(19) DANMARK

Patent- og
Varemærkestyrelsen

(10) **DK/EP 3553311 T3**

(12)
Oversættelse af europæisk patentskrift

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(51) Int.Cl.: *F 03 D 17/00 (2016.01)* *F 03 D 7/02 (2006.01)*

(45) Oversættelsen bekendtgjort den: **2023-01-23**

(80) Dato for Den Europæiske Patentmyndigheds
bekendtgørelse om meddelelse af patentet: **2022-11-02**

(86) Europæisk ansøgning nr.: **19168376.2**

(86) Europæisk indleveringsdag: **2019-04-10**

(87) Den europæiske ansøgnings publiceringsdag: **2019-10-16**

(30) Prioritet: **2018-04-12 DE 102018002982**

(84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**

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(54) Benævnelse: **ANORDNING OG FREMGANGSMÅDE TIL STYRING AF ET VINDKRAFTANLÆG**

(56) Fremdragne publikationer:
WO-A1-2017/000960
WO-A1-2017/093512
US-A1- 2010 014 969
US-A1- 2016 138 571

DEVICE AND METHOD FOR CONTROLLING A WIND TURBINE

The present invention relates to a device and a method for controlling a wind energy installation.

In order to ensure reliable operation of wind energy installations, it is known to provide control mechanisms by means of which, for example, external influences on the operation of the wind energy installations can be reacted to. As a function of a measured wind speed, it is possible, for example, to select one of various operating modes in order to keep the loads acting on the wind energy installation within predetermined limits. A conventional measure is, for example, to set the setting angles of rotor blades of a rotor of the wind energy installation such that bending moments acting on the rotor blades do not reach or exceed a bending moment threshold.

In this case, the bending moments that occur for each rotor blade can be determined individually by means of at least three sensors distributed on the circumference of the blade root, which define at least two measuring axes, and generally at least two sensor pairs, i.e., in total at least four sensors per rotor blade, and can be transformed into control variables which are used, for example, to calculate a control error.

The document DE 102 19 664 A1 discloses, for example, a sensor device assigned to a rotor for generating sensor signals as a function of the mechanical load on the rotor, wherein at least two sensor elements - preferably mounted in pairs - are assigned to at least one rotor blade of the rotor. An evaluation device is designed to determine evaluation signals representing the mechanical loads of at least one rotor blade on the basis of the sensor signals generated by the sensor elements assigned to this rotor blade. A control device receiving the evaluation signals can set at least one operating parameter of the wind energy installation, e.g., the blade adjustment, as a function of the evaluation signals.

US 2016/138571 A1 relates to a method for estimating rotor blade loads comprising measurement of several operating parameters of the wind energy installation via one or more sensors, estimating forces outside the plane and forces in the plane acting on the rotor blade, determining an application point for the forces outside the plane and an application point for the forces within the plane along a span of the rotor blade, estimating moments outside the plane based upon the forces outside the plane and the respective application points, estimating moments in the plane of the rotor blade based upon the forces in the plane and the respective application points, and calculating the load acting on the rotor blade based at least in part upon the moments outside the plane and within the plane.

According to US 2010/014969 A1, a wind energy installation or rotor load control compensates for the moment imbalance in a wind energy installation that includes a rotor with at least two blades with variable pitch.

It is an object of the invention to simplify the measurement of bending moments in and/or on rotor blades of a rotor of a wind energy installation. It is particularly an object to reduce the effort for measuring out-of-plane moments.

This object is achieved by a device and a method for controlling a wind energy installation according to the independent claims. Advantageous embodiments are the subject matter of the dependent claims.

A first aspect of the invention relates to a device for controlling a wind energy installation with a rotor that has at least one rotor blade connected to a rotor axis of the rotor by means of a rotor hub. The device preferably has a position detection device which is set up to detect a rotational position of the rotor blade with respect to the rotor axis and to output positional data which characterize a value of the rotational position. Furthermore, a sensor device is preferably provided which is arranged on and/or in the rotor blade and is set up to determine an impact moment acting on the rotor blade perpendicularly to a rotor blade surface and preferably perpendicularly to a chord surface, and to output sensor data which characterize a value of the determined impact moment, and an evaluation device which is set up to determine, by means of the positional data, a value of an out-of-plane moment of the rotor blade and to determine, from the determined in-plane moment and the sensor data with consideration of an effective direction of the determined impact moment relative to the chord surface of the rotor blade - in particular, a direction of a measuring axis of the sensor device - a value of an out-of-plane moment of the rotor blade. A control device is preferably set up to control the wind energy installation on the basis of the determined value of the in-plane moment and/or on the basis of the determined value of the out-of-plane moment.

A rotational position of the rotor blade with respect to the rotor axis within the meaning of the invention is in particular a rotation angle. The rotational position can in particular indicate an orientation of the rotor blade in a rotor plane defined by its rotational movement. Preferably, the rotational position, and in particular the rotation angle, is specified relative to a predetermined, e.g., vertical, position of the rotor blade.

A position detection device within the meaning of the invention is in particular a sensor arrangement with at least one position sensor which is set up to detect the position of the rotor blade with respect to a predefined position, and in particular the upper vertical position, of the rotor blade.

A drive torque within the meaning of the invention is in particular a torque or a force, e.g., caused by wind acting on the rotor, which is conveyed through the rotor axis - for example, the drive train of the wind energy installation.

A drive torque detection device within the meaning of the invention is, in particular, a sensor arrangement with at least one moment sensor which is set up for sensing the drive torque, or a computing arrangement which is set up to calculate or estimate the drive torque, e.g., based upon an angular velocity and/or an electrical power, or a computing arrangement which is set up to calculate or estimate the drive torque based upon the setpoint setting of the converter.

A chord surface within the meaning of the invention is, in particular, a cross-sectional area of the rotor blade in which there are rotor blade chords that extend from the rotor blade leading edge to the rotor blade trailing edge. The chord surface preferably extends parallel along a longitudinal axis of the rotor blade running from a rotor blade root to a rotor blade tip and along rotor blade chords running from a rotor blade leading edge to a rotor blade trailing edge. The chord surface therefore preferably has a surface normal which is perpendicular to the longitudinal axis of the rotor blade. If the rotor blades have a twist, the chord surface is not planar, but is a three-dimensionally twisted surface. In this case, the surface normal applies only locally to a profile section.

An evaluation device within the meaning of the invention is in particular a computing device which is set up to process provided data, and in particular positional data, drive torque data, and/or sensor data. The evaluation device can, for example, be designed as an integrated circuit and be set up to calculate values of bending moments, which act on the rotor blade in or out of selected directions, as a function of the provided data. The evaluation device can in particular be set up to transform the provided data or the determined bending moments characterized by the data - in particular, geometrically and/or as a function of the effective direction - in order to determine values for an in-plane moment or out-of-plane moment.

Within the meaning of the invention, an in-plane moment is in particular a bending moment which is tangential to the surface swept by the rotor blade while the rotor blade is moving, and in particular a bending moment acting on the rotor blade perpendicularly to the longitudinal axis of the rotor blade. For example, if the rotor blade is perpendicular to the rotor axis, the in-plane moment is a bending moment acting on the rotor blade in the direction of movement in the rotor plane defined by the movement of the rotor.

