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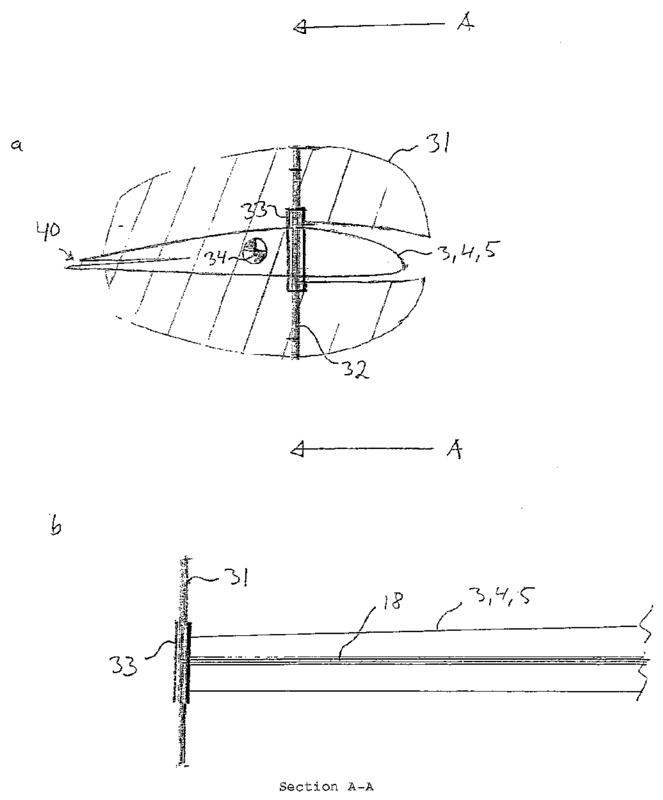
(54) Title: SPEED CONTROL SYSTEM FOR A WIND POWER PLANT'S ROTOR AND AN AERODYNAMIC BRAKE

(57) Abstract: An aerodynamic brake for a wind power plant comprising a wind turbine rotor with at least one blade having a blade tip, wherein the brake comprises a brake unit which is pivotally arranged about an axis B on the blade tip of the at least one blade and wherein the brake comprises regulating means which regulate the pivoting amplitude of the brake unit about the axis A relative to the rotational speed of the blade.



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SPEED CONTROL SYSTEM FOR A WIND POWER PLANT'S ROTOR AND AN AERODYNAMIC BRAKE

The present invention relates to a combined blade pitch and aero- or fluid-dynamic control system that causes a reduction in the variations of the external forces exerted on blades and hub.

The development of windmills or wind turbines for generating power, preferably in the form of electric power, has moved steadily in the direction of larger mills. Windmills with an output of about 5MW and a rotor diameter of more than 115-125m have now been designed and constructed. Windmills as large as 5MW and more have been designed primarily with a view to being installed offshore owing to the difficulties of transporting such large mills on land. The principles of these horizontal-axis windmills are virtually the same as those of their smaller sisters. They are based on a rotor consisting typically of three blades mounted on a central hub with shaft, the shaft being secured by a heavy-duty ball bearing. Blades, tower and hub must be dimensioned to withstand large bending moments due to both the wind forces on each individual blade in the wind direction and the dead weight of each blade in a plane substantially at right angles to the wind and with a constantly varying direction depending on whether the blade is on the way up or down in its rotational path. If each blade has a different load from the wind at a given instant, a moment will be produced which tries to turn the hub about an axis at right angles to the longitudinal axis of the shaft. This moment can in extreme cases be exceptionally large and the shaft must also be dimensioned to withstand such a moment. The central hub and the shaft also transfer the torque of the rotor directly or via a gear to the generator.

In addition, irregular thrusts on the rotor blades will subject both the rotor blades and the tower to large fatigue loads.

Maintenance costs for offshore windmills are initially greater than for land-based windmills. An interruption in energy production as a consequence of a fault in many cases also has greater consequences offshore because the weather conditions often do not permit boarding of the windmills to carry out the necessary repairs. Far out at sea, the wind conditions are also as a rule much stronger than on land. If it is desired to harvest as much of this energy as possible by increasing the nominal wind speed at which the blades are turned out of the wind, the wind power plant will be subjected to increased fatigue loads compared to a location in calmer wind conditions.

Large windmills or wind turbines have the advantage that maintenance and "one-off costs" such as control systems etc. per kWh of produced energy unit can be expected to be reduced. The disadvantage is that weight and material consumption increase per kWh of power produced in the case of such large mills. The optimal economic size of a land-based windmill is with today's technology estimated by many to be about 1-3MW.

