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(54) Benævnelse: **Vindturbine med buede rotorblade**

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DESCRIPTION

The present invention relates to a wind turbine with a tower with a nacelle arranged on the upper end of the tower. A rotor is mounted on the outside of the nacelle and is rotatable about a rotor axis of rotation. The rotor has a rotor hub and at least one rotor blade extending from the rotor hub.

In order for as much energy as possible to be absorbed from the wind by means of a wind turbine wind turbines have been developed so that the diameters of the rotors have become larger and larger. Known wind turbines already have a diameter of 90 m. This has the result that the mass of the rotor which as a rule comprises three rotor blades has likewise increased correspondingly. Inter alia for this reason rotor blades have been developed which are relatively light but which also have a corresponding rigidity to provide the necessary resistance against the wind.

As a rule the rotor blades used nowadays comprise a closed shell structure. The use of shell structures has the advantage that rotor blades can be manufactured with a relatively light mass and increased rigidity. Known rotor blades nevertheless still have a certain elastic pliability which naturally increases with the length of the rotor blades.

The elastic pliability of a rotor blade must be taken into account particularly when configuring a wind turbine of the front rotor type (i.e. the turbine is configured so that the wind always strikes the rotor first and then the tower), since the tips of the rotor blades are bent by the wind pressure in the direction of the tower. The stronger the wind so the more severely the rotor blade tips are bent in the direction of the tower. This bending of the rotor blade directed towards the tower can in the worst case be so great that it results in the rotor blade or rotor blades colliding with the tower.

In order to prevent such a collision, known wind turbines are configured so that the rotor is arranged on the nacelle at the greatest possible distance away from the tower. As a result of the large mass already mentioned of the rotor this arrangement has however the disadvantage that as the distance increases between the rotor and tower so the bending moment correspondingly increases and therefore the nacelle and tower have to be dimensioned so that they can absorb the bending moment, wherein this dimensioning incurs increased costs.

The present invention is concerned with the problem of providing a wind turbine with an optimized rotor which is configured so that it has the lowest possible mass and its rotor blades are designed so that a collision between the rotor blades and the tower can be reliably avoided.

This problem is solved by a wind turbine having the features of claim 1.

According to the invention the rotor blade is arranged on the rotor hub so as to be oriented with an inclination away from the tower at an obtuse angle to the rotor axis of rotation and is designed to be curved with respect to the longitudinal axis in at least one length section.

From DE 296 12 270 U1 it is known in order to prevent the rotor blades from colliding with the tower to arrange the rotor blades in a so-called cone angle. The cone angle is formed by the longitudinal axis of the rotor blade and a normal plane, wherein the normal plane extends from the intersection of the longitudinal axis and the rotor axis of rotation perpendicular to the rotor axis of rotation. This rotor configuration has however the drawback that to safely avoid a collision the cone angle has to be formed comparatively large (about 3 - 7°). However starting from a cone angle of 2° the bending moment is noticeably increased in the blade root (connection area of the rotor blade/rotor hub) by the centrifugal force. This is particularly disadvantageous because with wind turbines of the front rotor type this centrifugal force bending moment appears in addition to the bending moment arising through the wind pressure and thus intensifies detrimentally. For this reason the cone angle should amount as far as possible to less than 4°.

Furthermore the arrangement of the rotor blades with an increasing cone angle reduces the wind-exposed area of the rotor blades, which can lead to energy losses when generating power.

From WO 03/060319 A1 in order to prevent a collision of the rotor blades with the tower it is likewise known to arrange the rotor blades in a so-called cone angle. For this a suitable intermediate member is arranged between the rotor hub and the rotor blade.

With the present invention the rotor blades have a blade curvature in addition to a cone. Through this combination the largest possible distance from the tip of the rotor blade to the tower wall is achieved without the rotor configuration according to the invention having the aforementioned disadvantages of the known rotor configuration. By providing a blade curvature the cone angle can be selected considerably smaller than is known from the prior art whereby it becomes possible that the centrifugal forces are kept within the acceptable range and the wind-exposed area of the rotor blades is arranged practically perpendicular to the wind direction and thus the power output is improved.

According to an advantageous configuration of the invention the rotor blade is designed so that it is formed rectilinear in a first length section starting at the rotor hub up to a defined distance from the rotor hub, and is formed with a forwardly directed curvature in certain regions in a second length section adjoining the first length section and extending up to the tip of the rotor blade.