An out-of-plane moment within the meaning of the invention is in particular a bending moment which acts on the rotor blade perpendicularly to the surface swept by the rotor blade while the rotor blade is moving, and in particular perpendicularly to the longitudinal axis of the rotor blade. If the rotor blade is, for example, perpendicular to the rotor axis, the out-of-plane moment is a bending moment acting on the rotor blade perpendicularly to the rotor plane defined by the movement of the rotor.

An effective direction within the meaning of the invention is in particular a direction from which a determined bending moment acts on the rotor blade. The effective direction is preferably perpendicular to the longitudinal axis of the rotor blade. The effective direction is defined in particular by the direction of at least one measuring axis of the sensor device, which, for example, specifies in which direction a bending of the rotor blade is detected.

Controlling the wind energy installation is in particular regulating operating parameters of the wind energy installation during the operation thereof. Controlling can, for example, be switching off the wind energy installation, an azimuthal alignment of a nacelle of the wind energy installation, and/or the like. In particular, controlling the wind energy installation can be setting a setting angle or setting a generator moment and therefore the power output.

A setting angle within the meaning of the invention is in particular an angle between a rotor blade and a rotor plane, swept by the longitudinal axis of the rotor blade while the rotor is rotating, which is preferably perpendicular to the rotor axis or is a conical surface with rotors having a cone angle. Preferably, the setting angle is then defined as 0° when the rotor blade is in the operating position, i.e., supplies the maximum power at the rotor shaft during operation with an optimum speed of travel. Alternatively or additionally, however, the setting angle can also be defined as the angle between a rotor blade chord, which preferably extends at least substantially from a rotor blade leading edge to a rotor blade trailing edge at a defined profile section of the rotor blade, and the above-mentioned rotor plane or cone surface.

The impact moment within the meaning of the invention is preferably identical to the out-of-plane moment when the setting angle of the rotor blade is 0°.

In order to set a setting angle, the rotor blade can preferably be rotated about a longitudinal axis of the rotor blade to align the rotor blade with respect to the wind flowing towards the rotor blade - especially apparent wind. The invention is based in particular upon the approach of simplifying the measurement of bending moments in and/or on rotor blades of a rotor of a wind energy installation, in that the number of sensors used to determine the bending moments is reduced. Usually, the reduction in the number of sensors arranged in or on a rotor blade for detecting bending moments acting on the rotor blade is accompanied by a measurement error which is dependent upon the setting angle of the rotor blades, since, as the setting angle is increased, the remaining measuring axis/axes are increasingly aligned parallel to the surface, and in particular the rotor plane, swept during the movement of the rotor blade. With an increasingly parallel alignment of the measuring axis with respect to the rotor plane, the proportion of measured forces occurring perpendicular to the rotor plane is reduced, for example, while the proportion of measured forces occurring in the rotor plane is increased. Accordingly, in the case of an increasingly perpendicular orientation of the measuring axis to the rotor plane, for example, the proportion of measured forces occurring in the rotor plane is reduced, while the proportion of measured forces occurring perpendicular to the rotor plane is increased.

In order to compensate for this effect, a bending moment acting on the rotor blade tangentially to the surface, and in particular the rotor plane, swept by the movement of the rotor blade, i.e., a so-called in-plane moment, is preferably determined from information obtained otherwise. For example, the in-plane moment can be determined or derived from other variables, detected by sensors, which characterize the operation of the wind energy installation. In particular, the in-plane moment can be derived from a rotational position of the rotor blade, upon which depends, for example, a load on the rotor blade due to its dead weight.

In the calculation using the sensor data of the remaining sensors, the in-plane moment then preferably supplies a bending moment which acts perpendicularly to the surface swept while the rotor blade moves, i.e., a so-called out-of-plane moment. In this case, geometric relations between the determined in-plane moment and the impact moment characterized by the sensor data are preferably utilized in order to calculate the out-of-plane moment. In particular, the impact moment detected by means of a sensor device can be geometrically transformed as a function of the determined in-plane moment in order to obtain the out-of-plane moment. In this case, the effective direction of the detected impact moment relative to a chord surface of the rotor blade is preferably used in the transformation.

It is therefore possible to determine the out-of-plane moment even if the sensor device can detect, for example, only one impact moment acting perpendicularly to the chord surface, and the chord surface is rotated about a longitudinal axis of the rotor blade, i.e., the chord surface is not oriented in parallel to the rotor plane, and therefore the remaining measuring axis of the sensor device is not parallel to the effective out-of-plane moment.

In particular, the wind energy installation can thereby also be controlled reliably and precisely with a reduced number of sensors, and in particular with a sensor device which can detect exclusively an impact moment acting perpendicularly to the chord surface. In addition to savings in cost, this advantageously also enables a simplified system architecture, which is accompanied by a reduced susceptibility to errors. Since, according to the invention, in spite of the reduced number of sensors, i.e., with only one bending moment measurement per rotor blade, at least substantially the same measurement accuracy can advantageously be achieved as in measurements with several sensors, controlling the wind energy installation according to the invention - in particular, setting the setting angle of the rotor blade - is more efficient when there is only one bending moment measurement per rotor blade.

Overall, the invention allows a simplified measurement of bending moments acting on rotor blades of a rotor of a wind energy installation. In particular, the invention allows a reduction in the effort for determining out-of-plane moments.

In a preferred embodiment, the device further comprises a drive torque detection device which is set up to detect a drive torque acting on the rotor axis, and to output drive torque data which characterize a value of the drive torque. In this case, the in-plane moment is preferably also determined by means of the drive torque data. The in-plane moment can be determined in particular with consideration of a drive torque which is exerted on the rotor axis by the rotor blade via the rotor hub, for example. The in-plane moment can therefore be determined very precisely.

In a further preferred embodiment, the evaluation device is set up to determine an environmental condition on the basis of the determined value of the in-plane moment and/or the determined value of the out-of-plane moment. In addition, the control device is preferably set up to control the wind energy installation on the basis of the determined environmental condition.

An environmental condition within the meaning of the invention is in particular an external influence on the wind energy installation or the rotor, and in particular on the rotor blade. An environmental condition can, for example, be a wind speed, a wind direction, an air density, and/or the like. As a result, for example, the setting angle of a rotor blade can be set very favorably, or a nacelle of the wind energy installation and therefore the rotor axis can be oriented very favorably to the currently prevailing wind direction.

In a further preferred embodiment, the control device is configured to set a setting angle of the rotor blade on the basis of the determined value of the out-of-plane moment. The control device is preferably designed as a blade setting device.

A blade setting device within the meaning of the invention is in particular a mechanism for aligning the rotor blade - preferably by rotating about a longitudinal axis of the rotor blade. The blade setting device is preferably configured to set the setting angle of the rotor blade such that one or more criteria dependent upon the determined in-plane moment and/or the determined out-of-plane moment are met. For example, the blade setting device can be configured to set the setting angle such that the determined in-plane moment and/or out-of-plane moment does not reach or exceed a predetermined threshold value, or that all the rotor blades are loaded as uniformly as possible, whereby pitch and yaw moments are reduced.

The setting angle can therefore be changed, for example, in order to keep a mechanical load on the rotor blade by the wind driving the rotor blade below a predetermined load threshold value. This can be particularly favorable with regard to the service life of components of the wind energy installation.

