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(71) Applicant (*for all designated States except US*): **SE BLADES TECHNOLOGY B.V.** [NL/NL]; Jan Tinbergenstraat 290, NL-7554 ST Hengelo (NL).

(72) Inventors; and

(75) Inventors/Applicants (*for US only*): **SLOTH, Erik, Billeskov** [DK/DK]; Vorregårdsparken 85, DK-8410 Rønde (DK). **JENSEN, Rasmus** [DK/DK]; Lucerne Vangen 16, DK-9620 Aalestrup (DK). **GONZÁLEZ, Alejandro, Gómez** [CO/DK]; Bulowsgade 9,1, DK-8000 Århus C (DK). **RECK, Mads** [DK/DK]; Vestergade 8, 1. tv., DK-8900 Randers (DK). **NIELSEN, Thomas, Bjertrup** [DK/DK]; Vorup Kirkevej 31, DK-8940 Randers SV (DK). **ANDERSEN, Peter, Bjørn** [DK/DK]; Kirkeleddet 426, DK-3480 Fredensborg (DK).

(74) Agent: **PATRADE A/S**; Fredens Torv 3A, DK-8000 Aarhus C (DK).

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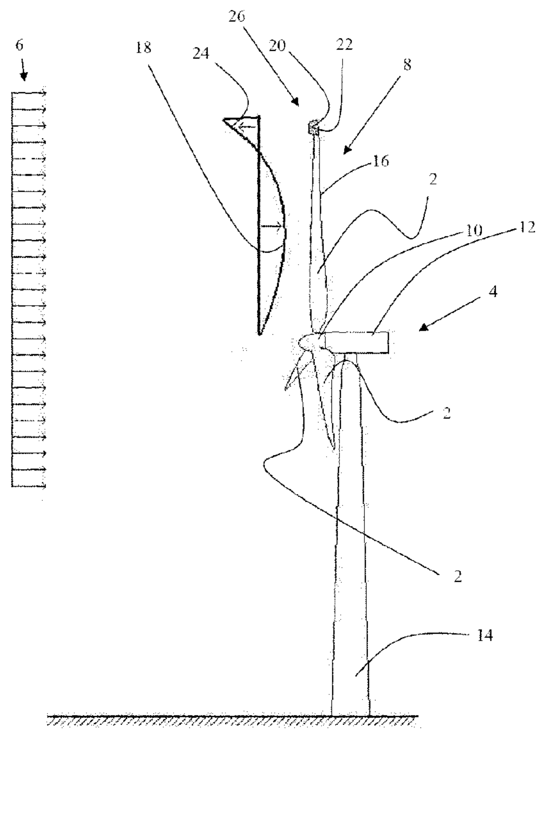
(54) Title: A BLADE FOR A WIND TURBINE AND A PRODUCTION METHOD THEREFORE

Fig. 1



(57) Abstract: A blade (2) for a rotor (8) of a wind turbine (4), the blade (2) having a blade airfoil section (16) adapted for applying a lift force to the blade (2) and an inverted lift zone section (20) adapted for providing an inverted thrust component (24) for reducing the total thrust during wind load. Also a production method is described.

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A BLADE FOR A WIND TURBINE AND A PRODUCTION METHOD THEREFORE

Field of the Invention

The present invention relates to a blade for a rotor of a wind turbine, the blade having a blade airfoil section adapted for applying lift force to the blade, wherein the lift force comprise a torque component acting in the rotor plane of the rotor for generating torque and a thrust component acting perpendicularly to the rotor plane for generating thrust.

Background of the Invention

Many types of wind turbines exist for harvesting energy from the wind; an example of which is known as a front runner. A front runner comprises a tower, a nacelle arranged on top of the tower, a horizontal rotor shaft supported by the nacelle, a rotor comprising at least one blade; each blade being attached to a hub at the centre of the rotor, and wherein the hub is attached to the rotor shaft for driving an electrical generator in the nacelle.