The reason that weight and material consumption increase per energy unit produced with the increasing size of the windmill is that the weight increases approximately by the third power of the longitudinal dimension (volumetric increase) whilst the sweep area of the rotor (defined as the area of the circle that encircles the rotor blades as they rotate), and thus the energy production, only increases by the square of the longitudinal dimension. This implies a comparison of a given location where the wind strength is the same in both cases. I.e., if it is desired to increase the size of the windmill whilst using the same technology as before, the weight per energy unit produced, and thus to a great extent the costs, will increase approximately linearly with the size of the windmill.

In addition, the rotational speed (angular velocity) will be reduced with increasing windmill rotor diameter. This is because the optimal blade tip speed is given as a function of the wind speed. The optimal ratio between blade tip speed and wind speed, hereafter called the tip speed ratio, will, for a three-bladed windmill, normally be in the order of 6 depending on the length/breadth ratio of the blades. When the wind speed is the same, the angular velocity of the rotor will therefore decrease for a windmill with a larger rotor diameter. The output produced, if losses are disregarded, is the product of the angular velocity of the rotor and the torque of the rotor; $P=M_T*\omega$, wherein P is output, M_T is torque and ω is angular velocity.

The increase of the torque that must be transferred from the aerodynamic rotor via the drive gear to an electrical generator when the output is increased by increasing the rotor diameter can then be estimated by the following considerations:

$$P=Cp*\rho*v^3*A = Cp*\rho*v^3*D^2*\pi/4,$$

wherein Cp is a constant, ρ is the density of the liquid or the air, v is the wind speed, A is the swept rotor area and D is the rotor diameter and

$\omega=v*6/(D*\pi)*2*\pi = 12*v/D$, wherein 6 is the tip speed ratio.

Inserting for P and ω in the formula $P= M_T*\omega$ gives:

$$M_T = Cp*\rho*v^3*D^2*\pi*D/(4*12*v) = Cp*\rho*v^2*D^3*\pi/48$$

$$\underline{M_T = k* D^3},$$

wherein k is constant for a given wind speed and air density.

Thus, like the weight of the rotor, the torque that is transferred from the rotor via the drive gear to the generator will increase by the third power of the rotor diameter whilst output only increases by the square of the rotor diameter. This means also that the transmission (gearbox) is subjected to disproportionately large loads in the case of large windmills, and it will be an advantage to have a direct-drive solution.

In the case of floating offshore mills or turbines that move back and forth in the wind direction, negative damping will occur because of the connection between output control via the blades' pitch system and the thrust from the wind on the rotor. This problem is described and partly solved in Norwegian Patent Application No. 20041208 (PCT/NO2005/000096). However, there is no prior art solution for keeping the output of the wind power installation completely constant whilst keeping the thrust of the wind on the rotor constant when the wind speed varies above the nominal wind speed.

The conditions described above illustrate the problem of increasing the rotor diameter of a windmill in order to increase output. Weight, and thus to a great extent the costs per kWh produced for a windmill in the megawatt class, increase approximately linearly with the rotor diameter, which speaks against building larger windmills using today's known technology. Fatigue in the blades and tower structure as a result of varying wind speeds are also a problem, especially for floating installations.

In developing the present invention, it has been an object to arrive at an improved control of wind power plants such that both the thrust on the rotor and the generator output can be kept constant when wind velocity varies.

One problem in particular is that if the wind suddenly increases in a situation where there is already a lot of wind (more than nominal wind speed, i.e., the windmill is running at full generator output) and the generator output is then sought to be kept constant by turning the rotor blades then the thrust of wind on the rotor will be reduced at the same time. Similarly, the thrust of the wind on the rotor is increased when the blades are turned back to maintain full output of the generator in the event of a reduction in the wind velocity. This causes large variations in the thrust and thus large fatigue loads on the structure

This problem is solved in this invention.

The conditions mentioned above represent the most significant limitations for constructing windmills offshore that are substantially larger than 3-5MW.

In this invention, the term "rotor" is used as a collective term for the blades that are mounted on the hub. The generator rotor where the magnets are mounted is referred to as the electrical rotor.

In this invention it is also sought to reduce wear on the moving parts and the fatigue loads that are exerted upon the windmill when it is operated in strong winds offshore and with an increased nominal wind speed.

This is achieved by means of the present invention as disclosed in the independent claims. Alternative embodiments of the invention disclosed in independent claim 1 are disclosed in the dependent claims that are linked to this claim.

By means of the present invention, the following advantages are obtained:

1. The wind power on the rotor in the wind direction is kept constant whilst the output of the generator is kept constant and thus there is no negative damping of the oscillations of the tower.

2. Reduction of fatigue loads on blades and tower.

In a first aspect of the invention there is provided an aerodynamic brake for a wind power plant comprising a turbine rotor with at least one blade which has a blade tip, wherein the brake comprises a brake unit that is pivotally arranged about an axis B on the blade tip of the at least one blade, and wherein the brake comprises regulating means which regulate the pivoting amplitude of the brake unit about axis B in relation to the rotational speed of the blade. This brake is used together with a standard blade pitch system according to the prior art. Blade pitch here is defined as the rotation of the rotor blades about their own longitudinal axis.