In a further preferred embodiment, the sensor device has exclusively one measuring axis, and in particular two sensor elements which are arranged in the region of a rotor blade root on the chord surface next to one another or on opposite sides of the chord surface. The two sensor elements are preferably set up to detect a bending of the rotor blade perpendicular to the longitudinal axis of the rotor blade. If the two sensor elements are preferably arranged on an upper side or a lower side of the rotor blade, the two sensor elements can reliably detect a bending of the chord surface. The impact moment acting perpendicularly to the chord surface on the rotor blade can be determined from the sensor-detected bending of the chord surface at two points adjacent to one another or opposite one another relative to the chord surface. According to the invention, the provision of two sensor elements in the region of the rotor blade root is sufficient to determine the out-of-plane moment precisely and reliably, while taking into account a separately determined in-plane moment.

In a further preferred embodiment, the sensor elements are designed as optical strain gauges. As a result, a bending of the rotor blade perpendicular to the longitudinal axis of the rotor blade, and in particular either a bending of the chord surface or a bending in the chord surface, can be reliably and precisely detected. In addition, sensor elements designed in this way are robust with respect to failures caused by external effects, such as lightning strikes.

In a further preferred embodiment, the sensor elements are designed as rod sensors. Rod sensors are sensors in which, in the region of the blade root, a rod-shaped component is fixed at one end to the blade wall and substantially parallel thereto, wherein the movement of the other end of the rod relative to the blade wall is detected by a sensor. With a load-related deformation of the rotor blade, sufficiently large transverse movements (angular deformation) as well as longitudinal movements of the rod end relative to the blade wall can therefore already be detected with rod lengths of only 50 to 100 cm. The rod is preferably produced from a material similar to the blade wall in order to compensate for temperature effects due to material expansion. Such a rod sensor is known in principle and is disclosed, for example, in DE 198 47 982 C2.

In a further preferred embodiment, the evaluation device is set up to determine, on the basis of the drive torque data, an individual blade drive torque which acts on the rotor blade. Preferably, the evaluation device is set up to assign the detected drive torque to at least two rotor blades of the rotor according to an - in particular, uniform - distribution. When determining the in-plane moment, the evaluation device weights the drive torque data, and in particular the value of the drive torque, in a preferred manner with a factor which takes account of the number of rotor blades of the rotor. In the case of a rotor with three rotor blades, the value of the drive torque for calculating the in-plane moment can be weighted, for example, with a factor of 1/3. Taking into account an individual blade drive torque allows very high precision in the determination of the in-plane moment.

In a further preferred embodiment, the evaluation device is set up to determine the individual blade drive torque with consideration of at least one of the following parameters: (i) positional data, e.g., a rotation angle of the rotor blade and/or other rotor blades of the rotor; (ii) wind energy installation parameters, e.g., an azimuthal alignment of the rotor axis - in particular, relative to the wind direction; (iii) environmental condition, e.g., a wind speed, wind direction, and/or (iv) further sensor data which are output by at least one further sensor device arranged on and/or in a further rotor blade. Preferably, the evaluation device is set up to determine the individual blade drive torque by a distribution function in which the detected drive torque and possibly one of the aforementioned variables are included. The individual blade drive torque can be determined, for example, with consideration of a high-altitude wind gradient, a horizontal oblique flow, a vertical oblique flow, and/or a ratio of detected impact moments of different rotor blades acting perpendicularly to the chord surface. This allows a dynamic determination of the in-plane moment acting on the rotor blade and therefore advantageously increases the precision and reliability of the subsequently determined out-of-plane moment.

A wind energy installation parameter within the meaning of the invention is in particular a variable that characterizes the wind energy installation, and in particular the rotor blade. In addition to an azimuthal alignment, a wind energy installation parameter can also, for example, be a height of the rotor, i.e., the distance of the rotor hub from the ground, a length of the rotor blade, and/or the like. Taking into account measured and/or estimated values such as a wind speed and/or a wind direction, what, for example, the high-altitude wind gradient, the inflow towards the rotor blade and/or the rotor blades, and/or the like are can therefore be determined, and in particular estimated.

In a further preferred embodiment, the drive torque detection device is set up to estimate and/or detect at least one operating parameter, e.g., a rotational speed, an electrical power, a converter characteristic value, a load on the drive train, a total moment, and/or the like, of the wind energy installation, and to determine the drive torque on the basis of the at least one estimated and/or detected operating parameter. The drive torque detection device preferably has a sensor arrangement which is set up to detect the operating parameter(s) by sensors. Alternatively or additionally, the drive torque detection device has a computing arrangement which is set up to determine or estimate the operating parameters by calculation. As a result, the in-plane moment can be determined very easily and reliably.

In a further preferred embodiment, the evaluation device is set up to transform the sensor data - in particular, geometrically - so that the sensor data characterize a proportion of the detected impact moment of the out-of-plane moment. The proportion, obtained by the transformation, of the detected impact moment in the out-of-plane moment can also be regarded as an approximate value for the out-of-plane moment - in particular, for small angles of incidence.

In this case, the evaluation device is preferably set up to transform the sensor data as a function of a setting angle of the rotor blade. Alternatively or additionally, however, the evaluation device can also be set up to transform the sensor data as a function of an angle between the effective direction of the detected striking moment and the chord surface of the rotor blade. For example, a value, characterized by the sensor data, of the impact moment, which acts perpendicularly to the chord surface, can be multiplied by the cosine of the setting angle in order to obtain at least a proportion of the out-of-plane moment. The evaluation device preferably determines other proportions of the out-of-plane moment by means of - in particular, geometric - transformation of the in-plane moments determined previously with consideration of at least the positional data - preferably as a function of the inflow angle and the impact moment. Such a calculation of the out-of-plane moment can be carried out efficiently, i.e., also with minimal computing effort, quickly and reliably.

The proportions of the out-of-plane moment obtained by the transformations, and in particular geometric transformations, are preferably to be understood as amounts which have to be offset against one another with corresponding signs in order to obtain the actual, effective out-of-plane moment. In particular, moment components which contribute to the in-plane moment, but also have a proportion in the direction of the out-of-plane moment, are taken into account. Consequently, a proportion of the out-of-plane moment arising from the pivot moment can also be taken into account. In other words, the proportions of the out-of-plane moment, which is formed from the impact moment and the pivot moment, can also be determined from the impact moment and the in-plane moment by corresponding transformations.

In a further preferred embodiment, the evaluation device is set up to determine, for each of the rotor blades of the rotor, a value of the out-of-plane moment - in particular, on the basis of sensor data which are generated by sensor devices each arranged on the different rotor blades - and values of the in-plane moment which are determined with consideration of positional data for each of the rotor blades. Preferably, a yaw moment and/or a pitch moment of the rotor is determined on the basis of the values, determined for each of the rotor blades, of the out-of-plane moment. In particular, the pitch and/or yaw moment can be calculated by adding the vectors of the out-of-plane moments of all rotor blades. Preferably, the blade setting device is set up to adjust the setting angle of the rotor blade on the basis of the determined yaw moment and/or pitch moment. In particular, the evaluation device can be set up, using the determined yaw moment and/or pitch moment, to calculate a control error on the basis of which the wind energy installation is controlled, and, in particular, the setting angle is set. For example, based upon the pivot and out-of-plane moment, the evaluation device can calculate the magnitude of a yaw moment, acting on the rotor, that loads an azimuth tracking device for azimuthal alignment of the rotor.

