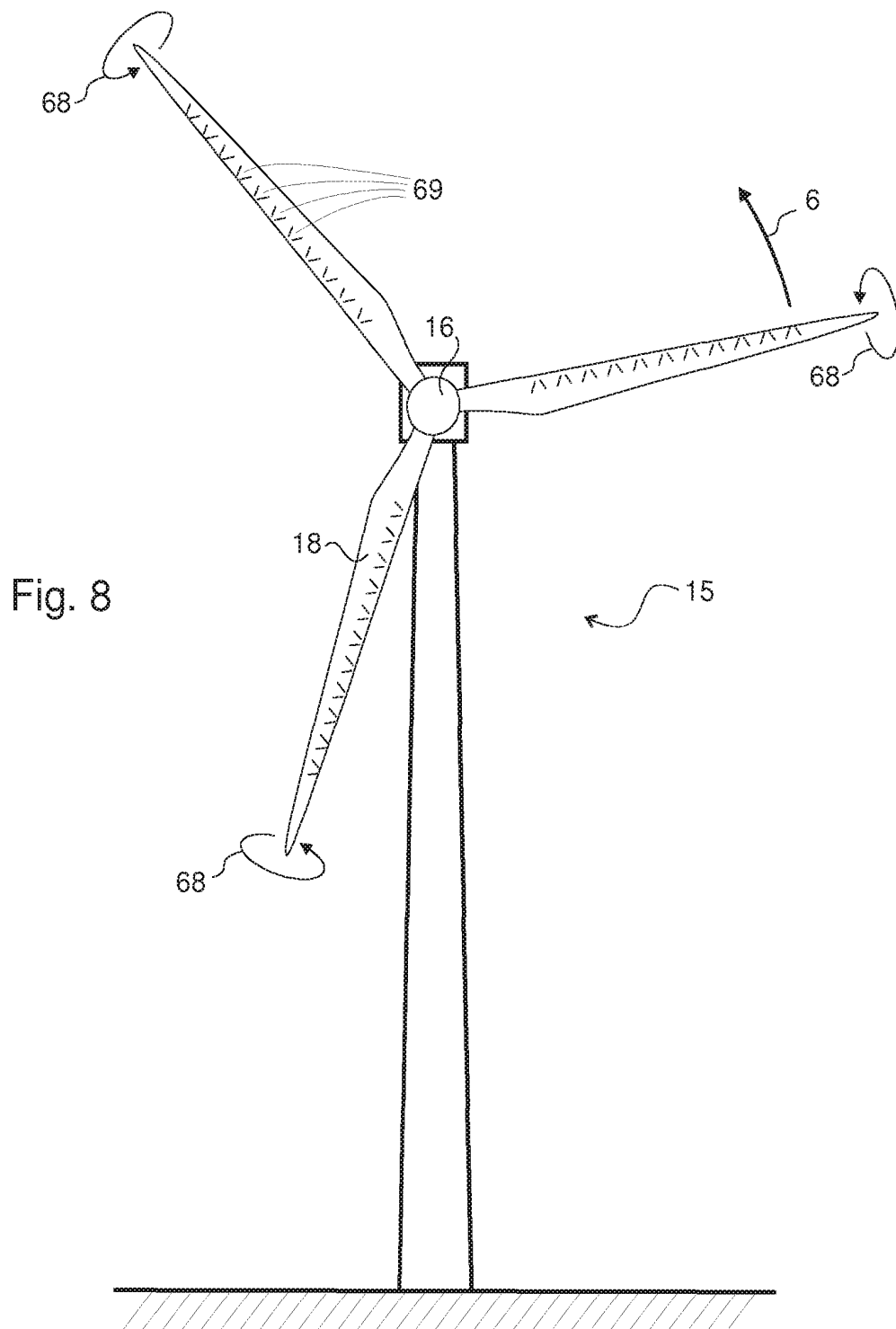


Fig. 9

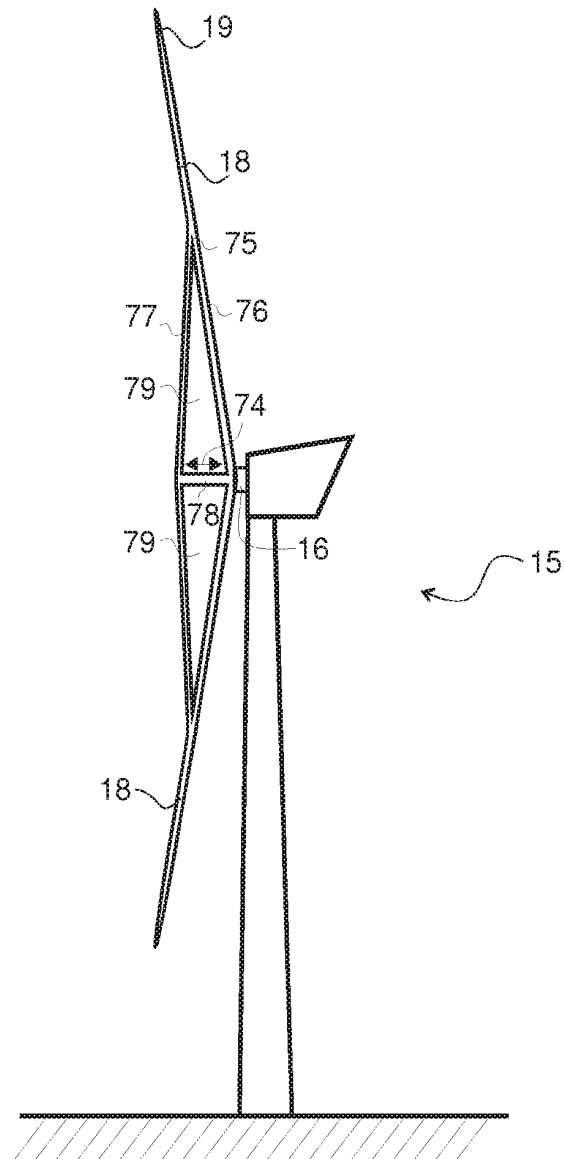


Fig. 10

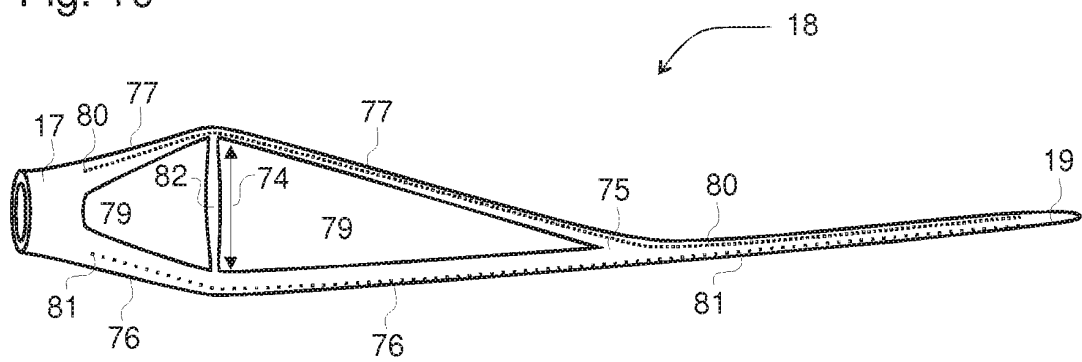