As the material and manufacturing technologies have evolved, the wind turbines have increased in size. The hub height achievable at present is in excess of 100 meters and the rotor diameter is also close to or in excess of 100 metres. The size of modern wind turbines imposes numerous challenges for the developers of the components for the wind turbines; for example, it is a challenge to satisfy the structural requirements to the blade structure and hub caused by increased loading, as the blade increases in length. To satisfy increased loading, the blade and hub must either be manufactured in high strength materials, which are expensive, or the dimensions must be increased to increase the moments of inertia and to limit the local stresses in the material. The disadvantage of the latter option is that, especially, transportation becomes more difficult with increased dimensions of the hub and blade. Furthermore, the weight of the hub and blade may increase and, thereby, influence the construction of the nacelle and tower.

During rotation of the rotor, the blade will be subject to changing conditions due to a number of factors, including the vertical wind speed profile (usually referred to as wind shear), inflow turbulence, and tower shadow effect. The vertical wind speed profile causes the wind speed closer to ground to be lower than the wind speed farther from the ground. The turbine blade will be subject to a higher wind speed and, thus, higher loading during the upper half the turn as compared to the lower half. Turbulence may affect the rotor blade throughout the rotation exciting a broad range of frequencies on the whole structure. The tower causes disturbances of the air in its vicinity both upstream as well as downstream. This is called the tower shadow effect. The blade is subject to the tower shadow effect around its 6 o'clock position (i.e. the blade pointing downwards when it is in front of the tower).

The blade of a wind turbine is shaped and configured for providing lift force. The lift force comprises a torque component acting in the rotor plane of the rotor for generating torque and a thrust component acting perpendicular to the rotor plane for generating thrust. The torque component is acting in the rotor plane, such that the rotor is turning about the centre axis upon application of the torque component. Upon seizure of the torque, the rotor blade will stop its rotation and come to rest due to friction, air resistance, and braking systems. The torque component enables power production. The thrust component is acting perpendicularly to the rotor plane, such that an axial force is applied to the hub of the wind turbine. The magnitude of the torque and thrust components are directly influenced by the wind speed. Most wind turbines will however employ means for limiting the torque component, such that the rotational speed of the rotor will not increase beyond a certain threshold. Examples of such means are devices for adjusting the pitch of the blade. The pitch is varied in order to achieve optimum performance until the rated torque component of the rotor is reached, after which the pitch is decreased again to maintain a constant torque and power output. The blade loading usually reaches a maximum at the rated torque before the pitch is decreased.

It is important that the blade is relatively stiff. Otherwise, the blade may collide with the tower. It is, therefore, not an option to accept a less stiff blade, as such a blade may flex more when the wind speed increases and, thereby, increase the risk of collision. The deflections of the blade must be kept within acceptable limits. The deflection of the blade varies during each turn of the rotor and due to changes in wind speed for example due to gust and will reduce the fatigue life of the blade.

International patent application WO2010/046760 discloses a wind turbine in which the blade not only can rotate at the hub in order to adjust the pitch but where the blade is parted up into an inner blade section and an outer blade section with a rotation mechanism in between, such that the outer blade section can be rotated about its longitudinal axis relatively to the inner blade section. Optionally, the outer blade section can be retracted telescopically into the inner part section in order to adjust the size of the rotor. These means can be used to control the strain on the rotor by winds, especially strong winds.

