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(54) Benævnelse: **UDLIGNINGSSYSTEM TIL EN ROTOR**

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DESCRIPTION

Field of Invention

[0001] This invention relates to the field of power generating wind turbines comprising a rotor having one or more blades, each with an actuator for adjusting the angle of pitch about its longitudinal axis.

[0002] In particular, this invention relates to a compensation system for independently modifying a rotor blade pitch angle signal output by a centralised controller of a rotor blade control system.

[0003] This invention also finds application for rotors in the field of fluid, particularly water, turbines, such as marine turbines.

Background to the Invention

[0004] Wind turbines are now a common means of generating electricity in many countries with tens of GigaWatts of installed capacity in Europe and the USA. Since the late 1990s, the power rating and size of wind turbines has increased rapidly to about 5MW and 120m rotor diameter today. Both the power generated by the wind turbine and the rotational speed of the rotor must be regulated to achieve viable operation of the wind turbine to avoid over-engineering, since the power available from the wind increases with the cube of wind speed, and to keep the rotational speed of the rotor within a safe operating range. In higher wind speeds, the regulation of the wind turbine is partly or wholly realised by adjusting the angle of pitch of the blades as the wind speed varies to keep the generated power or the rotational speed of the rotor constant, or for some other closely related purpose.

[0005] The blades are typically adjusted collectively; that is, the same pitch adjustment is made to all the blades. In so doing, account is taken only of the average wind speed over the whole rotor. The adjustment to the angle of pitch of the blades is determined by a centralised controller of a wind turbine rotor blade control system in response to measurements of the generated power or the rotational speed of the rotor constant or some other closely related measurements. The actuators adjust the pitch angle of the blades by the amount determined by the centralised controller.

[0006] When regulating the wind turbine in the above manner, other than gravity loads or blade misalignment loads, the loads on each blade would be the same provided a wind-field, with which the rotor interacts, is uniform; that is, symmetric about an axis through a hub of the rotor and perpendicular to the rotor. However, a real wind-field is not uniform. Instead, wind speed increases with height, is reduced in front of a tower supporting the rotor and varies turbulently over a disc swept by the blades. Consequently, particularly for large wind turbines, the loadings on each blade and the average wind speed representative thereof are different. This asymmetric loading on the rotor and thereby on the supporting structure varies continuously reducing the service life of the wind turbine.

[0007] To remove the asymmetric loads, the angle of pitch of each blade may be separately adjusted. In so doing, account is taken of the average wind speed over the blade.

[0008] US 4,297,076 discloses a wind turbine in which only the tip portions of the blades are variable in pitch. Bending moments on each blade are measured and cyclic adjustments of the pitch angles of the tips, differing only in phase, are derived from the asymmetry of the bending moments. This cyclic pitch adjustment leads to a reduction in cyclic asymmetric loading on the rotor.

[0009] US 6,361,275 discloses a wind turbine including an adjusting device for adjusting the pitch of each rotor blade. Loads on each blade are measured using strain gauges and/or wind speeds for each blade are measured using blade-mounted anemometers. All measurements are communicated to a central control device that determines the individual adjustments to the pitch angles of the blades required to achieve reduced loads. The adjustments to the pitch angles are then enacted by actuators connected to respective blades. This individual blade pitch adjustment leads to a reduction in asymmetric loading on the rotor. Another pitch controller is known from EP 1 666 723.

[0010] WO 2005/010358 discloses a wind turbine including an adjusting device for adjusting the pitch of each blade similar to US 6,361,275. Radial displacements from the rest position of the main shaft are measured using proximity sensors. All measurements are communicated to a central control device that determines the magnitude and/or the orientation of the asymmetric load on the rotor and thereby the individual adjustments to the pitch angles of the blades required to achieve reduced loads. The adjustments

to the pitch angles are then enacted by actuators connected to respective blades. This individual blade pitch adjustment leads to a reduction in asymmetric loading on the rotor.

[0011] WO 2007/104306 discloses a method for determining the individual adjustments to the pitch angles of the blades in the adjusting device disclosed in US 6,361,275. In US 6,361,275 the loads on each blade are measured, the adjustments required to achieve reduced loads determined and then enacted. The loads are collected, stored and a load distribution function determined. A plurality of periodic functions are determined from the distribution and then used to determine the adjustment of the pitch angles of the blades.

[0012] The above-mentioned prior art solutions to the problem of asymmetric wind turbine blade loading are limited or are difficult to tune and are wind turbine specific in design. In US 4,297,076 only cyclic asymmetric rotor loads are reduced. In US 6,361,275 cyclic and non-cyclic asymmetric rotor loads are reduced but a full dynamic analysis of the wind turbine is required which relies upon many attributes and physical parameters of the wind turbine and complex control devices.