From DE 298 80 145 U1 it is known to design a rotor blade so that it initially extends outwards at right angles to the rotor axis of rotation and is then further extended at a distance from the hub in an outwardly and forwardly directed curved manner. So that a sufficient spacing is achieved between the rotor blades and the tower, the known rotor blades have to have a corresponding sharp curvature. The sharp blade curvature required already leads however to great problems during production of the rotor blade negative form as well as during the subsequent production of the rotor blade itself. Serious difficulties occur even during the transport of the rotor blade as a result of the large dimensions of the rotor blades. Known rotor blades are as a rule on average at least 35 m long. When such rotor blades additionally have a sharp curvature, transport of the blades can still only be achieved with specially constructed transport means for this purpose whereby additional costs are incurred.

Rotor blades with too much blade curvature however have a further decisive disadvantage. Owing to the curvature of the blades high torsion loads arise in the blade which lead to an aerodynamically detrimental distortion of the rotor blade. Often known wind turbines are designed so that the rotor blades are mounted on the rotor hub for rotation about their longitudinal axis. The reason for this is that there is then the possibility of regulating the energy absorption from the wind through adjusting the orientation of the rotor blades wherein adjusting the rotor blades is carried out by blade adjustment systems. The adjusting moments required are then the lowest when the rotor blade is as straight as possible in the highest loaded state. On the other hand it is desired for safety reasons if the torsion moment of the blade acts so that the blade is turned in the load-reducing direction, the so-called feathering position.

With the present-day large installations which are designed only with a forward curvature the required forward curvature is already too much to be able to achieve a quiet operation and safety aspects. Both aspects are considerably improved by the combination according to the invention of the cone angle and the forward curvature.

The DE 298 80 145 U1 explicitly refers to the fact that the obtuse angled arrangement of the rotor blades relative to the rotor axis of rotation is disadvantageous. In addition to the disadvantages described above the conical arrangement of the rotor blades furthermore has the drawback of being very expensive to manufacture. On the other hand the "cone rotor" causes criticism from the aesthetics points of view.

Compared to this, with the present invention it has been recognised that an optimum rotor configuration can be achieved by combining these two rotor configurations which by themselves each have disadvantages.

The present invention offers the advantage that a collision can be avoided easily without significant losses in the power production or increased loads through the appearance of centrifugal forces or torsion.

Through the rotor structure according to the invention the rotor blade can be constructed so that a clear deformation of the blade structure can be permitted in the impact direction without impairing safety requirements. Furthermore the construction of the blade is effected with a clearly lower mass in the supporting blade structure. Particularly in the case of blades made from fibre compound materials with an epoxy resin matrix this advantage can be fully utilized since the durability of this matrix is particularly good and the structural safety when loaded from extreme loads and the operating stability lie very close together, and the material is thus utilized with optimum effect in each respect.

The rotor configuration according to the invention furthermore has the advantage that by combining the cone and slight blade curvature the advantages of a severe blade curvature are substantially achieved, but with the decisive difference that through the straight internal region and the inclined (about the cone angle) rotor blade the torsional loads in the blade and in the blade adjustment system are clearly reduced, thus the drawbacks of a sharp blade curvature are avoided.

The blade curvature according to the invention can have different forms. Thus the blade curvature can by way of example start already in the region of the rotor hub. The most advantageous design is achieved when the rotor blade in normal operation, thus with wind speeds somewhat below the nominal wind speed, is forced into a rectilinear form. For this it is easiest for the design to generate the forward curvature by overlapping the first two modes of vibration. In theory this leads to curvature profiles which start directly at the blade root with very small forward curvatures. Since the rotor blade root is configured comparatively very rigid, calculations conducted by the applicant have shown that in practice a forward curvature starting at about 40% of the rotor radius is sufficient, i.e. that the first length section makes up about 40% of the blade length.

The curvature in the second length section need not be made continuously. One advantageous design also proposes making the region of the blade tip straight again after a curved region. This can be particularly advantageous from the manufacturing and transport points of view.

As already mentioned above, through too sharp a rotor blade curvature, however, problems arise as regards the transportation of the rotor blades. According to a further advantageous configuration of the applicant the second length section can therefore also be configured so that it takes up less than a third of the rotor blade.

The rotor blade is coupled for rotation with the rotor hub via a blade bearing. The blade bearing has an outer ring and an inner ring wherein according to an advantageous configuration of the invention the inner ring is fixedly connected to the rotor hub and the outer ring is fixedly connected to the rotor blade.

Through the advantageous configuration of mounting the rotor blade on the outer ring the possibility arises of reducing the mass of the rotor even further. With known wind turbines the rotor blade is fixed as a rule on the inner ring of the blade bearing. In order to be able to save further mass the diameter of the rotor blade would have to be larger in its root region (the region where the rotor blade is connected to the hub).