In one embodiment, the brake unit can be mounted to a rotatable shaft with a centre axis B about which the brake unit can pivot.

In another embodiment, the brake unit can be rotatably mounted to a shaft having a centre axis B, which shaft is fixedly mounted to the blade.

Preferably, the shaft is attached to the brake unit forward of the centre of gravity of the brake unit in relation to the leading edge of the blade in its direction of motion.

In a preferred embodiment, the brake unit is configured having a gap which provides space for the blade as the brake unit pivots out.

In one embodiment, the brake unit is configured as a substantially flat disc. However, it is possible to envisage several designs of the brake unit. It may, for example, be, to varying degrees, concave or convex against the blade tip.

To regulate the degree of the pivoting amplitude of the brake unit, the aerodynamic brake in one embodiment is provided with regulating means that comprise a mechanical device.

In one embodiment, the regulating means can comprise a spring device and in a preferred embodiment the regulating means comprise a torsion spring.

Preferably, the torsion spring is mounted around the shaft.

In another embodiment, the regulating means comprise a steel cable that is fastened to the brake unit and passed through a longitudinal cavity in the blade to a spring-loaded, rotatable hub to which the steel cable is secured, which hub is arranged coaxially with the wind turbine rotor of the wind power plant.

When the wind increases beyond the nominal wind speed, the output of the generator will increase if the deflection of the blades, and thus the thrust on the rotor, is sought to be kept constant by pitching the blades out of the wind. This is prior art described in International Patent Application PCT/NO2005/000096. To avoid the output increasing at increased wind speed according to the prior art when the moment of the blades is sought to be kept constant, there is provided an aerodynamic brake which is operated if the rotational speed of the rotor increases beyond a given speed. By combining a certain pitching (but less than with today's technology) of the whole blade out of the wind when the wind speed increases so that the moments in the blades and thus the thrust on the rotor are kept constant whilst reducing the generator's electrical torque so that the generator output is kept constant and the rotational speed of the rotor increases, it is obtained that both the thrust on the rotor and the generator output can be kept constant when wind speed varies. This combination for obtaining both constant generator output and simultaneous constant thrust on the rotor is not known from the state of the art.

To attenuate the variations in the wind loads against the blades and to render the blades' pitch control system capable of reacting fast enough to the changes in the rotor's thrust (and thus the bending moment in the wind direction in the blades), the outer part of the blades are so designed that the resulting point of attack of the wind in a given cross-section is behind the structural neutral axis of the cross-section for bending about an axis that points approximately in the wind direction looking towards the blade in the wind direction whilst it rotates.

The blade is thus advantageously designed with little torsional rigidity in the outer part. The outer part of the blade will be subjected a torsional rotation and thus be turned partly out of the wind in the event of strong gusts and can thus react faster than the pitch control system which will have a slower reaction time, thereby achieving a gentler motion. This is the same effect that is known from the tip of eagle wings and from modern wind surfer sails which twist out at the top of the sail in gusts of wind

Presented below is a description of a non-limited example of a preferred embodiment of the invention which is illustrated in the attached figures, wherein:

Figure 1 shows a wind power plant with a rotor consisting of rotor blades and a ring-shaped hub;

Figure 2 shows a section of the central part of the turbine rotor with the ring-shaped hub and blades mounted in their respective pitch bearings;

Figures 3a-c show the position of the aerodynamic centrifugally triggered brake outermost on the blade tip;

Figure 4a shows a blade seen looking radially inwards towards the aerodynamic brake;

Figure 4b shows a section taken through the line A-A in figure 4a.

Figure 1 shows a wind power plant 1 with an output of 10-12 MW that is equipped with a large ring-shaped hub 6, where the ring forming the hub has a diameter in the order of 20 metres.

The cross-section of the hub 6 (the ring) has a diameter in the order of 2 metres. The rotor blades 3, 4, 5 have a length of 60m each and are disposed against pitch bearings 8, 9, 10 that are capable of turning the blades about their longitudinal axis on impulse from a pitch control system (not shown).

The pitch bearings are arranged in the ring-shaped hub 6. Fig. 2 shows rotor 2 with blades 3, 4, 5 mounted in pitch bearings 8, 9, 10. The pitch bearings are fixedly mounted in the hub 6 with an angle of 120 degrees between each bearing.

The hub 6 consists of a hollow circular tube, the circle having a diameter of 15% of the diameter of the rotor and the tube having a cross-section of 70% of the cross-section of the blades 3, 4, 5 at their attachment against the pitch bearing. On the inside of the hub there is arranged an electrical rotor 11 which is supported against a stator part 12. The stator 12 is supported by bending-stiff beams 13 which conduct the forces into the rest of the supporting structure via a cylindrical tube 14.