[0013] WO 2005/010358 differs from US 6,361,275 only in the measurements made. In WO 2007/104306 only that part of the non-cyclic asymmetric rotor loads consisting of a finite set of sinusoids is reduced. The frequencies of the sinusoids are integer multiples of the nominal cyclic rotor frequency and the adjustments made to each blade are the same except for phase shifts. When the rotor has three blades, the phase shifts are 120 degrees and 240 degrees.

[0014] A common feature of the prior art is the communication of all load measurements to a central control device. Moment loads on the rotor blades are coordinate transformed into a coordinate system defined by tilt and yaw, the adjustment required to reduce the asymmetric loads on the rotor are determined in this transformed coordinate system and then inverse coordinate transformed to determine the adjustments of the pitch to each blade. For a three bladed wind turbine, the procedure is very similar to the Parks transform used to derive the d-q representation of an electrical machine dynamic model from its three-phase representation. In WO 2007/104306, the coordinate transform, T, and the inverse coordinate transform, T^{-1}, is clearly shown in Figure 7. In WO 2005/010358, the measurement of the radial displacements from the rest position of the main shaft obviates the need to coordinate transform loads into a coordinate system defined by tilt and yaw. Nevertheless, the adjustments of the pitch of each blade still require to be determined using the inverse coordinate transform or by some other means. Although their absence does not indicate otherwise, the use of either the coordinate transform or the inverse coordinate transform or the use of equivalent means is a definitive indication that an adjusting device for adjusting the pitch of each rotor blade is a central control device.

[0015] This invention has as its aim to provide an alternative solution to the problem of reducing asymmetric rotor loads, which is simpler than prior art solutions and simpler to retrofit to existing installations.

Summary of the Invention

[0016] According to a first aspect of this invention, there is provided a compensation system according to claim 1.

[0017] According to a second aspect of this invention, there is provided a wind turbine according to claim 11.

[0018] According to a third aspect of this invention, there is provided a method according to claim 15.

[0019] A typical wind turbine installation, or the like, includes a rotor having a number of blades, each with an actuator for adjusting the angle of pitch about its longitudinal axis. The installation includes a rotor blade control system having a central controller for collectively controlling the pitch of each of the blades by outputting a collective rotor blade pitch angle signal to each actuator.

[0020] The compensation system of this invention is adapted to modify the rotor blade pitch angle signal received from the central controller and output a compensated rotor blade pitch angle signal to the actuator for each blade independently in order to counteract the loads on the blades caused by the non-uniformity of the wind-field, with the benefit of reducing the asymmetric rotor loads.

[0021] The first sensing means is adapted to measure the load on a respective rotor blade. Based upon the load on the blade due to non-uniformity in the wind-field, the compensation system is adapted to output the compensated rotor blade pitch signal such that the actuator connected thereto does not adjust the pitch of the blade according to the signal received from the central

controller, as in the prior art systems, but instead adjusts the pitch of the blade according to the compensated signal received from the compensation system. In this way the pitch of the respective blade is adjusted in accordance with the pitch control demanded by the central controller but also to counteract the load on that blade due to the non-uniformity in the wind-field.

[0022] The compensation system of this invention is therefore a reactive system and can reduce the asymmetric rotor loads due to non-uniformity in the wind-field, which greatly increases the service life of the installation.

[0023] The individual compensation system for each rotor blade pitch angle does not depend on either the load measurements for any other blade or on the compensated rotor blade pitch angle for any other blade other than through the common collective rotor blade pitch angle signal provided by the central controller.

[0024] The blade loads may be measured by one or more strain gauges or optical-fibre sensors, or any equivalent. The blade control means may be implemented in hardware, software embedded in a digital platform dedicated to that task or software embedded in a digital platform shared with the actuator, sensing means or centralised controller or any equivalent. The actuator may be electromechanical or hydraulic, or any equivalent.

[0025] The blade control means, using the load measurements, determines the correct adjustment in pitch angle to counteract the loads caused by the non-uniformity of the wind-field. This adjustment is made continuously or at time intervals sufficiently short that the functionality of compensation system is not impaired.

[0026] No modification to the centralised controller of the rotor blade control system is necessary since the rotor blade pitch angle signal output thereby is still utilised by the compensation system, and the performance of the centralised controller is unaffected. In other words, the centralised controller does not need to be retuned when the compensation system is installed. The compensation system in accordance with this invention is therefore particularly advantageous in that it is simple to retrofit to existing installations. In some circumstances it is possible to install the compensation system connected between the centralised controller and a standard actuator. In other circumstances, the compensation system can be integrally supplied with an improved actuator and connected directly to the centralised controller. For interface reasons, the improved actuator would need to have the same bandwidth as the standard actuator it replaces.