In order to compensate for or at least reduce this yaw moment, the setting angle of the rotor blades can be corrected cyclically over the rotor revolution by means of the blade setting device, for example. This allows reliable operation of the wind energy installation and an extension of the service life.

In a further preferred embodiment, the evaluation device is set up to additionally determine the value of the in-plane moment and/or out-of-plane moment acting on the rotor blade with consideration of a tilt angle of the rotor axis with respect to the horizon, and/or an orientation angle of the rotor blade with respect to a rotor plane (also called cone angle) which extends perpendicularly to the rotor axis. Preferably, the evaluation device is set up to compensate for the continuously changing influence of the dead weight of the rotor blade on the in-plane moment by means of a correction calculation. In particular, the evaluation device can take into account the proportions of the dead weight of the rotor blade in the in-plane moment by means of preferably geometric transformations of the measured or calculated rotor blade position or drive torque. Preferably, a corrected out-of-plane moment can then also be determined on the basis of the in-plane moment corrected in this way. This enables a particularly effective control of the wind energy installation, and in particular a particularly effective setting of the inflow angle.

In a further preferred embodiment, the evaluation device is set up to determine the value of the rotor thrust acting on the tower from the out-of-plane moments of the individual blades. This is preferably done with consideration of the tilt angle and a possible cone angle. This makes it possible to know the main load on the tower, which can then be limited by a controller, so that the tower, as a very expensive individual component, can be protected from overloading.

A second aspect of the invention relates to a method for controlling a wind energy installation with a rotor which has at least one rotor blade connected to a rotor axis of the rotor by means of a rotor hub. The method preferably has the following steps: (i) detecting a rotational position of the rotor blade with respect to the rotor axis, and outputting positional data which characterize a value of the rotational position; (ii) determining an impact moment acting on the rotor blade perpendicularly to a longitudinal axis of the rotor blade and preferably perpendicularly to a chord surface of the rotor blade, and outputting sensor data which characterize a value of the detected impact moment; (iii) determining, by means of the positional data, a value of an in-plane moment of the rotor blade, and determining, by means of the determined in-plane moment and the sensor data with consideration of an effective direction of the determined impact moment relative to the chord surface of the rotor blade - in particular, a direction of a measuring axis of the sensor device - a value of an out-of-plane moment of the rotor blade; and (iv) controlling the wind energy installation on the basis of the determined value of the in-plane moment and/or the determined value of the out-of-plane moment.

In a preferred embodiment, the method further has the following step: detecting a drive torque acting on the rotor axis, and outputting drive torque data which characterize a value of the drive torque. In this case, the in-plane moment is preferably also determined by means of the drive torque data.

In a further preferred embodiment, an environmental condition is determined on the basis of the determined value of the in-plane moment and/or the determined value of the out-of-plane moment, and the wind energy installation is controlled on the basis of the determined environmental condition. As a result, for example, the setting angle of a rotor blade can be set very favorably, or a nacelle of the wind energy installation and therefore the rotor axis can be oriented very favorably to the currently prevailing wind direction.

In a further preferred embodiment, a setting angle of the rotor blade is set on the basis of the determined value of the out-of-plane moment. The setting angle can therefore be changed, for example, in order to keep a mechanical load on the rotor blade by the wind driving the rotor blade below a predetermined load threshold value. This can be particularly favorable with regard to the service life of components of the wind energy installation.

The features and advantages described with regard to the first aspect of the invention and its advantageous embodiment also apply, at least where technically sensible, to the second, third, and fourth aspects of the invention and its advantageous embodiment, and vice versa.

The invention is explained in more detail below on the basis of non-limiting exemplary embodiments, which are illustrated in the figures. At least in part schematically, the figures show:

Fig. 1 a first preferred embodiment of a wind energy installation;

Fig. 2 a preferred exemplary embodiment of a rotor;

Fig. 3 a preferred exemplary embodiment of a rotor blade;

Fig. 4 a second preferred exemplary embodiment of a wind energy installation; and

Fig. 5 a preferred exemplary embodiment of a method according to the invention.

Fig. 1 shows a preferred exemplary embodiment of a wind energy installation 1 with a rotor 2, which has three rotor blades 3 mounted rotatably about a rotor axis R via a rotor hub 4, and a device 10 for setting a setting angle of each of the rotor blades 3. The rotor hub 4 of the rotor 2 is mounted on a nacelle 5 of the wind energy installation 1, which nacelle is preferably mounted rotatably about a vertical axis of rotation A on a tower 6 so that the nacelle 5 or the rotor axis R can be aligned azimuthally with respect to a wind direction WR. The illustration in Fig. 1 is a simplified illustration, without taking into account a tilt angle of the rotor axis and/or a cone angle of the rotor blades 3 with respect to the rotor axis R.

In order to be able to regulate the power absorbed by the wind energy installation 1 via the rotor 2, the wind energy installation 1 has, for example, a control device 60 designed as a blade setting device which is set up to set the setting angles of the rotor blades 3 with respect to a rotor plane E defined by the movement of the rotor blades 3. In particular, the control device 60 is preferably set up to adjust the setting angle of at least one rotor blade 3 on the basis of a determined in-plane moment acting on the rotor blade 3, and/or a determined out-of-plane moment acting on the rotor blade 3. In the example shown, the in-plane and out-of-plane moments relate to a bending moment acting on the rotor blade 3 in the rotor plane E or perpendicularly to the rotor plane E. The in-plane and out-of-plane moments can be determined using the device 10 as follows:

The device 10 preferably has a position detection device 20 which is set up to detect a rotational position of the rotor blade 3 with respect to the rotor axis R and to output positional data which characterize a value of the rotational position, and a drive torque detection device 30 which is set up to detect a drive torque acting on the rotor axis R and to output drive torque data which characterize a value of the drive torque. In addition, the device 10 preferably has a sensor device 40 which is arranged on and/or in the rotor blade 3 - in particular, in the region of a rotor blade root 3b - and is set up to determine an impact moment acting on the rotor blade 3 perpendicularly to a longitudinal axis of the rotor blade and to output sensor data which characterize a value of the determined impact moment, and an evaluation device 50 which is set up to determine, by means of the positional data and the drive torque data, a value of the in-plane moment and, furthermore, to determine, from the determined in-plane moment and the sensor data, taking into account an effective direction of the determined impact moment relative to a chord surface of the rotor blade 3, a value of the out-of-plane torque, and to output the determined values to, for example, the control device 60 set up as a blade-setting device.

Alternatively or additionally, the evaluation device 50 can also be set up to use the determined values of the in-plane moment and the out-of-plane moment for determining an environmental condition, which characterizes an external influence on the wind energy installation 1 - in particular, on the rotor 2 or the rotor blades 3. The determined environmental condition can then be output to the control device 60 for controlling the wind energy installation 1, e.g., for aligning the nacelle 5 relative to the wind direction WR or for switching off the wind energy installation 1 at excessively high wind speeds.

Fig. 2 shows an exemplary embodiment of a rotor 2 with three rotor blades 3, wherein the rotor 2 is rotatably mounted about a rotor axis perpendicular to the plane of the figure. The movement of the rotor blades 3 defines a rotor plane E which corresponds to the plane of the figure in the shown illustration. A bending moment M_{zB} in the rotor plane E, which is also referred to as the in-plane moment, acts on each of the rotor blades 3 during operation, i.e., when the rotor 2 rotates due to the wind.