Each pitch bearing is connected to the opposite side of the hub via tension rods 15, all of which are connected to one another in a central anchor ring or anchor plate. The rotor and stator are equipped with naturally ventilated cooling ribs 16. The load-bearing cross-section of the hub 6 (the ring) consists of a closed circular hollow profile of about 2 metres in diameter which is capable of taking up large torsional moments and bending moments simultaneously.

Stator 12 is supported by bending-stiff beams 13 which conduct the forces into the rest of the supporting structure via a cylindrical tube 14.

Each pitch bearing is connected to the opposite side of the hub via tension rods 15, all of which are connected to one another in a central anchor ring or anchor plate. The torque M_T of the rotor 6 which causes energy production is taken up directly in the stator 12 without passing via a central shaft.

The fixed shaft 12 is, in the present application, therefore identical with the generator stator and consists of a short annular ring with a large peripheral diameter, adapted to the peripheral diameter of the hub 6, arranged directly against the motor housing 14 or supporting structure 7 of the wind power plant.

The torsion damping of the rotor 2 and the hub 6 in the rotor plane (defined here as a plane that intersects the outer tip of the three blades) is carried out by active modulation of the generator power output by means of the control system of a power transformer (rectifier/inverter, not shown), together with an aerodynamic brake 31 which provides aerodynamic damping in the rotor plane. Elements from known generator technology with which a person of skill in the art will be familiar, can be used together with this invention without this being described in more detail here. These elements may, e.g., be inclined stator windings or magnets, or an irregular distance between the magnets or the stator windings to avoid cogging etc., but are not limited thereto.

Coaxial with the centre of the circular hub 6, there is provided (not shown) a slip ring bearing which transfers necessary electric power to the rotor 2 for pitch control motors, laser distance metres, lights etc. In addition, electrical contact is provided between the rotor and nacelle/tower for discharge current in connection with strokes of lightening (not shown).

The blades 3, 4 and 5 are equipped with an aerodynamic centrifugally triggered brake 31 at their outermost end. The aerodynamic brake 31 consists of a disc mounted on a rotatable shaft 32 secured in bearing 33 forward of the centre of gravity of the disc seen in its direction of motion in its rotational path.

A steel cable 18 which restrains the disc from rotating about bearing 33 owing to the centripetal forces on the disc, is passed in a sleeve (not shown) through the respective blades 3, 4, 5 to the small spring-loaded rotatable hub 19. When the centripetal forces for the blades 3, 4, 5 exceed the total spring load of the springs, the brakes 31 are turned out as shown in Figure 10 and cause a braking of the blades due to drag.

In that shaft 32 is placed in proximity to and immediately forward of the area centre of the disc 31, the wind moment that arises when the disc turns out and tries to press the disc back will be small. Thus, a disc with a relatively small weight and a relatively small spring load can be used to obtain a substantial aerodynamic braking effect.

The outer part of the blades 3, 4, 5 is such that the structural neutral axis for bending about the strong axis of the blade lies forward of the resultant force for the wind pressure around the blade in a given cross-section of the blade. At the same time, the blade is made extra torsion-flexible by opening the profile by inserting a split 40 in the rear edge of the blade.

The aerodynamic effect of the rotor and the thrust on the rotor 2 are both kept constant simultaneously for a given average wind strength by combining both regulation of the pitch angle of the blade (turning of the whole blade together about its longitudinal axis) and use of a separate aerodynamic brake and regulation of the electrical torque of the generator at the same time.

Figures 3b-c show blades where the relative resultant force of the wind in a section on the innermost part of the blade is coincident with the structural neutral axis of the cross-section and a section on the outermost part of the blade where the relative resultant force of the wind is behind the neutral axis.

Figures 4a and 4b show an aerodynamic centrifugally triggered brake 31 having a centre of gravity 34 and with shaft 32 secured in bearing 33. Steel cable 18 passed through blades 3, 4, 5 is also shown.