[0027] So that the blade control means is not installation specific, in a preferred embodiment it is designed for a rotor with constant rotational speed and infinitely stiff support structure; that is, there is no fore-and-aft or lateral acceleration of the rotor hub to which the blade is attached. The design of the blade control means depends on a dynamic analysis of the compensation system in a reference frame with fixed origin and rotating with the rotor at constant rotational speed. It does not depend on the rest of the installation. The design is, thus, much simplified depending only on the attributes of the blade, actuator and sensing means. When, as is practically always the case, the rotational speed of the rotor is not constant and the support structure is not infinitely stiff, the reference frame has a non-fixed origin and rotates with the rotor at non-constant rotational speed; that is, the reference frame is non-inertial.

[0028] To compensate for the difference between the fixed-origin reference frame and the non-inertial reference frame the compensation system in accordance with the preferred embodiment includes second sensing means for measuring acceleration of the rotor blade. The blade control means, determines a modified load on the rotor blade, based upon the measured load and acceleration, using standard methods for the conversion between reference frames, such that the compensated rotor blade pitch angle signal is based upon the modified blade load. These modifications to the load have the form of fictitious forces; for example, the fictitious force corresponding to the blade out-of-plane bending moment is $-m_b l\ddot{z}_R + J\dot{\Omega}_{yR}$ where m_b is the mass of the blade, l is the distance of the centre of mass of the blade from the axis of rotation of the rotor, $\ddot{z}_R$ is the linear acceleration of the centre of rotation of the rotor perpendicular to the rotor, J is the inertia of the blade about the axis of rotation of the rotor and $\dot{\Omega}_{yR}$ is the out-of-plane angular acceleration of the blade about its centre of rotation.

[0029] The loads on the blade caused by the non-uniformity of the wind field and, thus, the adjustment in the pitch angle of the blade are in part almost periodic, that is, strongly dependent on the rotor azimuth and almost repeating with every rotation of the blade. During an instant rotation, this almost periodic adjustment in the pitch angle is similar to the adjustments made during the preceding rotations. In a preferred embodiment, the blade control means determines the almost periodic part of the adjustment to the pitch angle from the adjustments during the preceding rotations to make better use of the actuator capabilities. The standard methods for the control of repetitive processes can be adapted to this context. The non-periodic part of the adjustment is still determined by the blade control means from the measurements of the blade loads and, preferably, accelerations.

[0030] In a preferred embodiment of the invention, the blade out-of-rotor-plane root bending moment and the fore-and-aft

acceleration of the hub are measured. The compensation system preferably adjusts the blade pitch angle such that the blade root bending moment has a specified value derived from the pitch angle determined by the centralised controller. No adjustment is made to the pitch angle when the blade root bending moment is at its reference value. The same specified value for the blade root bending moment is used for all the blades in the rotor. All the blades, thus, have the same root bending moment and, other than in the plane of the rotor, the rotor loads balance.

[0031] As the blade sweeps through the wind-field, both the magnitude and angle of attack of the wind speed relative to the blade vary. The loads caused by the non-uniformity of the wind-field are more dependent on the changes in the angle of attack of the blade mean wind speed arising from the non-uniformity of the wind-field rather than on the changes in the magnitude. The adjustments to the blade pitch angle made by the compensation system much reduce these changes in the angle of attack. Consequently, all loads on the blade caused by the non-uniformity of the wind field can be reduced. Also reduced are the asymmetric loads on the rotor caused by blade misalignment, that is, the blades not being attached to the hub with exactly the intended pitch but with small errors.

Brief Description of the Drawings

[0032] Preferred embodiments of the present invention will now be described in detail with reference to the accompanying drawings, in which:

Figure 1 shows a wind turbine;

Figure 2 shows a rotor blade including the compensation system in accordance with this invention and an actuator;

Figure 3 shows a first preferred embodiment of the compensation system;

Figure 4 shows a second preferred embodiment of the compensation system; and

Figure 5 shows a quasi-periodic element for the blade control means of the compensation system.

Detailed Description

[0033] Figure 1 depicts a wind turbine 1. It consists of a tower 2, a nacelle 3 supported by the tower 2, and a rotor 6 with three blades 5 attached to a hub 4. Each blade 5 is attached radially to the hub 4 by a bearing 10 and is able to pitch about its longitudinal axis 7. The rotor 6 rotates in a near vertical plane. A generator (not shown) and transmission system (not shown) connecting it to the hub 4, are housed in the nacelle 3. A centralised controller 19 of a rotor blade control system is also housed in the nacelle 3.

[0034] Figure 2 depicts a blade 5, an actuator 11 and the compensation system 12 for the wind turbine 1. The blade 5 is supported by the bearing 10 and is pitched about its longitudinal axis 7 by the actuator 11. The compensation system 12 includes fibre-optic, or other suitable, sensors 8 for measuring blade root bending moments; sensors 9 for measuring acceleration of the centre of rotation of the rotor 6; and blade control means 13. The compensation system 12 is connected to the actuator 11 and the centralised controller 19.