The in-plane moment M_{zB} is preferably composed of at least two parts: a drive torque M_a and a bending moment M_{gi} which is dependent upon the rotational position of the respective rotor blade 3 and generated by the dead weight of the rotor blade 3, wherein the index i indicates the respective rotor blade. If a tilt angle of the rotor axis and/or a cone angle of the rotor blades relative to the rotor axis is present, the resulting moments also need to be taken into account when determining the in-plane moment M_{zB}, as described in greater detail below with respect to Fig. 4.

The drive torque M_a can, for example, represent a torsion load of a drive train connected to the rotor 2, which torsion load, multiplied by the rotational speed (angular velocity), ultimately represents the useful power. Due to the at least substantially rigid connection of the three rotor blades 3, the individual rotor blades 3 act, via a rotor hub, on the drive train connected to the rotor 2. The drive torque

M_a therefore results from the vector sum of the in-plane moments M_{zB} of the individual rotor blades 3.

If the drive torque M_a is detected, it can be distributed to the individual rotor blades 3, e.g., according to a distribution function, if necessary taking into account environmental conditions, wind energy installation parameters, and/or the like, but, alternatively, also uniformly. It is preferably assumed that an individual blade drive torque $1/3 \cdot M_a$ acts on each of the individual three rotor blades 3.

The bending moment M_{gi} generated by the dead weight of the rotor blade 3 is in particular dependent upon the rotation angle α between an upper vertical V and the current orientation of the rotor blade 3. If the rotation angle α of a rotor blade 3 is, for example, 0°, i.e., the corresponding rotor blade 3 is oriented in a direction of the vertical V, the rotor blade 3 points upwards with a rotor blade tip. In this rotational position, the dead weight of the rotor blade 3 does not cause a bending moment dependent upon its dead weight. If the rotation angle α of a rotor blade 3 (i=1) as shown in Fig. 2 is, for example, 90°, the corresponding rotor blade 3 is oriented horizontally. In this rotational position, the dead weight of the rotor blade 3 causes the maximum dead-weight-dependent bending moment M_g. The rotation angle or time-dependent and dead-weight-dependent bending moment M_{gi} may, for example, be expressed by $\sin(\alpha) \cdot M_{stat}$. M_{stat} in this case preferably denotes the static moment of the rotor blade, which in turn is a production or installation parameter. Static moment M_{stat} denotes the moment which acts on the blade root during an orientation perpendicular to gravitational acceleration.

In total, the approximate bending moment (in-plane moment) acting on each individual rotor blade 3 in the rotor plane E is as follows:

$$M_{zB} = \sin(\alpha) \cdot M_{stat} + 1/3 \cdot M_a.$$

Fig. 3 shows a preferred exemplary embodiment of a rotor blade 3 in a side view. The rotor blade 3 has an underside 3a′, i.e., a pressure side facing the wind flowing towards the rotor blade 3, and an upper side 3a″, i.e., a suction side facing away from the inflowing wind.

The rotor blade 3 is rotated with respect to a rotor plane E which is defined by the rotational movement of the rotor blade 3 about a rotor axis - for example, in order to enable a particularly favorable flow into the rotor blade 3. In particular, a chord surface 3a of the rotor blade 3, which chord surface preferably extends along a longitudinal axis of the rotor blade (perpendicular to the plane of the figure) from a rotor blade leading edge in the direction of a rotor blade trailing edge, is rotated by a setting angle Θ with respect to the rotor plane E. When the rotor blade 3 is rotated in such a way, sensor data of a sensor device, which is set up to provide an impact moment M_{fB} acting on the rotor blade 3 perpendicularly to the chord surface 3a, supply only a faulty estimation of a bending moment M_{yB}, which is also referred to as out-of-plane moment, acting on the rotor blade 3 perpendicularly to the rotor plane E. The same also applies to sensor data of a sensor device which is set up to detect a pivot moment M_{eB} on the rotor blade 3 parallel to the chord surface 3a - in particular, in the chord surface 3a - and perpendicular to the longitudinal axis of the rotor blade.

The fault can be compensated for in a conventional, metrologically complex manner in that the detected impact moment M_{fB}, which acts on the rotor blade 3 perpendicularly to the chord surface 3a and in particular perpendicularly to a longitudinal axis of the rotor blade, is transformed with consideration of a pivot moment M_{eB} acting on the rotor blade 3 in parallel to the chord surface 3a and perpendicularly to the longitudinal axis of the rotor blade.

If the pivot moment M_{eB} acting on the rotor blade 3 in parallel to the chord surface 3a and perpendicularly to the longitudinal axis of the rotor blade cannot be detected, e.g., because corresponding sensor elements have advantageously been omitted, it is nevertheless possible according to the invention to determine the out-of-plane moment M_{yB} precisely and reliably by transforming the detected impact moment M_{fB} acting on the rotor blade 3 perpendicularly to the chord surface 3a, taking into account an independently determined in-plane moment M_{zB} (see Fig. 2). In this case, the effective direction of the detected impact moment M_{fB} is preferably taken into account, e.g., using the setting angle Θ, from which the orientation of the detected impact moment M_{fB} relative to out-of-plane moment M_{yB} can be derived. If the effective direction of the detected impact moment is not perpendicular to the chord surface 3a, an angle between its effective direction and the chord surface 3a can also be taken into account.

The out-of-plane moment M_{yB} can, for example, be expressed as follows in components of the impact moment M_{fB} and of the pivot moment M_{eB}:

$$M_{yB} = \cos(\Theta)\cdot M_{fB} - \sin(\Theta)\cdot M_{eB}.$$

The in-plane moment M_{zB}, in contrast, can, for example, be expressed as follows in components of the impact moment M_{fB} and of the pivot moment M_{eB}:

$$M_{zB} = \sin(\Theta)\cdot M_{fB} + \cos(\Theta)\cdot M_{eB},$$

from which an equation results by transformation:

$$M_{eB} = (M_{zB} - \sin(\Theta)\cdot M_{fB})/\cos(\Theta)$$

The out-of-plane moment M_{yB} can then be expressed as follows, independently of the pivot moment M_{eB} acting on the rotor blade 3, in parallel to the chord surface 3a:

$$M_{yB} = \cos(\Theta)\cdot M_{fB} - \sin(\Theta)\cdot(M_{zB} - \sin(\Theta)\cdot M_{fB})/\cos(\Theta).$$

An out-of-plane moment M_{yB} determined in this way - in particular, by means of only two sensor elements of a sensor device, which are arranged in the region of a rotor blade root, e.g., opposite each other on the upper side 3a'' and on the lower side 3a' of the rotor blade 3, and are set up to measure a bending of the rotor blade 3 on the opposite sides of the rotor blade 3 - can be advantageously used to control the wind energy installation, and in particular the setting angle Θ.

Fig. 4 shows a second preferred exemplary embodiment of a wind energy installation 1 in which a nacelle 5 is tilted relative to the horizon H by a tilt angle τ and has a rotor 2 with several rotor blades 3 which are rotatably mounted about a rotor axis R. The tilting of the nacelle 5 also results in a tilting of a rotor plane E, which is arranged to be perpendicular with respect to the rotor axis R, by tilt angle τ relative to a vertical V.

