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DE 020110825 U1 **US 20060000269 A1**
US 20040174542 A1

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(54) Title of the Invention: **Monitoring of rotor blade load in a wind turbine**
Abstract Title: **System to measure load on a wind turbine blade**

(57) A system to monitor load on a wind turbine blade comprising a rigid rod 10, with a first end 11 fixed to the blade 5 where the cross-section of the blade 5 is an airfoil, a second free end having a marked screen and an electromagnetic sensor 13 to sense repeatedly one or more marks on the screen. The sensor 13 may be a non-contact profiling sensor or a laser profiling sensor, which may be a CCD device. The rigid rod 10 and sensor 13 may be arranged in the blade. Measurement of the blade bending may include bending in a flapwise, edgewise or twist direction. The system may include a data processor to determine a measure of bending based on movements of the marks on the screen. The rod may rest on a pivot (14, Fig 3) fixed to the blade between the free and fixed ends of the rod. The pivot may be spherical, allowing the rod to move in three axes. The system may comprise a controller which receives the measure of blade bending from the data processor and generates control signals in response to this data and pre-stored parameters, to vary a parameter such as blade pitch or yaw angle.

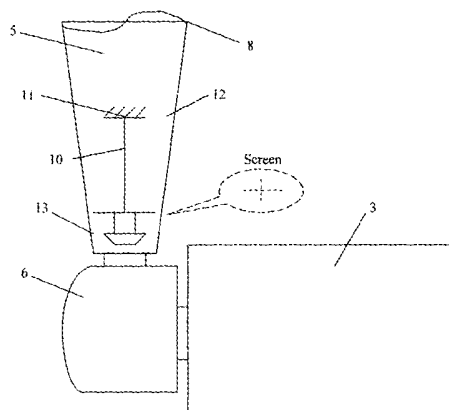


Fig.2

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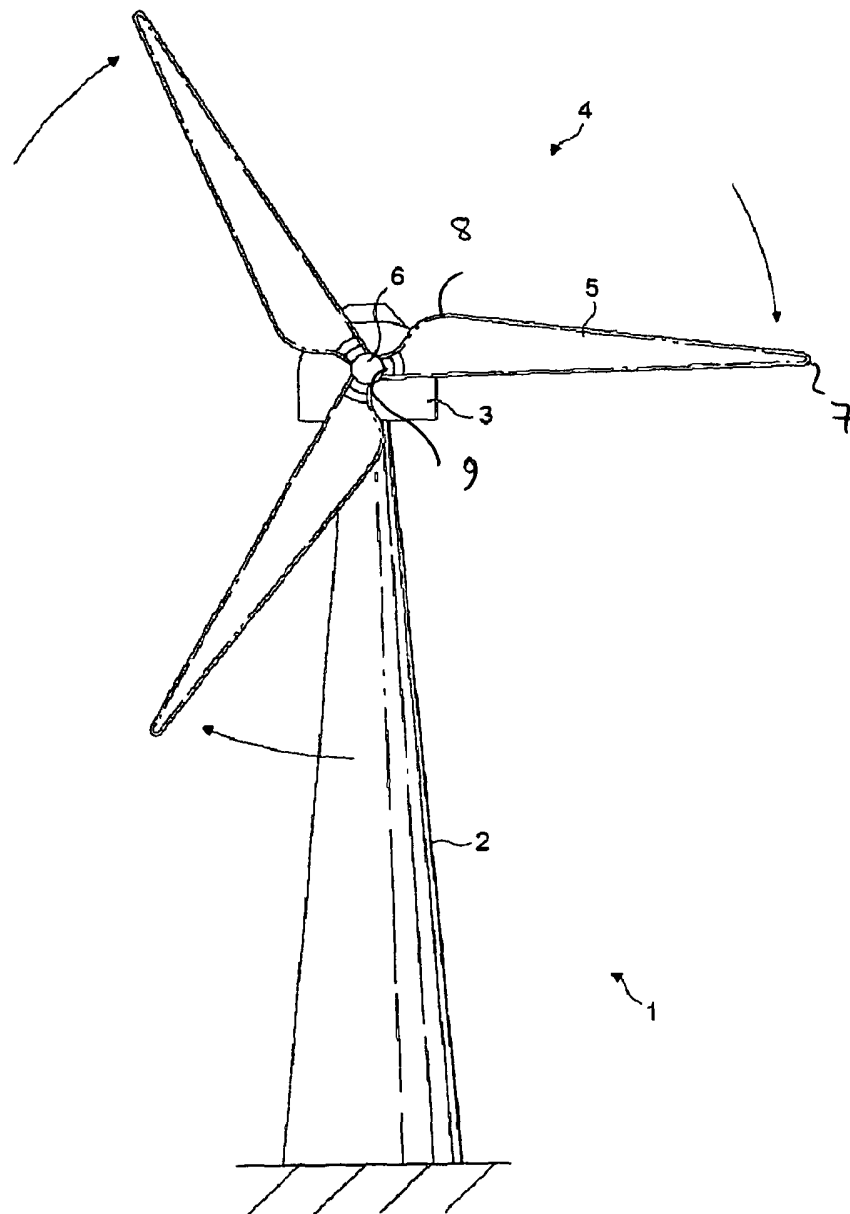