[0035] The out-of-.rotor-plane root bending moment of the blade 5, μm, and the acceleration of the centre of rotor rotation perpendicular to the plane of rotation of the rotor, α_m, are determined from the measurements made by the sensors 8 and 9 and communicated to the blade control means 13.

[0036] Figure 3 depicts a first preferred embodiment of the blade control means 13. It comprises a first blade control means element 14, a second blade control means element 15, a third blade control means element 17, a fourth blade control means element 18 and a summing element 16. In the first preferred embodiment the fluctuations in the root bending moment, caused by the non-uniformity of the wind field, are treated as disturbances to be counteracted by the blade control means 13. The fluctuations include a number of components and the blade control means 13 concentrates its effort on counteracting the most significant ones at low frequencies; for example, those centred on once or twice the rotational frequency of the rotor 6 with stochastically varying amplitude and phase.

[0037] The measured value of the blade out-of-rotor-plane root bending moment, μ_m, obtained by the fibre-optic sensors 8, and the measured value of the fore-and-aft acceleration of the hub, α_m, obtained by sensor 9, are communicated to the first blade control means element 14. The first blade control means element 14 modifies μ_m to compensate for the fore-and-aft acceleration of the hub 4; that is, it compensates for the centre of rotation of the blades not being fixed and the rotational speed not being constant.

[0038] The corrected blade out-of-rotor-plane root bending moment, μ_{mod}, is communicated to the second blade control means element 15 which determines the adjustment in pitch angle, β_b, required to counteract the fluctuations in the root bending moment, caused by the non-uniformity of the wind field. The second blade control means element 15 includes filters (not shown) to select, for counteraction, the most significant components in the fluctuations in μ_{mod}. Those skilled in the art will appreciate that suitable filters are well known. The second blade control means element 15 also includes a band-pass filter (not shown) with low frequency wash-out to avoid overriding the collective adjustment, β_{col}, being made by the centralised controller 19 to the pitch angle of the blade 5, and with high frequency roll-off to mitigate against the effects of high frequency noise and parasitic dynamics.

[0039] The blade control means 13 ensures stability of the compensation system 12 through the design of the second blade control means element 15, that is, through the design of the filters (not shown). The dynamics, on which the design of the second blade control means element 15 depend, are the dynamics of the blade 5, the actuator 11 and the sensors 8 and 9. Because of the modification made to μ_m by the first control means element 14, the design of the second blade control means element 15 does not depend on any other aspects of the wind turbine dynamics.

[0040] A summing element 16 adds β_b and a modified collective adjustment, β_{colmod}, (described in detail below) to determine the total adjustment to the pitch angle, β_t, which is communicated to the third blade control means element 17. The third blade control means element 17 compensates β_t for the nonlinear aspect of the blade aerodynamics and provides smooth switch-in and switch-out of the compensation system. The compensated rotor blade pitch angle signal, β_{dem}, is communicated to the actuator 11.

[0041] The collective adjustment to the pitch angle, β_{col}, obtained from the centralised controller 19 is communicated to the fourth blade control means element 18. The compensation system 12 introduces additional dynamics between the centralised controller 19 and the actuator 11. The fourth blade control means element 18 modifies the low frequency dynamics between the centralised controller 19 and the pitch angle to be the same as the dynamics of a standard pitch actuator with some specified bandwidth. No modification to the centralised controller 19 is then necessary and its performance is unaffected. The collective pitch demand modified by the fourth blade control means element 18, β_{colmed}, is communicated to the summing element 16. Better use of the actuator capabilities can be made by including an element in the blade control means to cater for the almost periodic part of β_{dem}. This blade control means periodic element 25 (described in detail below) would be positioned between the second blade control means element 15 and the summing element 16, acting on β_b.

[0042] Figure 4 depicts a second preferred embodiment of the blade control means 13'. It consists of the first blade control means element 14, a fifth blade control means element 23, the third blade control means element 17, a sixth blade control means element 24 and a comparator element 22.

[0043] The actuator 11 is a pitch actuator; that is, it causes the actual pitch angle of the blade to follow a demanded pitch angle. In the second preferred embodiment, the actuator 11 is, in effect, converted to a moment actuator; that is, it causes the actual root bending moment of the blade 5 to follow a demanded root bending moment. The pitch angle of the blade 5 is adjusted to counteract, within the bandwidth of the moment actuator, the fluctuations in the root bending moment, caused by the non-uniformity of the wind-field.