The larger diameter is advantageously achieved by mounting the blade on the bearing outer ring in accordance with the invention without having to correspondingly increase the diameter of the connection region in the rotor hub. Through this geometrical form when using the same amount of material as was used previously the resistance moment can be maximised.

The loads which arise are practically not changed by the change in the geometry in the blade root region since the bending moments remain practically constant compared with the known configuration, and through the preferred mounting of the rotor blade on the outer ring in accordance with the invention the possibility has been provided of saving material and keeping the resistance moment constant so that a further reduction in the rotor mass is achieved through the advantageous configuration.

By mounting the inner ring of the blade bearing on the rotor hub the essential advantage arises that the dimensions of the hub body can be kept smaller than with the known rotor configuration.

According to a further advantageous configuration of the invention the rotor axis of rotation is formed inclined upwards relative to the horizontal.

This configuration is likewise known from the DE 296 12 720 U1 and the DE 298 870 145. It does have however the great disadvantage that in order to be able to reliably prevent a collision the exposed surface area of the rotor blade is also here arranged unfavourably to the wind direction and therefore this configuration may lead to severe losses of power.

Through the combination with the cone and the blade curvature the incline can however appear correspondingly slight so that the losses of power can be suitably minimized.

The blade adjustment frequently takes place so that the ring of the blade bearing on which the rotor blade is mounted has a gearing. A pinion which is set in rotational movement by an adjusting drive engages with the gearing whereby an adjustment of the angular position of the rotor blade becomes possible. As already mentioned above, with the known wind turbines the rotor blade is mounted on the inner ring of the blade bearing. The inner ring has internal gearing for the purpose of adjustment and the pinion and the adjustment drive are also arranged on the inside correspondingly. With advantageous designs of the rotor configuration according to the invention the blade is mounted on the outer ring of the blade bearing. The outer ring has correspondingly external gearing and the adjustment drive is mounted on the outside.

Through the external arrangement of the adjustment drive the blade attachment on the hub side can be made clearly more rigid than before since the flange interior can be used for a circumferential uninterrupted reinforcement rib. The compact method of construction enables a clearly more rigid design of the hub, an important criterion when constructing the blade bearing. On the other hand this leads with the same rigidity to clear advantages for the operating strength of the rotor hub, the screw fitting of the blade bearing and hub, and the blade bearing. Furthermore the external arrangement of the adjustment drives through the enlarged lever arm to the centre point of the blade bearing causes higher adjustment moments with the same drive power. Furthermore through the external arrangement the driving power units are subjected to practically no restriction in size, as was the case with the internal arrangement.

The rotor configuration according to the invention combines not only all the advantages of the known individual solutions but also produces additional synergy effects. Thus the rotor configuration according to the invention offers the advantage that all the components can be configured again substantially lighter than when implemented as individual features. Furthermore through the comparatively small dimensions additional advantages are achieved during casting and transportation of the hub body.

With the known arrangement the access into the interior of the rotor blade was only very restrictedly possible as a result of the adjustment drive. This access is now clearly much easier through the external arrangement of the adjustment drive according to advantageous configurations of the invention.

The invention will now be explained in further detail with reference to an exemplary embodiment. In the drawings:

Fig. 1 shows a wind turbine with a rotor configuration according to the invention;

Fig. 2 shows a section through the rotor of a wind turbine according to the invention in the region of the rotor blade/rotor hub connection.

Figure 1 shows a wind turbine 1 with a tower 2 with a nacelle 3 mounted on the upper end of the tower. A rotor 5 which is rotatable about a rotor axis of rotation 4 is mounted on the nacelle and has a rotor hub 6 as well as rotor blades 7 which extend outwards from the rotor hub 6 and are rotatable about a longitudinal axis 8.

In the illustrated exemplary embodiment the rotor blades 7 are mounted relative to the rotor hub 6 at a cone angle α which is formed by the longitudinal axis 8 of the rotor blade 7 and the normal plane, wherein the normal plane extends from the intersection of the longitudinal axis 8 and the rotor axis of rotation 4 perpendicular to the rotor axis of rotation 4. The rotor blades 7 are configured so that they have a first length section I which is formed to run rectilinearly from the rotor hub. The first length section I is adjoined by the second length section II which extends with a forwardly directed curvature up to the tip of the rotor blade.

So that the rotor blades can rotate freely and do not collide with the tower, the rotor 5 is arranged relative to the nacelle 3 so that there is an overhang U relative to the tower axis 9. As shown in Fig. 1 the overhang U can be made advantageously shorter by the rotor blade configuration according to the invention than would be the case if for example the rotor were to only have the conical arrangement of the rotor blades.