FIG. 1

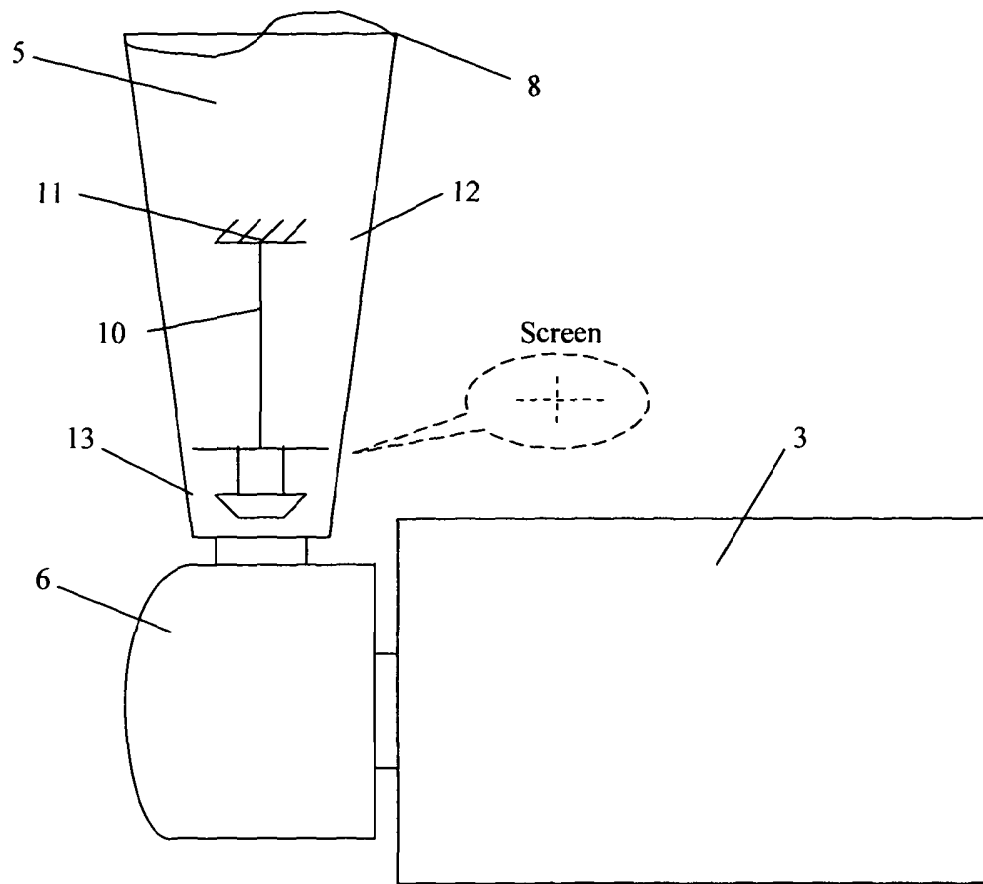


Fig.2

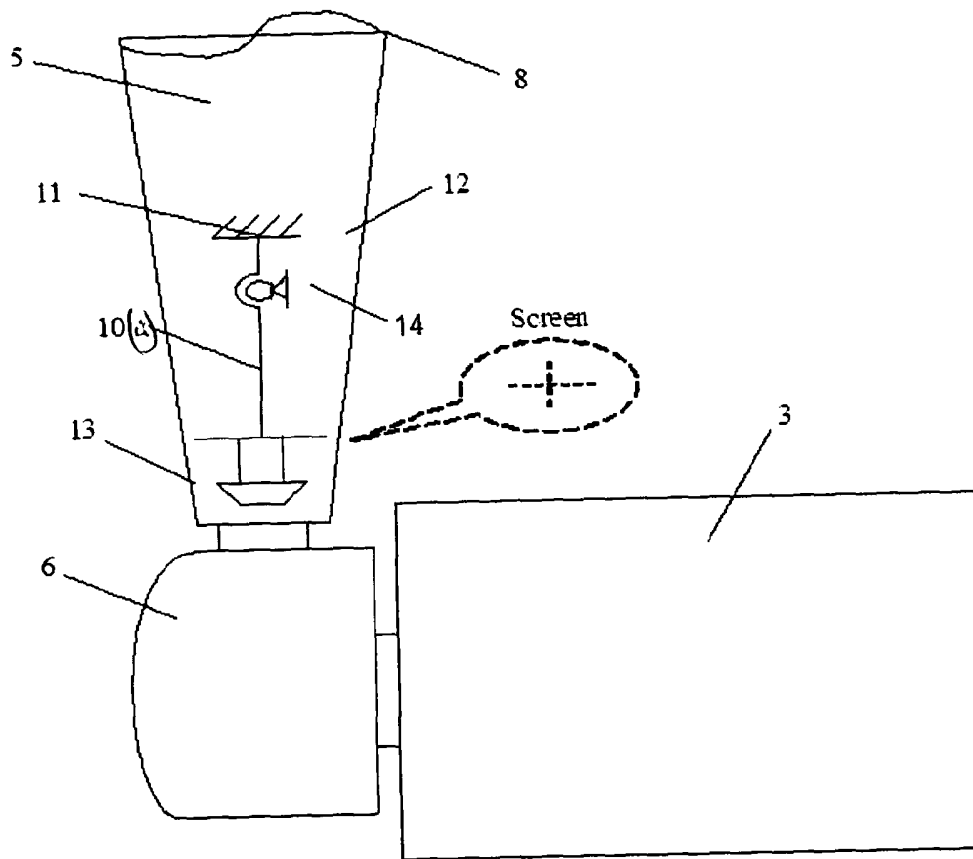


Fig.3

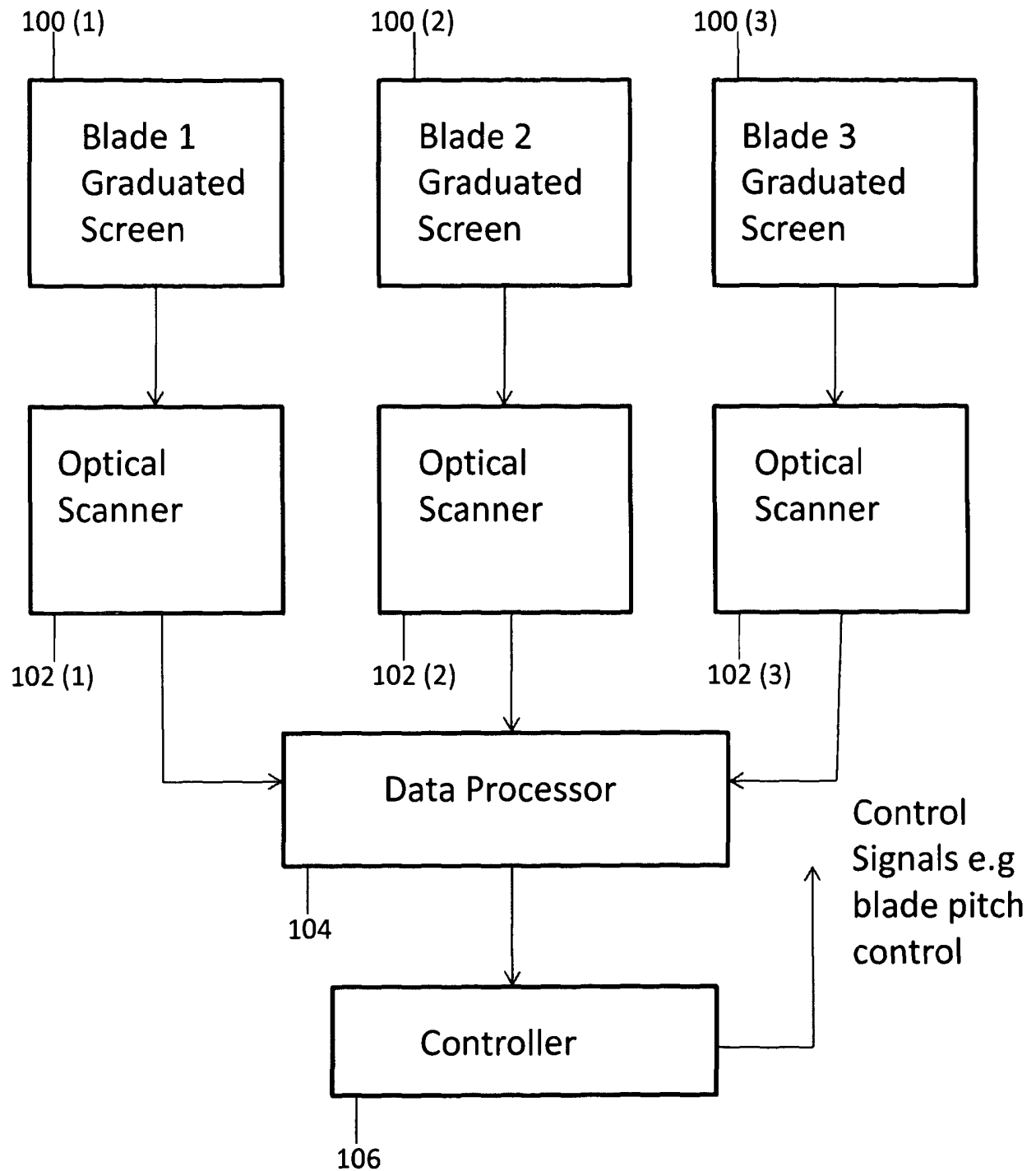


Figure 4

MONITORING OF ROTOR BLADE LOAD IN A WIND TURBINE

This invention relates to wind turbines, and more specifically to the monitoring of loads on wind turbine rotor blades.

5 It is well known to monitor parameters affecting wind turbine rotor blades during operation. The load on the blades will vary according to wind speed and it is important for the wind turbine to be able to react to changes in wind speed. This may be in order to prevent damage to the blades at higher wind speeds or to increase the energy extracted from the wind at lower wind speeds.

10 WO 03/029750 discloses a sensor construction which measures the deflection of a wind turbine blade. A rod is arranged along the deformation neutral line of a blade and is fixed at the tip end of the blade. The rod is restrained by guides along its length so that it can move along the longitudinal blade axis as the blade flexes. The end of the rod near the
15 root end of the blade is attached to a linear transducer such as a magnet which generates a signal in response to axial movement of the rod. This signal may be used to determine the amount of bending of the blade.