The rotor blades 3 are preferably additionally tilted by a cone angle φ relative to the rotor plane E, so that they move on the lateral surface of a cone, and in particular of a truncated cone, during rotation about the rotor axis R. In other words, the rotor blades 3 sweep a conical surface while moving. A proportion of an in-plane moment, acting on each of the rotor blades 3, which originates from the dead weight of the rotor blades 3, is therefore now not only dependent upon the rotation angle (see Fig. 2), but also upon the tilt angle τ and/or the cone angle φ. In particular, the corresponding weight forces acting in the direction of the vertical V now also contribute a part to bending moments, i.e., the out-of-plane moments, acting on the rotor blades 3 perpendicularly to the surface swept by the rotor blades 3 during rotation about the rotor axis R, i.e., the lateral surface of the cone.

In order to take into account the weight forces acting on the rotor blades 3 in the case shown in Fig. 4, a correction calculation can be performed, in the context of which the weight forces are transformed into the lateral plane of the cone or perpendicularly thereto. For the corrected in-plane moment, given:

$$M_0(\alpha) = |\cos(\alpha)|\cdot\sin(\tau\text{-}\cos(\alpha)\cdot\varphi)M_g,$$

the following results:

$$M_{zB}{}^{‘} = \cos(\sin(\alpha)(\tau\text{-}\cos(\alpha)\varphi))\cdot\sin(\alpha)\cdot M_g + \sin(\sin(\alpha)(\tau\text{-}\cos(\alpha)\varphi))\cdot M_0(\alpha)+1/3\cdot M_\alpha.$$

For the corrected out-of-plane moment, the following accordingly results:

$$M_{yB}{}^{‘} = M_{yB} - \sin(\sin(\alpha)(\tau\text{-}\cos(\alpha)\varphi))\cdot\sin(\alpha)\cdot M_{g\,-}\, \cos(\sin(\alpha)(\tau\text{-}\cos(\alpha)\varphi))\cdot M_0(\alpha).$$

M_{yB} is here the uncorrected out-of-plane moment:

$$M_{yB} = \cos(\Theta)\cdot M_{fB} - \sin(\Theta)\cdot(M_{zB} - \sin(\Theta)\cdot M_{fB})/\cos(\Theta),$$

in which the values M_{fB} of an impact moment, which is measured perpendicularly to the chord surface of the rotor blade, are included (see Fig. 3).

Fig. 5 shows a preferred embodiment of a method 100 for controlling a wind energy installation with a rotor which has at least one rotor blade connected to a rotor axis of the rotor by means of a rotor hub. In a method step S1, a rotational position of the rotor blade with respect to the rotor axis is preferably detected, and positional data P are output which characterize a value of the rotational position. In a further method step S2, a drive torque acting on the rotor axis can be detected, and drive torque data M, which characterize a value of the drive torque, can be output. On the basis of the positional data P and the drive torque data M, an in-plane moment M_{zB} can then be determined for the rotor blade in a method step S3. The corresponding value of the in-plane moment M_{zB} is output.

Preferably, the in-plane torque M_{zB} is determined in method step S3 with consideration of a tilt angle of the rotor axis relative to a horizontal line and/or a cone angle of the rotor blades relative to a rotor plane perpendicular to the rotor axis, which advantageously results in a corrected in-plane moment.

In a further method step S4, an impact moment acting on the rotor blade perpendicularly to a longitudinal axis of the rotor blade is preferably detected, and sensor data S are output which characterize a value of the detected impact moment. An out-of-plane moment M_{yB} can be determined in a further method step S5 from these sensor data S and the determined in-plane moment M_{zB} with consideration of the effective direction of the determined impact moment relative to a chord surface of the rotor blade. The corresponding value of the out-of-plane moment M_{yB} is output.

In this case as well, the tilt angle of the rotor axis with respect to a horizontal line and/or the cone angle of the rotor blades with respect to a rotor plane running perpendicular to the rotor axis can preferably be taken into account, which advantageously results in a corrected out-of-plane torque.

In a further method step S6, the wind energy installation can be controlled - in particular, a setting angle of the rotor blade can be set - using the determined value of the preferably corrected in-plane moment M_{zB}, and/or using the determined value of the preferably corrected out-of-plane moment M_{yB}.

Preferably, on the basis of the determined values of the preferably corrected in-plane moment M_{zB} and/or the preferably corrected out-of-plane moment M_{yB}, an environmental condition is determined, and the wind energy installation is controlled on the basis of the determined environmental condition. In this case, further sensor-detected variables or information derived therefrom, which characterize the operating state of the wind energy installation, may be taken into account.

For example, based upon the values of the in-plane and out-of-plane moments M_{zB}, M_{yB} determined, if necessary over a certain period of time, at different setting angles of the rotor blades, at different azimuthal orientations of the nacelle, and/or the like, a wind speed can be determined from a lookup table or a characteristic curve.

List of reference signs

1	Wind energy installation
2	Rotor
3	Rotor blade
3a	Chord surface
3a′, 3a″	Underside, upper side
3b	Rotor blade root
4	Rotor hub
5	Nacelle
6	Tower
10, 11	Device
20	Position detection device
30	Drive torque detection device
40	Sensor device
50	Evaluation device

60	Control device
100, 200	Method
S1-S6	Method steps
R	Rotor axis
E	Rotor plane
A	Axis of rotation
H	Horizon
V	Vertical
WR	Wind direction
M_g	Dead weight bending moment
M_a	Drive torque
M_{zB}	In-plane moment
M_{zB}'	Corrected in-plane moment
M_{yB}	Out-of-plane moment
M_{yB}'	Corrected out-of-plane moment
M_{fB}	Impact moment acting perpendicularly to the chord surface
M_{eB}	Pivot moment acting in parallel to the chord surface

α	Rotation angle
Θ	Setting angle
τ	Tilt angle
φ	Cone angle

P	Positional data
M	Drive torque data
S	Sensor data

PATENTKRAV

1. Anordning (10) til styring af et vindkraftanlæg (1) med en rotor (2), der er forsynet med mindst ét rotorblad (3), der ved hjælp af et rotornav (4) er forbundet med en rotorakse (R) af rotoren (2), hvilken anordning omfatter:

– en positionsregistreringsanordning (20), der er indrettet til at registrere en drejestilling af rotorbladet (3) i forhold til rotoraksen (R) og udlæse positionsdata (P), der beskriver en værdi for drejestillingen;

– en sensoranordning (40), der er anbragt på og/eller i rotorbladet (3) og er indrettet til at beregne et slagmoment ($M_{fB,}$), der indvirker på rotorbladet (3) vinkelret på en rotorbladslængdeakse og fortrinsvis vinkelret på en kordeflade (3a) af rotorbladet (3), og udlæse sensordata (S), der beskriver en værdi for det beregnede slagmoment ($M_{fB,}$);

– en analyseanordning (50), der er indrettet til ved hjælp af positionsdataene (P) at beregne en værdi for et in-plane-moment (M_{zB}) for rotorbladet (3) og på baggrund af det beregnede in-plane-moment (M_{zB}) og sensordataene (S) under hensyntagen til en effektiv retning af det beregnede slagmoment (M_{fB}) i forhold til rotorbladets (3) kordeflade (3a), særligt en retning af en måleakse af sensoranordningen (40), at beregne en værdi for et out-of-plane-moment (M_{yB}) for rotorbladet (3); og

– en styringsanordning (60), der er indrettet til at styre vindkraftanlægget (1) på grundlag af den beregnede værdi for in-plane-momentet (M_{zB}) og/eller den beregnede værdi for out-of-plane-momentet (M_{yB}).