In a second aspect of the invention for which patent is sought, a method is provided for reducing the effect of the variation in wind load on a wind power plant , wherein the wind power plant comprises at least one blade with an adjustable blade angle, at least one generator and at least one control unit which controls the angle of the blade and the generator's electrical moment of resistance, wherein the produced output of the at least one generator is sought to be held constant in that the blade angle of the blades and the electrical moment of resistance of the at least one generator are regulated in a per se known manner. In addition, an aerodynamic brake is arranged on the tip of the blades to further reduce the effect of rapidly increasing wind loads on the wind power plant. This is done in the following way in wind conditions above nominal wind speed, i.e., when the generator produces full output:

In the event of a short-term increase in the wind speed in relation to the then average wind speed, the bending moment of each blade in the wind direction (flap moment) is kept constant by turning the blade as required. The rotor's thrust will then be kept almost constant. How much each blade is to be turned (pitched) is computed by a control system which has sensors in the blade that measure the moment. If the bending moment is kept constant when the wind increases, the rotational speed of the rotor will increase. The generator's electrical torque can then be reduced, thereby ensuring that that the generator output is nevertheless kept constant. If no further regulation takes place in such a situation where control is effected according to constant thrust on the rotor, the rotor will continue to increase its speed to an unacceptable level. To prevent this from happening, an aerodynamic brake is used that can be activated, e.g., by centrifugal forces. By setting the centrifugal brake to be activated just above one desired rotational speed of the rotor, the system can be controlled. Thus, both constant output of the generator and constant thrust on the rotor have been obtained simultaneously. This is not known to have been be solved by other types of control systems which can only control either the thrust or the output to a constant level, not both at the same time to a completely constant level.

PATENT CLAIMS

1. A speed control system for a wind power plant's turbine rotor having at least one blade wherein both the generator output and the rotor thrust in the wind direction are simultaneously kept constant when wind strength varies, characterised in that the turbine rotor is equipped both with turnable blades (pitch regulated) and with independent aerodynamic brake(s) (31).

2. A speed control system according to claim 1, characterised in that the aerodynamic brake is centrifugally regulated.

3. An aerodynamic brake according to claim 1, characterised in that the brake comprises a brake unit which is pivotally arranged about an axis B on the blade tip of the at least one blade and that the brake comprises regulating means that regulate the pivoting amplitude of the brake unit about the axis B relative to the rotational speed of the blade.

4. An aerodynamic brake for a wind power plant comprising a turbine rotor with at least one blade having a blade tip, characterised in that the brake comprises a brake unit that is pivotally arranged about an axis B on the blade tip of the at least one blade and that the brake comprises regulating means that regulate the pivoting amplitude about the axis B relative to the rotational speed of the blade.

5. An aerodynamic brake according to claim 1, characterised in that the brake unit is mounted to a rotatable shaft with an axis B about which the brake unit can pivot.

6. An aerodynamic brake according to claim 1, characterised in that the brake unit is rotatably mounted to a shaft with an axis B, which shaft is fixedly mounted to the blade.

7. An aerodynamic brake according to claim 1, characterised in that the shaft is attached to the brake unit forward of the centre of gravity of the brake unit relative to the leading edge of the blade in its direction of motion.

8. An aerodynamic brake according to claim 1, characterised in that the brake unit is configured with a gap that provides space for the blade as the brake unit pivots out.

9. An aerodynamic brake according to claim 1, characterised in that the brake unit is configured as a substantially flat disc.

10. An aerodynamic brake according to claim 1, characterised in that the regulating means comprises a mechanical device.

11. An aerodynamic brake according to claim 1, characterised in that the regulating means comprise a spring device.

12. An aerodynamic brake according to claim 1, characterised in that the regulating means comprise a torsion spring.

13. An aerodynamic brake according to claim 1, characterised in that the torsion spring is mounted about the shaft.

14. An aerodynamic brake according to claim 1, characterised in that the regulating means comprise a steel cable which is fastened to the brake unit and passed through an elongate cavity in the blade to a spring-loaded, rotatable hub to which the steel cable is fastened, which hub is arranged coaxially with the wind turbine rotor of the wind power plant.

15. A method for reducing the effect of a variation in wind load on a wind power plant, wherein the wind power plant comprises at least one blade having an adjustable blade angle, at least one generator and at least one control unit which controls the blade angle of the blade(s) and the electrical moment of resistance of the generator, wherein the produced output of the at least one generator is sought to be kept constant in that the blade angle of the blades and the electrical moment of resistance of the at least one generator are regulated in a per se known way, characterised in that on sudden increases in wind the thrust on the rotor is kept constant by turning the blades and that the increase in speed of the rotor which then occurs is reduced and controlled in that an aerodynamic brake is in addition activated.