A problem with this known construction is that it only measures deflections of the wind turbine blade that cause axial movement of the rod. Although
20 WO 03/029750 is proposed for measuring both edgewise and flapwise deflection, in practice it is not suitable for measuring edgewise deflection or rotational deflection caused by blade twisting. A further problem is that the rigid rod used extends over most of the length of the blade. In extreme load conditions the tips of very long blades can bend by an amount
25 approaching 90°. This is a problem that is exacerbated as rotor blades get longer. Under such extreme bending the long rigid rod is very prone to damage. The present invention aims to address these problems.

According to the invention there is provided a system for monitoring loading on a wind turbine blade, comprising a rigid rod having a first end fixed to the blade at a location where the blade cross-section is an airfoil and a second free end having a marked screen and an electromagnetic sensor arranged to sense repeatedly one or more graduations or marks on the screen.

Embodiments of the invention have the advantage that they enable flapwise, edgewise and rotational bending to be monitored simultaneously.

In one preferred embodiment the electromagnetic sensor comprises a laser profiling sensor for capturing the graduated or marked screen. In an alternative embodiment the electromagnetic sensor may be a CCD imaging device. The laser profiling sensor and CCD imaging device both have the advantage of providing a cheap and effective way of monitoring movement of the graduated or marked screen with blade bending.

The CCD imaging device may be sensitive to visible light or infrared light. In the case of a visible light CCD, the system may further comprise a light source to illuminate the screen.

Preferably the rigid rod and the optical sensor are arranged within the blade. Typically wind turbine blades are hollow and the rod may be fixed at a point where the blade has an airfoil cross-section. This may be towards the root, extending over only a small part of the blade length to enable the rigid rod to be made relatively short. This is advantageous as a long rigid rod is prone to damage either through lightning strikes or through bending of the blade under severe loads. The latter is a particular problem as blades get longer and, at their tips, can bend by up to 90° out of their plane in resting conditions.

Where the sensor is a laser profiling sensor it detects light reflected by the screen. Alternatively where the sensor is a CCD imaging system it takes

pictures of the marks on the screen and compares their positions over successive images.

Preferably, data from the sensor is processed by a data processor which can determine a measure of blade bending from interframe movements of the screen graduations or mark(s). Preferably the data processor receives data from each of a plurality of sensors, one mounted with a respective fixed rod and screen in each blade of the wind turbine rotor. This enables conditions to be maintained simultaneously in each blade of the rotor to give a more complete picture of the loading the rotor is under.

Preferably a controller receives the measure of blade bending from the data processor and may generate control signals such as a blade pitch control or a rotor yaw control to reduce the loading on individual blades or the entire rotor when the measured movement exceeds a predetermined value. This may be an overall amount of movement or a value in either the X or Y directions indicating excessive edgewise and/or flapwise bending.

Preferably the optical sensors are located proximate the respective graduated screen and preferably near the blade roots. Preferably signalling between the sensors and other components is wireless to avoid the need for any wires which are generally undesirable in wind turbine blades.

The screen may be marked with graduations or lines which enable deflection in different directions to be determined. Preferably the mark comprises at least one cross.

In one embodiment of the invention, the rod rests on a pivot fixed to the blade and arranged between the fixed and free ends of the rod. The pivot may be is spherical, for example a ball hinge, whereby the rod can move in three axes with respect to the pivot. This enables flapwise, edgewise

and twist deflection to be detected. The position of the pivot on the blade may be movable so enabling a pivot to be used with different length rods.

The invention also resides in a wind turbine comprising a plurality of blades and a system for monitoring loading as described above.

- 5 Embodiments of the invention will now be described, by way of example only, and with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of a wind turbine;

Figure 2 is a schematic view of a first embodiment of the invention;

- 10 Figure 3 is a schematic view of a second embodiment of the invention; and

Figure 4 is a block diagram of the major components of a preferred embodiment of the invention.