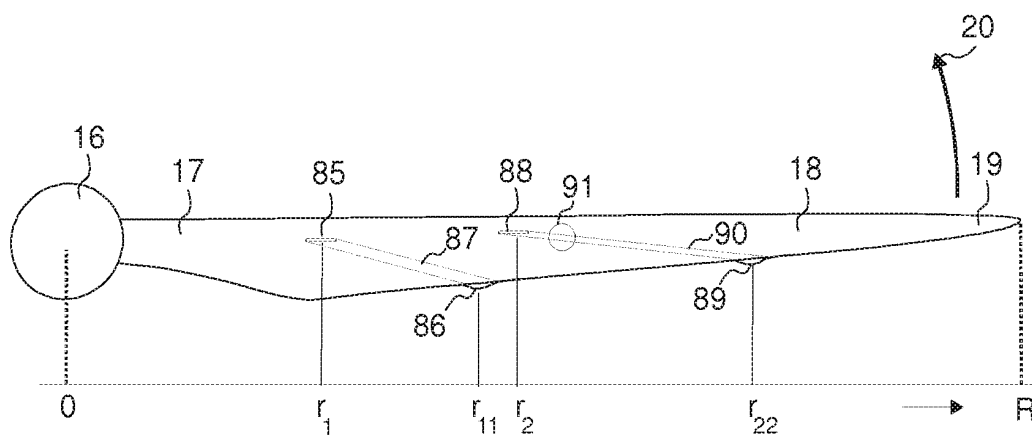


Fig. 11



REFERENCES CITED IN THE DESCRIPTION

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