2. Anordning (10) ifølge krav 1, der desuden omfatter

– en drivmomentregistreringsanordning (30), der er indrettet til at registrere et drivmoment (M_a), der indvirker på rotoraksen (R), og udlæse drivmomentdata (M), der beskriver en værdi for drivmomentet (M_a),

hvor in-plane-momentet (M_{zB}) desuden beregnes ved hjælp af drivmomentdataene (M).

3. Anordning (10) ifølge et af de foregående krav, hvor

– analyseanordningen (50) er indrettet til på grundlag af den beregnede værdi for in-plane-momentet (M_{zB}) og/eller den beregnede værdi for out-of-plane-momentet (M_{yB}) at beregne en miljøbetingelse, og

– styringsanordningen (60) er indrettet til at styre vindkraftanlægget (1) på grundlag af den beregnede omgivelsesbetingelse.

4. Anordning (10) ifølge et af de foregående krav, hvor styringsanordningen (60) er indrettet til på grundlag af den beregnede værdi for out-of-plane-momentet (M_{yB}) at indstille en indstillingsvinkel (Θ) for rotorbladet (3).

5. Anordning (10) ifølge et af de foregående krav, hvor sensoranordningen (40) udelukkende omfatter en måleakse, særligt udelukkende omfatter to sensorelementer, der er placeret i området ved en rotorbladrod (3b) på kordefladen (3a) ved siden af hinanden eller på over for hinanden liggende sider af kordefladen (3a).

6. Anordning (10) ifølge et af de foregående krav, hvor sensorelementer i sensoranordningen (40) er udformet som optiske strækmålere eller som stavsensorer.

7. Fremgangsmåde (100) til styring af et vindkraftanlæg (1) med en rotor (2), der er forsynet med mindst ét rotorblad (3), der ved hjælp af et rotornav (4) er forbundet med en rotorakse (R) af rotoren (2), hvilken fremgangsmåde omfatter følgende trin:

– registrering (S1) af en drejestilling af rotorbladet (3) i forhold til rotoraksen (R) og udlæsning af positionsdata (P), der beskriver en værdi for drejestillingen;

– beregning (S4) af et slagmoment (M_{fB}), der indvirker på rotorbladet (3) vinkelret på en rotorbladslængdeakse og fortrinsvis vinkelret på en kordeflade (3a) af rotorbladet (3), og udlæsning af sensordata (S), der beskriver en værdi for det beregnede slagmoment (M_{fB});

– beregning (S3) af en værdi for et in-plane-moment (M_{zB}) for rotorbladet (3) ved hjælp af positionsdataene (P) og beregning (S5) af en værdi for et out-of-plane-moment (M_{yB}) for rotorbladet (3) ved hjælp af det beregnede in-plane-moment (M_{zB}) og sensordataene (S) under hensyntagen til en effektiv retning, særligt en retning af en måleakse af sensoranordningen (40), af det beregnede slagmoment (M_{fB}) i forhold til rotorbladets (3) kordeflade (3a); og

– styring (S6) af vindkraftanlægget (1) på grundlag af den beregnede værdi for in-plane-momentet (M_{zB}) og/eller den beregnede værdi for out-of-plane-momentet (M_{yB}).

8. Fremgangsmåde (100) ifølge krav 7, der desuden omfatter følgende trin:

– registrering (S2) af et drivmoment (M_a), der indvirker på rotoraksen (R), og udlæsning af drivmomentdata (M), der beskriver en værdi for drivmomentet (M_a);

hvor in-plane-momentet (M_{zB}) desuden beregnes ved hjælp af drivmomentdataene (M).

9. Fremgangsmåde (100) ifølge krav 7 eller 8, hvor der på grundlag af den beregnede værdi for in-plane-momentet (M_{zB}) og/eller den beregnede værdi for out-of-plane-momentet (M_{yB}) beregnes en omgivelsesbetingelse, og vindkraftanlægget (1) styres på grundlag af den beregnede omgivelsesbetingelse.

10. Fremgangsmåde (100) ifølge et af kravene 7 til 9, hvor der på grundlag af den beregnede værdi for out-of-plane-momentet (M_{yB}) indstilles en indstillingsvinkel (Θ) for rotorbladet (3).

11. Fremgangsmåde (100, 200) ifølge et af kravene 8 til 10, hvor der på grundlag af drivmomentdata (M) beregnes et individuelt bladdrivmoment, der indvirker på rotorbladet (3).

12. Fremgangsmåde (100, 200) ifølge krav 11, hvor det individuelle bladdrivmoment beregnes under hensyntagen til mindst ét af de følgende parametre:

– positionsdata (P);

– parametre for vindkraftanlægget;

– miljøbetingelse; og/eller

– yderligere sensordata (S), der udlæses af mindst én yderligere sensoranordning (40), der er placeret på og/eller i et yderligere rotorblad (3).

13. Fremgangsmåde (100, 200) ifølge mindst et af kravene 7 til 12, hvor mindst ét driftsparameter for vindkraftanlægget (1) estimeres og/eller registreres, og drivmomentet (M_a) beregnes på grundlag af det i det mindste ene estimerede og/eller registrerede driftsparameter.

14. Fremgangsmåde (100, 200) ifølge et af kravene 7 til 13, hvor sensordataene (S) transformeres på en sådan måde, at sensordataene beskriver en andel af det registrerede slagmoment (M_{fB}) i out-of-plane-momentet (M_{yB}).

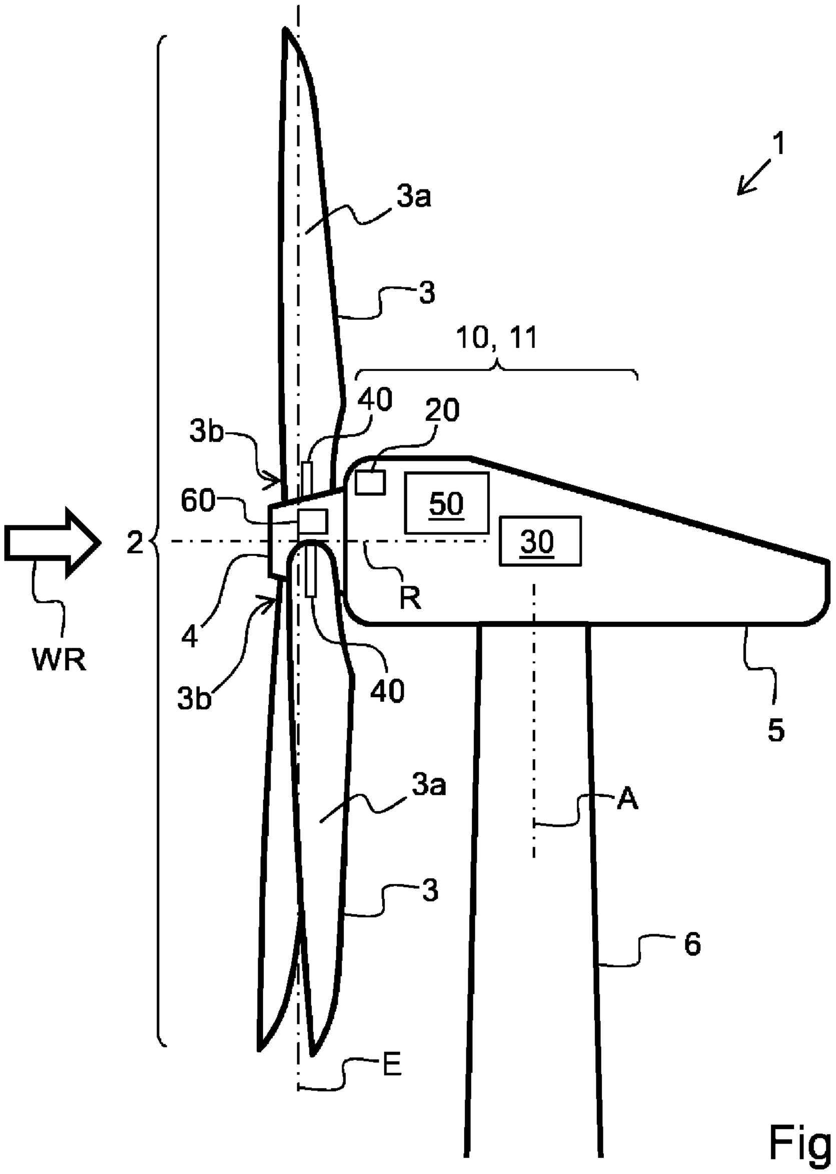
15. Fremgangsmåde (100, 200) ifølge et af kravene 7 til 14, hvor