- 15 The wind turbine of Figure 1 generally comprises a nacelle 3 mounted for rotation on a tower 2. A rotor 4 comprising a plurality of rotor blades 5 and a hub 6 is mounted to the nacelle. A generator (not shown) is housed within the nacelle and has a rotor shaft which is turned by rotation of the rotor blades to generate power. The connection between the rotor and the generator may be through a gear box or a direct coupling depending on
20 the type of turbine.

- 25 The rotor blades 5 have an airfoil cross-section over most of their length from the tip 7 to the point of maximum chord length 8. The roots 9 of the blades, where they attach to the rotor hub have a circular cross-section and this part of the blade contributes little lift. The design and shape of
blade roots varies between manufacturers and some blade roots have an airfoil cross-section.

Although not shown in Figure 1, the blades also have a degree of twist. That is the angle of attack of the leading edge of the blade that varies along the length of the blade. This is required to optimise lift as the rotational speed of the blade varies along the blade length with the tip moving very much faster than the root. This difference becomes more pronounced as blade lengths increase.

Figure 2 illustrates a first embodiment of the invention and shows how a sensor system may be mounted within one or more of the rotor blades to monitor deformation or bending of the blades when they are under load. A rigid rod or bar 10 is arranged within a blade with one end 11 fixed to the blade at a point 12 along the blade length where the blade has an airfoil cross-section. Thus, this point is somewhere between the tip 7 and the point of maximum chord length 8. The rod is preferably hollow and made of lightweight rigid material for example a PMMA such as Plexiglas (RTM) or plastics and is preferably not metallic to avoid lightning strikes. The rod is preferably relatively short compared to the blade. In one preferred embodiment the rod is fixed at a nearby airfoil cross-section and extends towards the root. The rod may be fixed to an internal surface of the blade or on an internal spar via an inter-frame depending on the location chosen to mount the rod. The free end of the rod has a two dimensional graduated or marked screens attached to it. In Figure 2 the screen is shown as being oval in shape with graduations or mark(s) as simple as a cross for example.

Alternatively any other shape could be used, for example rectangular or circular. The free end of the rod and the screen are preferably arranged towards the root of the blade. The graduations on the screen can be line divisions and, as the blade deflects, the rigid rod will move with the blade and the line divisions will also move in both an edgewise and flapwise direction. This movement can be detected and measured in screen profile

to derive an indication of movement in both the flapwise and edgewise directions.

An optical sensor 13 is mounted at the root of the blade for detection of movement of the screen. The sensor is a non-contact profiling sensor

- 5 In one embodiment the sensor comprises an optical profiling sensor such as a laser light or non-coherent light source which emits a beam of coherent or non-coherent light at the moving target screen. The sensor may be fixed. As the sensor is fixed near the blade root, it does not move relatively to the rod and screen when the blade is under load.
- 10 The screen has graduations or mark(s) which are either reflective or non-reflective and the optical non-contact sensor captures the screen profile. As the screen moves with respect to the sensor, so the reflected signal received by different pixels of the array will change with displacement and can be measured to determine displacement. For example, the X-Y
- 15 displacements of the cross on the screen represent the blade's flapwise and edgewise bending under load and changes in orientation of the cross indicate the blade's rotational bending. More than one cross may be used and other marks or graduations may be used. A data processing unit processes the measured screen profile and can compare it against
- 20 previous measured profiles and determine how far, and in what direction, individual graduations or mark(s) have moved. These values can then be used to generate a value for flapwise and edgewise bending. A controller receives these values and may generate alert and/or alarm signals when measured bending reaches predetermined levels and may generate
- 25 control signals to vary a system parameter such as blade pitch angle or rotor yaw position to reduce loading.