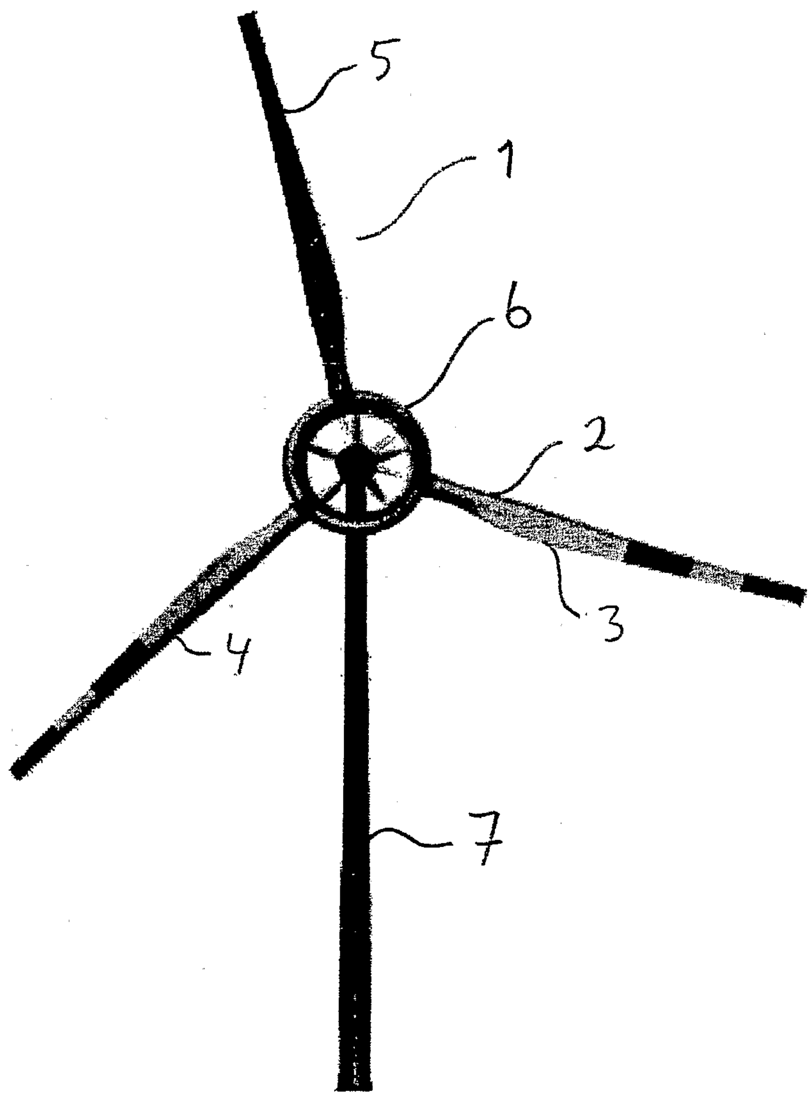


Fig 1

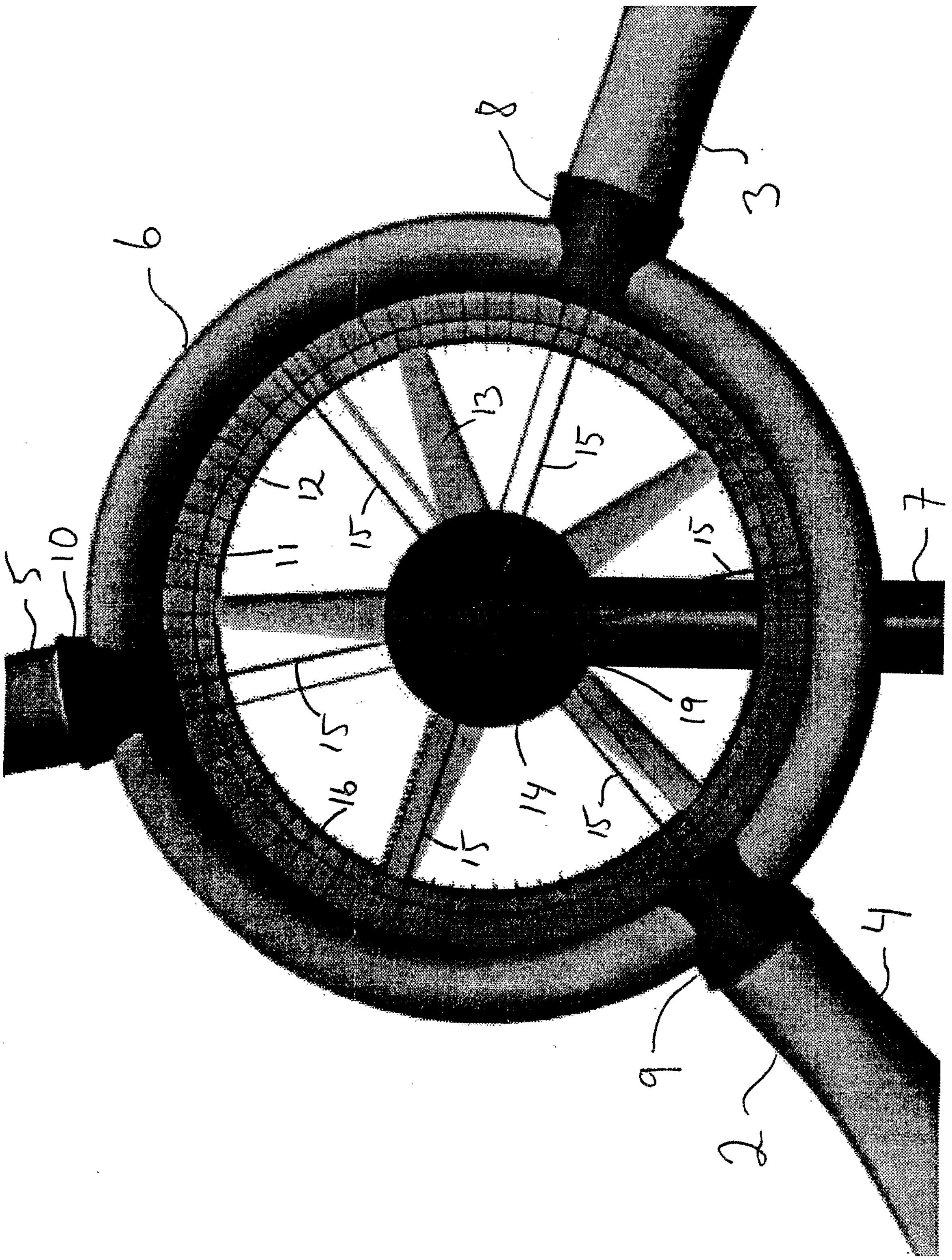


Fig 2

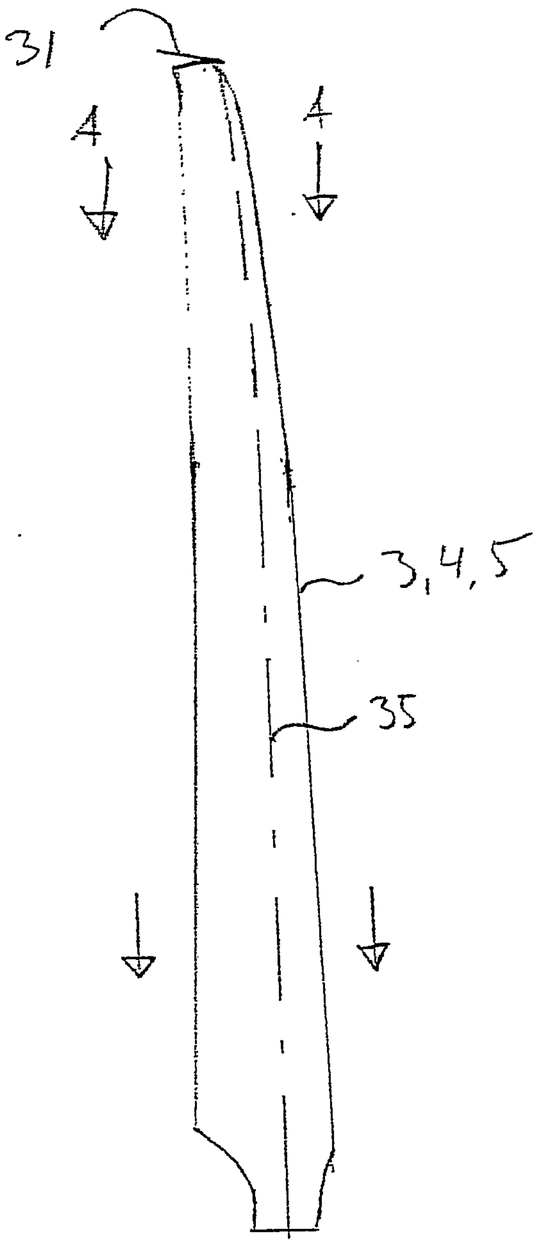


Fig 3a

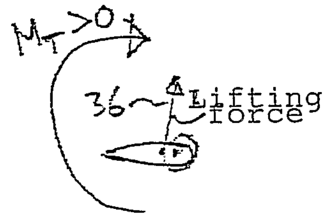


Fig 3b

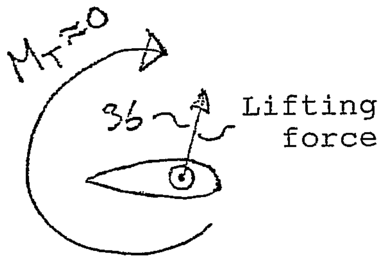


Fig 3c

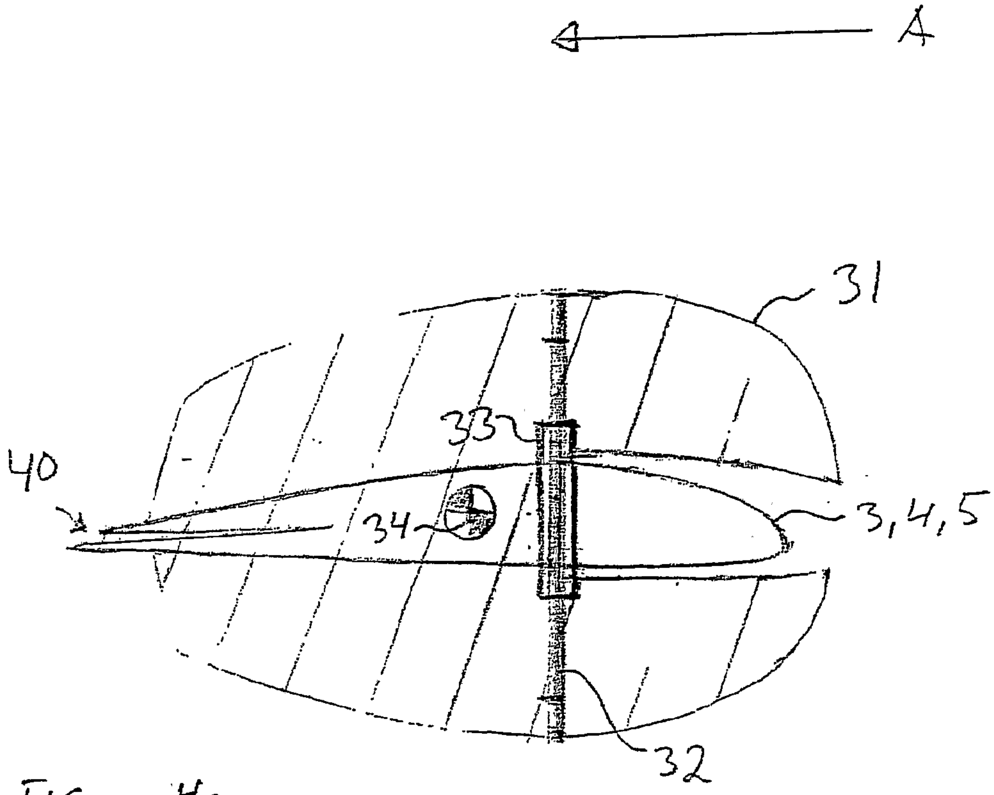
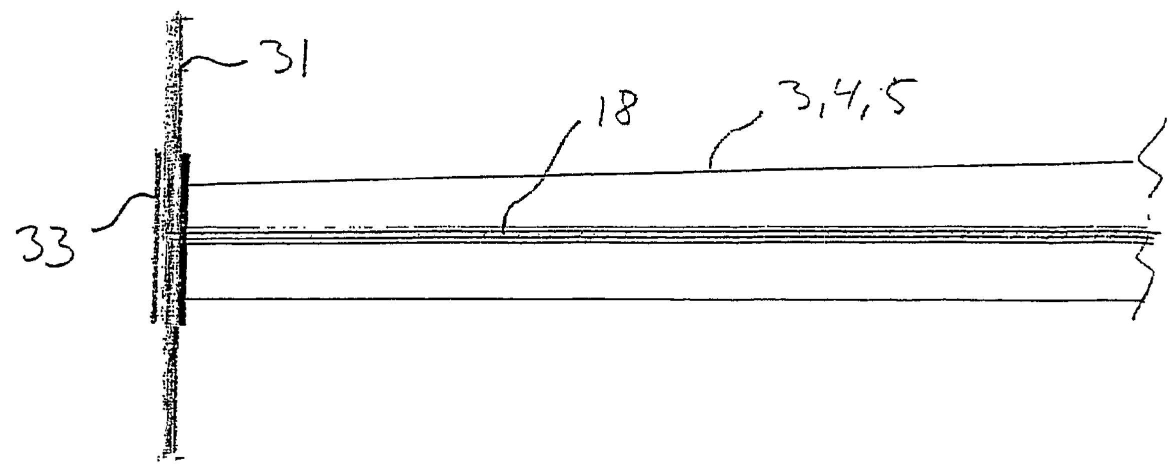


FIG 4a



Section A-A

FIG 4b

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO2006/000358

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: F03D

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2005090781 A1 (SWAY AS), 29 Sept 2005 (29.09.2005), page 5; page 7, line 8 - line 13; page 7, line 34 - line 38, claims 1,5	1-3,15
Y		4-14
	--	
X	WO 2004099608 A1 (LM GLASFIBER A/S), 18 November 2004 (18.11.2004), page 1, claim 14	1
Y		2-15
	--	

[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

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

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Date of the actual completion of the international search
19 January 2007

Date of mailing of the international search report
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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4180372 A (LIPPERT, JR), 25 December 1979 (25.12.1979), column 1, line 54 - line 64; column 3, line 39 - line 42	4
Y		1-3,5-15
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X	US 5570859 A (QUANDT), 5 November 1996 (05.11.1996), column 4, line 64 - line 68; column 5, line 1 - line 11, abstract	4
Y		1-3,5-15
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