– der for hvert af rotorbladene (3) på rotoren (2) beregnes en værdi for out-of-plane-momentet (M_{yB});

– der på grundlag af værdierne, der beregnes for hvert af rotorbladene, for out-of-plane-momentet (M_{yB}) beregnes et giringsmoment og/eller et hældningsmoment for rotoren (2), og

– indstillingsvinklen (Θ) for rotorbladet (3) indstilles på grundlag af det beregnede giringsmoment og/eller hældningsmoment.

16. Fremgangsmåde (100, 200) ifølge et af kravene 7 til 15, hvor værdien for in-plane-momentet (M_{zB}), der indvirker på rotorbladet (3), og/eller out-of-plane-momentet (M_{yB}) desuden beregnes under hensyntagen til en hældningsvinkel (τ) af rotoraksen (R) i forhold til det vandrette niveau (H) og/eller en retningsvinkel (φ) af rotorbladet (3) i forhold til et rotorplan (E), der ligger vinkelret på rotoraksen (R).


1
3a
3
10, 11
40
20
3b
60
50
2
30
R
4
WR
3b
40
5
3a
A
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6
E

Fig. 1

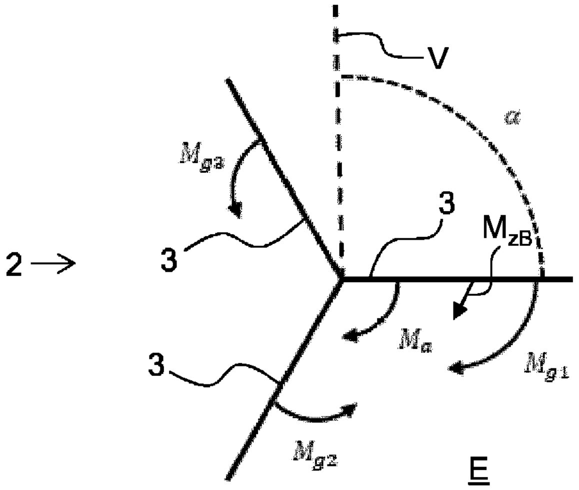
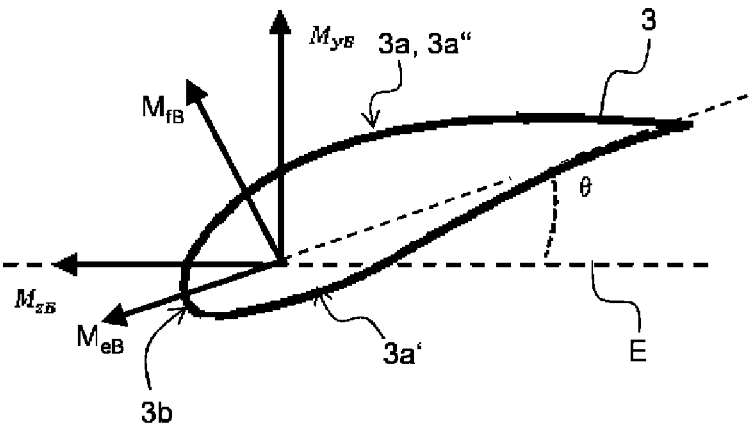

V
α
M_{g3}
3
M_{zB}
2
3
M_a
M_{g1}
3
M_{g2}
E

Fig. 2

Fig. 3



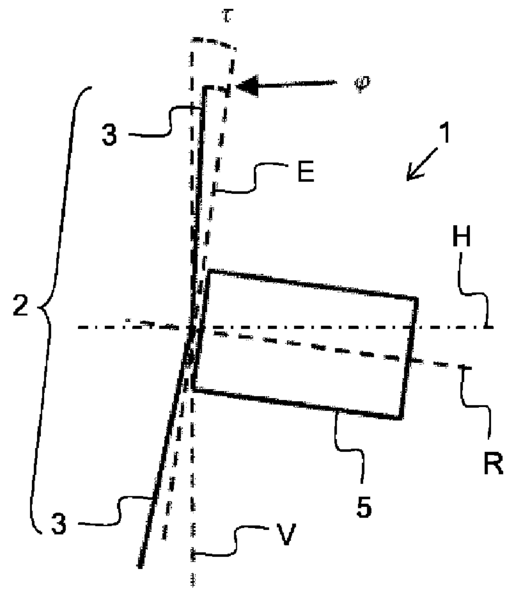


Fig. 4

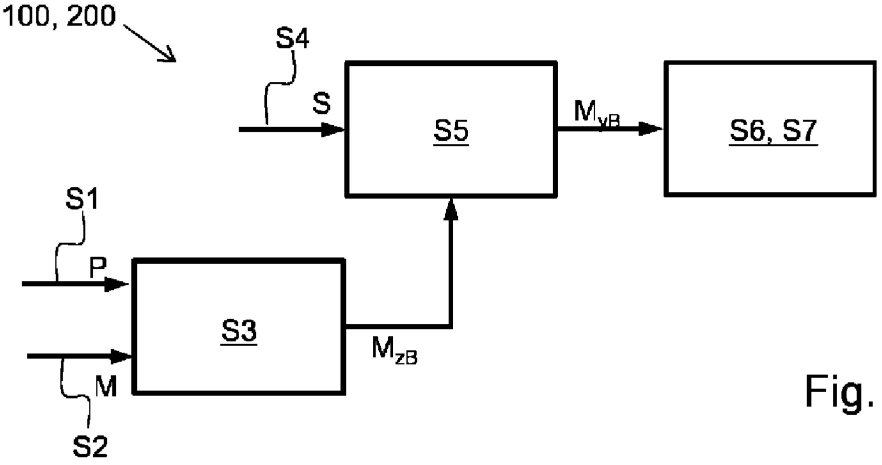


Fig. 5