Instead of a laser profiling sensor, the optical sensor may be an imaging device, for example a CCD imaging device which is fixed in position near the root of the blade and takes successive images of the graduated

screen. By comparing these images values, the degree and sense of bending can be generated in the same manner as discussed above and the resultant control signals used to vary the pitch of angle of the blades or rotor yaw to reduce the load of the blades.

- 5 Other non-contact optical sensing techniques may be used for determining the movement of graduations on the two-dimensional screen and will occur to those skilled in the art.

Figure 3 shows a second embodiment of the sensing arrangement. This is the same as that of figure 2 except that a longer rigid rod or bar is used.

- 10 This longer rod 10a is fixed in the same manner as the shorter rod of figure 2 above and is also mounted at a position where the blade has an airfoil cross section although this point will typically be nearer the blade tip than in the figure 2 embodiment. The fixed end of the rod 10a is supported by a ball hinge 14 about which the rod can pivot. This distance
15 between the fixed end of the rod and the hinge is less than the distance between the hinge and the free end at which the graduate or marked screen is mounted. Other pivots could be used but a ball pivot such as a pivot hinge is preferred as the rod can move over the ball hinge in three axes to reflect flapwise, edgewise and twist movement of the blade.

- 20 The pivot, here ball hinge 14, may be mounted on a movable part of an axial slide that is fixed on the internal blade surface or on a spar that provides strengthening for the blade. The ball hinge may then be used to accommodate different lengths of rods which require the ball hinge to be mounted at a different distance from the blade root.

- 25 Figure 4 is a schematic representation of a control system based on the sensing arrangement described above. Each blade has a rigid rod and screen and an optical sensor which provides signals to a common data processor and controller. The example shown is for a 3-bladed rotor but the system may be used with rotors having other number of blades. The

graduated screens are shown at 100 and the optical sensors at 102. At regular intervals, for example every few seconds, or on conditional triggering, for example when each blade is in an upright position, signals from the optical sensors are sent to a data processor 104 either through a
5 wired connection or wirelessly and, following analysis of the data, an output is sent to a controller 106 which may be a PC or other suitable device. The controller generates control signals in accordance with its programming, for example to raise alerts or vary a parameter such as blade pitch or yaw angle. The PC may form part of, or communicate with,
10 an existing wind turbine controller to execute control functions.

The data processor 104 and controller 106 are preferably arranged with other wind turbine control components, for example, in the hub or in the nacelle.

Embodiments of the invention have many advantages. As the graduated
15 screen can detect movement in both the X and Y directions (or flapwise and edgewise directions), the system can be used to monitor flapwise and edgewise bending deformation of blades as well as blade twist or rotational deformation which includes both flapwise and edgewise components. The measurements made by the system are of both flapwise
20 and edgewise deformation simultaneously. In contrast, prior art systems such as those described and discussed above can only monitor deformation in a single direction at any one time.

The measurement is based on line width graduations or mark(s) on a screen with or without light reflection on these lines as long as there is
25 clear optical contrast against the screen background. Additional optical illumination is not necessary to sense movement although it is used in preferred embodiments. Optical illumination may be used, either using a light source or a laser but is not necessary.

In contrast to prior art systems, the rigid rod may be placed near or towards the root of the blade, at a point where the blade has an airfoil cross-section, for example at or in the region of the point of maximum chord length or at another point where bending can easily be detected.

- 5 This minimises the length of rigid rod required. The laser profiling sensor or other optical sensor may be placed close to the screen at the free end of the rigid rod towards the root and the laser profiling sensor may be placed some distance away from the actual root end to reduce further the length of rigid rod required.
- 10 Thus, with a relatively short rod located towards the blade root, the rod is not subjected to a large bending displacement. This is highly advantageous with long rotor blades where bending towards the tip may approach 90° in very high winds. The risk of damage to the rod in such conditions is minimised and so is the risk of damage due to lightning
- 15 strikes.