Fig. 2 shows in a half section a connecting flange 20 of a rotor hub which is coupled by a blade bearing 21 to a rotor blade 22. The blade bearing is a four-point bearing which has an inner ring 23 and an outer ring 24, wherein the inner ring 23 is fixedly connected to the connecting flange 20 of the rotor hub by screw connections 25 and the rotor blade 22 is fixedly connected to the outer ring 24 by the screw connections 26.

As already repeatedly mentioned known wind turbines are as a rule configured so that the rotor blade 22 is mounted on the inner ring 23. The illustrated embodiment has on the other hand the advantage that either a rotor blade can be used which has a larger rotor connection diameter or conversely the possibility exists that the rotor connection diameter remains the same and the diameter of the connection flange in the rotor hub is formed smaller whereby a more compact hub is advantageously produced.

In addition to the advantages already discussed above this configuration offers a further advantage with regard to the flange screw fitments: The screw fitment of the rotor blade with the blade bearing is clearly to be considered more critical than the screw fitment of the rotor hub with the blade bearing, which is ascribed to the great pliability of the blade root which is made from fibre compound materials. A larger flange diameter at the blade root compared to the connection flange thus increases the commercial viability of the two flange connections.

Patentkrav

1. Vindenergianlæg (1) med et tårn (2), en på den øverste ende af tårnet (2) anbragt gondol (3), en rotor (5), der er lejret udvendigt på gondolen drejeligt omkring en drejeakse (4) for rotoren, og som har et rotornav (6, 20) og i det mindste et rotorblad (7, 22), der strækker sig fra rotornavet (6, 20), hvor rotorbladet (7, 22) er anbragt på rotornavet (6, 20) orienteret hældende bort fra tårnet (2) i en stump vinkel i forhold til rotorens drejeakse (4), kendetegnet ved, at rotorbladet (7, 22) i i det mindste et længdeafsnit er udformet buet i forhold til længdeaksen (8).

2. Vindenergianlæg ifølge krav 1, kendetegnet ved, at rotorbladet (7, 22) er udformet sådan, at det i et første længdeafsnit (I), der begynder ved rotornavet (6, 20), er udformet forløbende lige frem til en defineret afstand fra rotornavet (7, 22), og i et andet længdeafsnit (II), der slutter sig til det første længdeafsnit, og som strækker sig frem til rotorbladets spids, områdevist er udformet fremadrettet buet.

3. Vindenergianlæg ifølge krav 2, kendetegnet ved, at det andet længdeafsnit (II) udgør mindre end en tredjedel af rotorbladet (7, 22).

4. Vindenergianlæg ifølge et af de foregående krav, kendetegnet ved, at rotorbladet (7, 22) er drejeligt koblet med et på rotornavet (6, 20) monteret bladleje (21), bladlejet (21) har en yderring (24) og en inderring (23), hvor inderringen (23) er fast forbundet med rotornavet (6, 20), og yderringen (24) er fast forbundet med rotorbladet (7, 22).

5. Vindenergianlæg ifølge et af de foregående krav, kendetegnet ved, at rotorens drejeakse (4) skråner opad i forhold til den vandrette linje.