[0044] The measured value of the blade out-of-rotor-plane root bending moment, μ_m, obtained by the fibre-optic sensors 8, and the measured values of the accelerations and the fore-and-aft acceleration of the hub 4, α_m, obtained by sensor 9, are communicated to the first blade control means element 14. The first blade control means element 14 modifies μ_m to compensate for the fore-and-aft acceleration of the hub 4; that is, it compensates for the centre of rotation of the blade 5 not being fixed and the rotational speed not being constant. The corrected blade out-of-rotor-plane root bending moment, μ_{mod}, is communicated to the comparator element 22. The comparator element 22 subtracts μ_{mod} from the demanded root bending moment, μ_{dem}, to determine the root bending moment error, μ_e, which is communicated to the fifth blade control means element 23. The fifth blade control means element 23 is the moment actuator controller that acts to drive μ_e to zero. It does so by requiring the blade 5 be

pitched to the appropriate angle, β_m. The fifth blade control means element 23 consists of a PI controller (not shown) together with filters (not shown) with high frequency roll-off to mitigate against the effects of high frequency noise and parasitic dynamics.

[0045] The blade control means 13' ensures stability of the improved blade actuation system 12 through the design of the fifth blade control means element 23, that is, through the design of the PI controller and the filters. The design of the fifth blade control element 23 also determines the bandwidth of the moment actuator. The dynamics, on which the design of the fifth blade control means element 23 depend, are the dynamics of the blade 5, the actuator 11 and the sensors 8 and 9. Because of the modification made to μ_m by the first control means element 14, the design of the fifth blade control means element 23 does not depend on any other aspects of the wind turbine dynamics.

[0046] The required pitch angle, β_m, is communicated to the third blade control means element 17. The third blade control means element 17 compensates β_m for the nonlinear aspect of the blade aerodynamics and provides smooth switch-in and switch-out of the improved actuation system. The compensated adjustment to the pitch angle, β_{dem}, is communicated to the actuator 11.

[0047] The collective adjustment to the pitch angle, β_{col}, obtained from the centralised controller 19 is communicated to the sixth blade control means element 24. The sixth blade control means element 24 converts β_{col} to the equivalent blade root bending moment, μ_{dem}. The compensation system introduces additional dynamics between the centralised controller 19 and the actuator 11. The sixth blade control means element 24 also modifies the dynamics between the centralised controller 19 and the pitch angle to be the same as the dynamics of a standard pitch actuator with some specified bandwidth. No modification to the centralised controller 19 is then necessary and its performance is unaffected. The collective pitch demand modified by the sixth blade control means element 24, μ_m, is communicated to the comparator element 22. Better use of the actuator capabilities can be made by including an element in the blade control means 13' to cater for the almost periodic part of β_{dem}. This blade control means periodic element 25 (described in detail below) would be positioned between the fifth blade control means element 23 and the third blade control means element 17, acting on β_m.

[0048] Figure 5 depicts a blade control means periodic element 25. It consists of a seventh blade control means element 26 and a summing element 27. A measurement of the azimuth angle, θ_a, and β_i are communicated to the seventh blade control means element 26. In the first preferred embodiment, β_i is β_b, and in the second preferred embodiment, β_i is β_m. Using β_i from the preceding cycles, the seventh blade control means element 26 determines β_c, the almost periodic adjustment to the pitch angle of the blade. The summing element 27 adds β_i and β_c to obtain β_o. In the first preferred embodiment β_o is communicated to summing element 16, and in the second preferred embodiment β_o is communicated to the third blade control means element 17.

[0049] While the forgoing description and drawings represent the preferred embodiments of the present invention, it will be apparent to those skilled in the art that various changes and modifications can be made therein without departing from the scope of the present invention which is defined by the appended claims. For example, it will be appreciated that the acceleration measurement may be derived from a differentiated velocity measurement.

REFERENCES CITED IN THE DESCRIPTION

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UDLIGNINGSSYSTEM TIL EN ROTOR

PATENTKRAV

1. Udligningssystem (12) til uafhængig ændring af et rotorvinge-stigningsvinkelsignal (β_{col}), der afgives af en centraliseret styreenhed (19) af et rotorvingestyringssystem for en rotor med en flerhed af rotorvinger, hvilket udligningssystem (12) omfatter:

et første detekteringsmiddel (8), der er konfigureret til at måle en belastning (μ_m) på en enkelt rotorvinge (5); og

et vingestyringsmiddel (13), der er konfigureret til at:

modtage et rotorvinge-stigningsvinkelsignal (β_{col}), der er fælles for samtlige rotorvinger, fra rotorvingestyringssystemets centraliserede styreenhed (19); og

afgive et udlignet rotorvinge-stigningsvinkelsignal (β_{dem}), der er baseret på den målte belastning (μ_m) på den enkelte rotorvinge (5) og det modtagne rotorvinge-stigningsvinkelsignal (β_{col}), for at modvirke vingebelastning, både cyklisk og ikke-cyklisk, på grund af uensartethed i et vindfelt, indbefattende turbulens, der indvirker på den enkelte rotorvinge (5),