The use of a non-contact optical system is also advantageous as it is generally undesirable to introduce wiring into the rotor blades. Wiring is problematic in a rotating system and is prone to damage from lightning strikes and can degrade in hostile environmental conditions such as are

20 prevalent as an off-shore site.

Various modifications to the embodiments described are possible and will occur to those skilled in the art. For example the point at which an end of the rod is fixed to the inside of the blade may vary and the type of optical sensor used may vary. The scope of the invention is defined solely by the

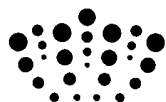
25 following claims.

CLAIMS

1. A system for monitoring loading on a wind turbine blade, comprising a rigid rod having a first end fixed to the blade at a location where the blade cross-section is an airfoil and a second free end having a marked screen and an electromagnetic sensor arranged to sense repeatedly one or more graduations or marks on the screen.
2. A system according to claim 1, wherein the sensor comprises a non-contact profiling sensor for capturing the graduated or marked screen.
3. A system according to claim 2, wherein the sensor is an electromagnetic profiling sensor.
4. A system according to claim 1, 2, or 3, wherein the rigid rod and optical sensor are arranged within the blade.
5. A system according to any of claims 1 to 4 wherein the sensor comprises a laser profiling sensor.
6. A system according to claim 5 wherein the sensor is a CCD imaging device.
7. A system according to any preceding claim, comprising a data processor for receiving successive data from the optical sensor and for processing the data to determine movement of the graduations on the screen and to determine from the movement a measure of blade bending.
8. A system according to claim 7, wherein the measure of blade bending includes bending in a flapwise and/or an edgewise direction, and/or a twist direction.
9. A system according to any of claims 1 to 8, wherein the graduations or marks on the screen comprise at least one cross.

10. A system according to claim 7, 8 or 9, wherein the data processor receives data inputs from optical sensors mounted in each blade of a wind turbine rotor.
11. A system according to any of claims 7 to 10, comprising a controller
5 for receiving the measure of blade bending from the data processor and for generating control signals in response to the received measures and pre-stored parameters.
12. A system according to claim 11, wherein the control signals include blade pitch control signals or yaw angle signals whereby the loading of the
10 blade can be varied when the measure of bending exceeds a threshold.
13. A system according to any preceding claim, wherein the fixed end of the rod is located in a region of the blade that has an airfoil cross-section.
14. A system according any preceding claim, wherein the optical sensor
15 is located near the blade root and proximate the graduated or marked screen.
15. A system according to any preceding claim, wherein the rod extends axially along the blade.
16. A system according to any preceding claim, wherein the rod rests
20 on a pivot fixed to the blade and arranged between the fixed and free ends of the rod.
17. A system according to claim 16, wherein the pivot is spherical, whereby the rod can move in three axes with respect to the pivot.
18. A system according to claim 16 or 17 wherein the position of the
25 pivot on the blade is movable.

19. A wind turbine comprising a rotor having a plurality of blades, and a load monitoring system according to any preceding claim.
20. A wind turbine according to claim 19 dependent on claim 10, wherein the data processor is located in the wind turbine nacelle.
- 5 21. A wind turbine according to claim 19 dependent on claim 11, wherein the data processor is located in the wind turbine nacelle.



Application No: GB0821808.3

Examiner: Mr Christopher Smith

Claims searched: 1 - 21

Date of search: 10 March 2009

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 - 3, 5 - 10, 13 - 15 & 19	US2006/0000269 A1 (LEMIEUX et al) See whole document, especially figures 3 and 5 and related text
A	-	US 2004/0174542 A1 (HANDMAN et al)
A	-	DE 20110825 U1 (GUENTHER)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X:

Worldwide search of patent documents classified in the following areas of the IPC
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The following online and other databases have been used in the preparation of this search report
ONLINE: WPI, EPODOC, TXTE

International Classification:

Subclass	Subgroup	Valid From
G01L	0001/04	01/01/2006
G01B	0011/16	01/01/2006
G01M	0011/08	01/01/2006