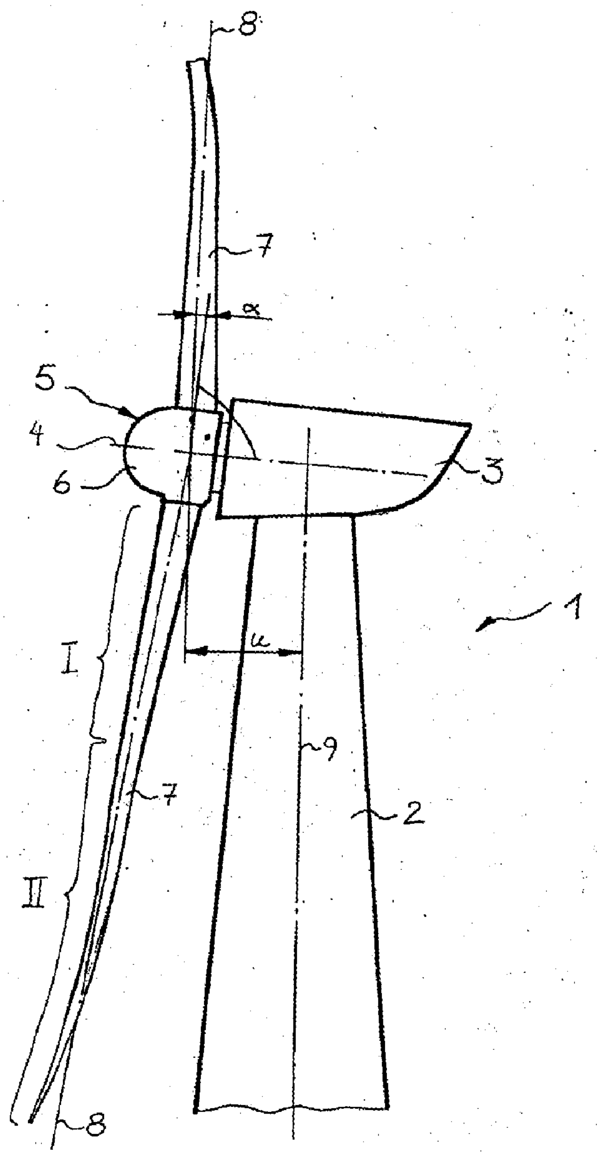

Fig 1

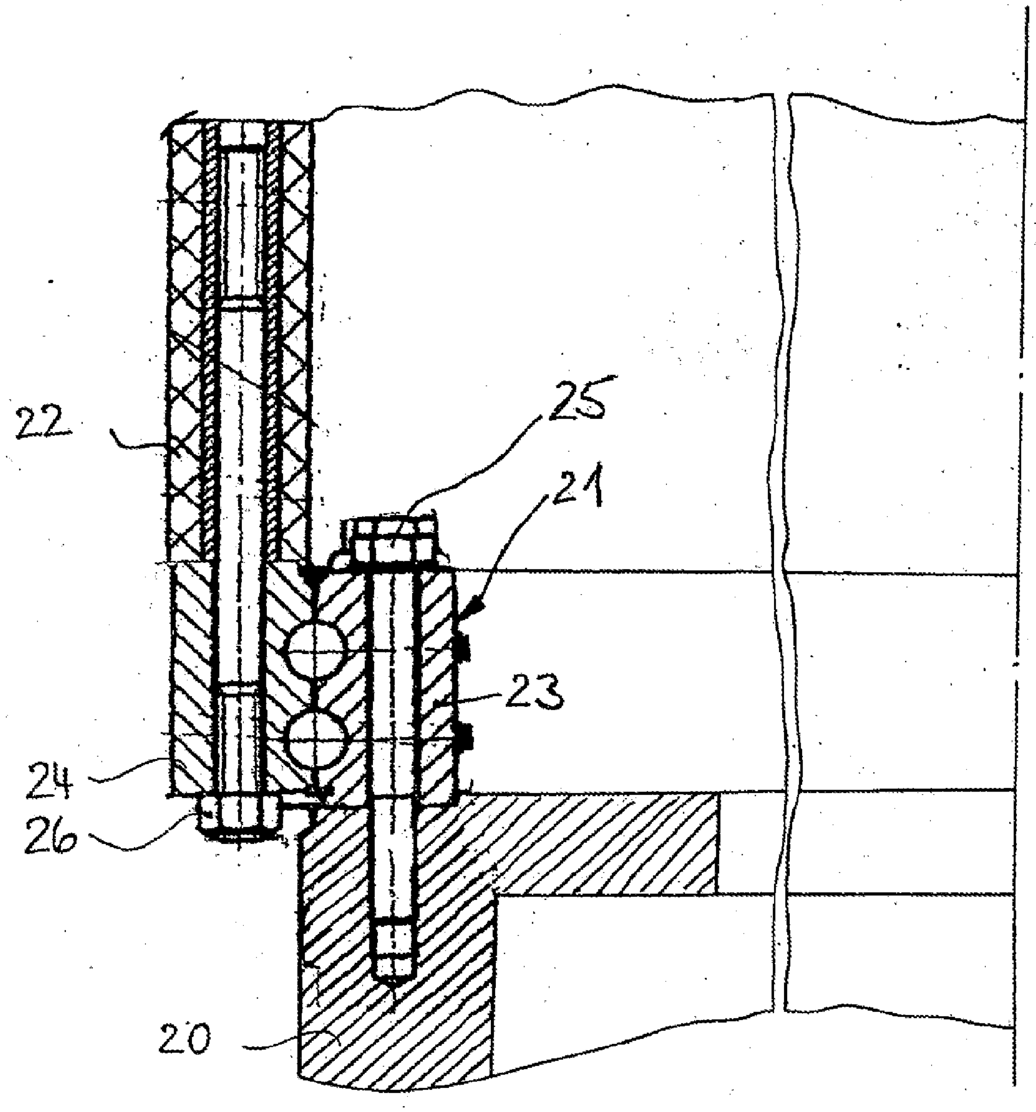

Fig 2