hvor vingestyringsmidlet (13) omfatter et første styringsmiddelelement (14), hvilket første styringsmiddelelement (14) bestemmer det udlignede rotorvinge-stigningsvinkelsignal (β_{col}) ved at bestemme en ændret vingebelastning (μ_{mod}) på den enkelte rotorvinge (5), hvor ændringerne af den målte belastning (μ_m) til at bestemme den ændrede belastning (μ_{mod}) på den enkelte rotorvinge (5) har form af fiktive kræfter, hvor den ændrede belastning (μ_{mod}) udligner forskellen mellem en fast, oprindelig referenceramme for rotorvingen (5), der roterer sammen med rotoren (6) ved en konstant rotationshastighed, og en ikke-inerti-referenceramme for den enkelte rotorvinge (5).

2. Udligningssystem (12) ifølge krav 1, hvilket udligningssystem endvidere omfatter et andet detekteringsmiddel (9) til måling af rotorbladets acceleration (α_m), og hvor vingestyringsmidlet (13) endvidere er tilpasset til at bestemme den ændrede belastning (μ_{mod}) på rotorvingen (5), baseret på den målte belastning (μ_m) og acceleration, således at det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}) er baseret på den ændrede vingebelastning, der skal udlignes for forskellen mellem rotorvingens faste oprindelige referenceramme og ikke-inerti-referenceramme.

3. Udligningssystem (12) ifølge krav 1 eller 2, hvor vingestyringsmidlet (13) er tilpasset til at bestemme det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}) baseret på justering i vingestigningsvinkel (β_b), der er krævet for at udligne for svingninger, på grund af ikke-ensartethed i vindfeltet, i den ændrede vingebelastning (μ_{mod}) og det rotorvinge-stigningsvinkelsignal (β_{col}), der er modtaget fra den centraliserede styreenhed (19).

4. Udligningssystem (12) ifølge krav 1, 2 eller 3, hvor vingestyringsmidlet (13) er tilpasset til at bestemme det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}), der er baseret på vingebelastningsfejl (μ_e), der er forskellen mellem vingebelastning (μ_{dem}), der er krævet af den centraliserede styreenhed (19), og som bestemmes ud fra det modtagne rotorvinge-stigningsvinkelsignal (β_{col}) og den bestemte ændrede vingebelastning (μ_{mod}).

5. Udligningssystem (12) ifølge et hvilket som helst af kravene 1 til 4, hvor det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}) endvidere er baseret på udligning af ikke-lineære aspekter af rotorvingens (5) aerodynamik.

6. Udligningssystem (12) ifølge et hvilket som helst af kravene 1 til 5, hvor det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}) endvidere er baseret på nærmest periodiske stigningsvinkelsjusteringer, der er afledt af én eller flere forudgående rotationer af rotorvingen (5).

7. Udligningssystem (12) ifølge et hvilket som helst af kravene 1 til 6, hvor belastningen, der måles af det første detekteringsmiddel (8), er rotorvingens bøjningsmoment (μ_m) uden for rotorplanets base.

8. Udligningssystem (12) ifølge et hvilket som helst af kravene 1 til 7, hvor det første detekteringsmiddel er en fiberoptisk sensor (8) eller en deformationsmåler.

9. Udligningssystem (12) ifølge et hvilket som helst af kravene 2 til 8, hvor accelerationen, der måles af det andet detekteringsmiddel (9), er en aksial acceleration (α_m) langs en rotationsakse (7), der er vinkelret på et plan eller en rotation af rotorvingen (5).

10. Udligningssystem (12) ifølge et hvilket som helst af kravene 2 til 9, hvor det andet detekteringsmiddel (9) er et accelerometer.

11. Vindturbine (1), der omfatter en flerhed af udligningssystemer (12,12,..) ifølge et hvilket som helst af kravene 1 til 10 og en rotor (6) med en flerhed af vinger (5), hvor hvert udligningssystem er:

forbundet med en tilsvarende vinge (5) af rotoren;

tilpasset til at modtage det rotorvinge-stigningsvinkelsignal (β_{col}), der er beregnet for den kollektive stigningsstyring af flerheden af rotorvinger, fra den centraliserede styreenhed (19); og

tilpasset til at afgive et tilsvarende udlignet rotorvinge-stigningsvinkelsignal (β_{dem}) for uafhængig stigningsstyring af dens tilsvarende rotorvinge (5).

12. Vindturbine (1) ifølge krav 11, når det afhænger af et hvilket som helst af kravene 2 til 10, hvor det første detekteringsmiddel (8) er placeret ved basen af hver rotorvinge (5) og det andet detekteringsmiddel (9) er placeret ved rotorvingernes rotationscentrum.

13. Vindturbine (1) ifølge krav 11 eller 12, hvilken vindturbine endvidere omfatter et rotorvingestyringssystem med en centraliseret styreenhed (19) for afgivelse af rotorvinge-stigningsvinkelsignalet (β_{col}).

14. Vindturbine (1) ifølge et hvilket som helst af kravene 11 til 13, hvor hver vinge (5) er forbundet med en tilsvarende aktuator (11), der er forbundet med det tilhørende tilsvarende udligningssystem (12) for styring af vingens stigning baseret på det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}).

15. Fremgangsmåde til uafhængig ændring af en rotorvinge-stigningsvinkelsignal- (β_{col}) afgivelse fra en centraliseret styreenhed (19) af et rotorvingestyringssystem for en rotor med en flerhed af rotorvinger, hvilken fremgangsmåde omfatter følgende trin:

måling af en belastning (μ_m) på en enkelt rotorvinge (5);

modtagelse af et rotorvinge-stigningsvinkelsignal (β_{col}), der er fælles for samtlige vinger, fra den centraliserede styreenhed (19) af rotorvingestyringssystemet og

afgivelse af et udlignet rotorvinge-stigningsvinkelsignal (β_{dem}), der er baseret på den målte belastning på den enkelte rotorvinge (5) og det modtagne rotorvinge-stigningsvinkelsignal (β_{col}), for at

modvirke vingebelastning, både cyklisk og ikke-cyklisk, på grund af uensartethed i et vindfelt, indbefattende turbulens, der indvirker på rotorvingen,

hvor det udlignede rotorvinge-stigningsvinkelsignal (β) bestemmes ved at bestemme en modificeret belastning (μ_{mod}) på den enkelte rotorvinge (5), hvor ændringerne af den målte belastning (μ_m) har form af fiktive kræfter, hvor den ændrede belastning (μ_{mod}) udligner for forskellen mellem en fast, oprindelig referenceramme for den enkelte rotorvinge (5), der roterer sammen med rotoren (6) ved en konstant rotationshastighed, og en ikke-inerti-referenceramme for den enkelte rotorvinge (5).

16. Fremgangsmåde ifølge krav 15, hvilken fremgangsmåde endvidere omfatter trinnene med:

måling af rotorvingens acceleration (α_m) og

bestemmelse af den ændrede belastning (μ_{mod}) på rotorvingen (5), der er baseret på den målte belastning (μ_m) og acceleration, således at det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}) er baseret på den ændrede vingebelastning, der skal udlignes for forskellen mellem faste, oprindelige og ikke-inerti-referencerammer for rotorvingen.

17. Fremgangsmåde ifølge krav 15 eller 16, hvilken fremgangsmåde endvidere omfatter trinnet med:

bestemmelse af det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}), der er baseret på justering i den vingestigningsvinkel (β_b), der er krævet for at udligne for svingninger, på grund af ikke-ensartethed i vindfeltet, i den ændrede vingebelastning (μ_{mod}) og rotorvinge-stigningsvinkelsignalet (β_{col}), der er modtaget fra den centraliserede styreenhed (19).

18. Fremgangsmåde ifølge krav 15, 16 eller 17, hvilken fremgangsmåde endvidere omfatter trinnet med:

bestemmelse af det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}), der er baseret på vingebelastningsfejl (μ_e), der er forskellen mellem den vingebelastning (μ_{dem}), der er krævet af den centraliserede styreenhed (19), bestemt ud fra det modtagne rotorvinge-stigningsvinkelsignal (β_{col}), og den bestemte ændrede vingebelastning (μ_{mod}).

19. Vingestyringsmiddel (13) til anvendelse i udligningssystemet (12) ifølge et hvilket som helst af kravene 1 til 10, hvilket vingestyringsmiddel (13) er konfigureret til at:

modtage et rotorvinge-stigningsvinkelsignal (β_{col}), der er fælles for samtlige rotorvinger (5), fra rotorvingestyringssystemets centraliserede styreenhed (19); og

afgive et udlignet rotorvinge-stigningsvinkelsignal (β_{dem}), der er baseret på en målt belastning (μ_m) på den enkelte rotorvinge (5) og det modtagne rotorvinge-stigningsvinkelsignal (β_{dem}), for at modvirke vingebelastning, både cyklisk og ikke-cyklisk, på grund af uensartethed i et vindfelt, indbefattende turbulens, der indvirker på rotorvingen (5),

hvor vingestyringsmidlet (13) omfatter et første styringsmiddelelement (14), hvilket første styringsmiddelelement (14) bestemmer det udlignede rotorvinge-stigningsvinkelsignal (β_{dem}) ved at bestemme en ændret vingebelastning (μ_{mod}) på den enkelte rotorvinge (5), hvor ændringerne af den målte belastning har form af fiktive kræfter, hvor den ændrede belastning (μ_{mod}) udligner for forskellen mellem en fast, oprindelig referenceramme for den enkelte rotorvinge (5), der roterer sammen med rotoren (6) ved en konstant rotationshastighed, og en ikke-inerti-referenceramme for den enkelte rotorvinge (5).

DRAWINGS

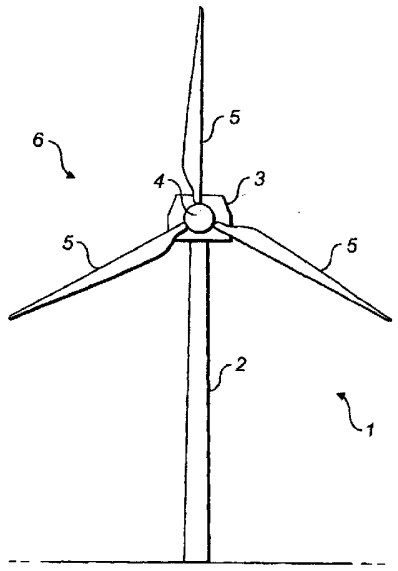


FIG. 1

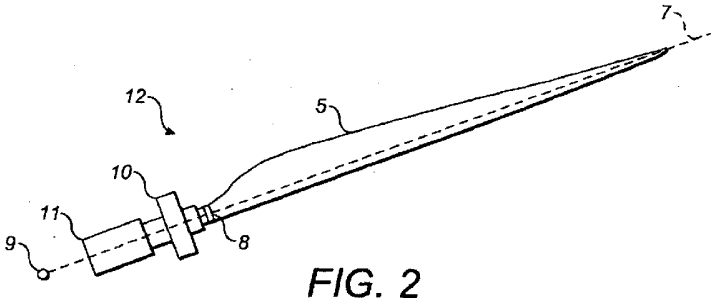


FIG. 2

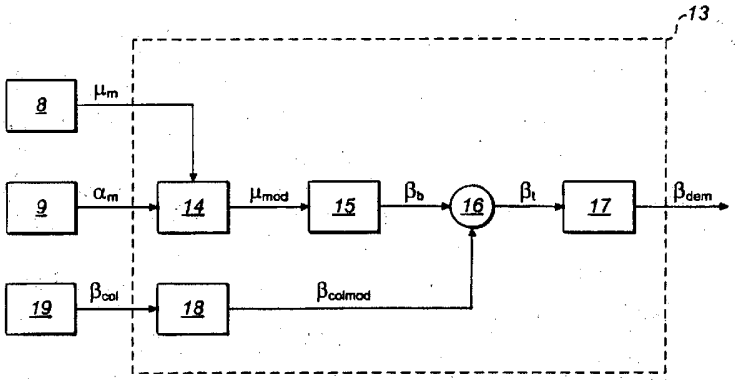

13
8
μm
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18
βcolmod

FIG. 3

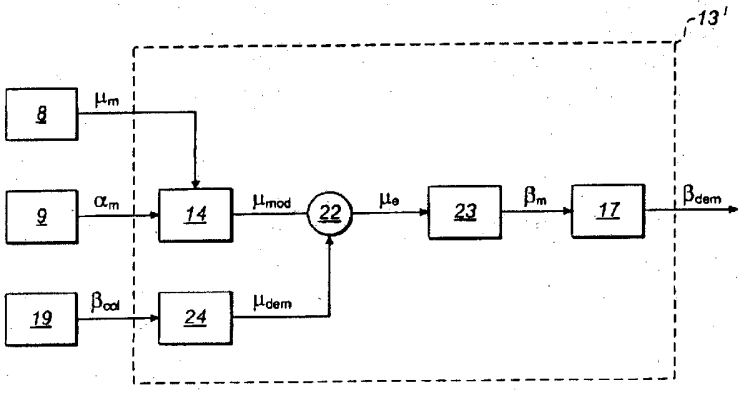

13'
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μm
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αm
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μmod
22
μe
23
βm
17
βdem
19
βcol
24
μdem

FIG. 4

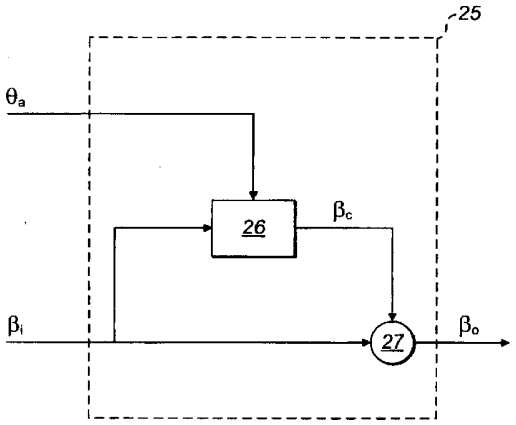


FIG. 5