International patent application WO 2008/052677 discloses a wind rotor blade and a turbine comprising such blade. The blade has a flexible central spar that extends essentially from the root of the blade to the tip of the blade. The central spar is capable of pitch flexing around a central axis of the spar. A leading edge fairing and a trailing edge fairing are attached to the spar. The blade responses to increases of the load applied by flexing the leading edge fairing and the trailing edge fairing to continuously change the blade pitch from the root to the tip. The blade pitch is able to change from a positive to a negative lift along the blade from the root to the tip, to counteract some of the positive lift to reduce thrust and torque of the blade. The pitch flex is caused by the load of the wind on the blade, although, tensioning tows are employed in the corners of the central spar in order to provide an adjustment of the warp of the spar. The disadvantage of a blade according to WO 2008/052677 is that the blade is subject to load that varies substantially during each turn due to a continuous flexing of the blade caused by the varying load during a turn. The blade according to WO 2008/052677 therefore has a reduced fatigue life.

Object of the Invention

The object of the present invention is to define an improved blade for a wind turbine, especially to reduce the risk of colliding with the tower and improving the fatigue life.

Description of the Invention

According to the present invention, this is achieved by a blade for a rotor of a wind turbine, the blade having at least one blade airfoil section and at least one inverted lift zone section. Whereas the at least one blade airfoil section of the blade is shaped and configured for providing lift force, the at least one inverted lift zone section is shaped and configured for counteracting the thrust that results from the lift by the at least one blade airfoil section.

In more detail, the blade has at least one blade airfoil section adapted for applying a lift force to the blade, wherein the lift force comprise a torque component acting in the rotor plane of the rotor for generating torque and a thrust component acting perpendicularly to the rotor plane for generating thrust. The blade also has at least one inverted lift zone section comprising inverted lift means adapted for applying an inverted lift force to the inverted lift zone section during rotation of the rotor, and wherein the inverted lift force comprises an inverted thrust component directed opposite the thrust component from the blade airfoil section.

It is herewith achieved that the thrust component of each blade and, hence, the resulting thrust component of the rotor acting on the hub of the wind turbine is lower than without the invention. The resulting thrust will be lowered by the amount applied by the inverted lift means in the inverted lift zone section. This reduces the deflections of the blade. As a result, the length of the blade may be increased without requiring a corresponding increase in stiffness and without increasing the risk of the blade colliding with the tower due to deflections of the blade. Furthermore, the deflections of the blade are reduced during operation because the inverted lift force is applied without the need of continuously flexing the blade, thus reducing the fatigue loading and therefore increasing the fatigue life of the blade.

This is in contrast to the aforementioned WO 2008/052677 disclosing a blade with a central spar that is forcing the blade to pitch flex about its central axis in dependence of the wind load. Whereas the blade in WO 2008/052677 has a varying length of that part of the blade that provides inverted lift force, the invention is characterised in well defined sections of the blade, where at least one section is a blade airfoil section that provides lift and at least one sections is an inverted lift zone section that counteracts thrust.

As already mentioned, the loading of the blade varies throughout each turn, causing the deflection of the blade in an axial direction to vary within a maximum and minimum axial deflection. The blade is subject to these loading conditions even at low wind speeds. By applying the well defined inverted lift zone section or sections that is/are not dependent on a the load-induced pitch flex of the blade as in the aforementioned WO 2008/052677, the deflections during each turn are dampened also at low wind speed, such the distance between the maximum and minimum deflection is smaller. More important, even, the invention, thereby, improves the fatigue life by reducing deflections throughout the entire operational regime of the wind turbine.

Simulations have shown that the deflections of the blade during operation of the wind turbine are lowered significantly as compared to reference blade without an inverted lift zone section. This effect is achieved throughout the entire operational regime of the blade. The inverted lift zone section has a dampening effect on the blade with regards to deflections. As the resulting thrust component of the rotor is the main contributor to the axial force acting on the hub of the wind turbine, the invention has an advantageous effect on the useful life of the wind turbine, not only with respect to the blade but also with respect to the hub, as the deflections are lowered and thereby causing less fatigue.

The blade has an elongate shape with a root end and a tip at opposite ends of the blade. The root is attached to the hub of the wind turbine. The blade and hub define the rotor of the wind turbine. The rotor comprises at least one blade and may have two, three, four, or more blades, but will typically have three blades. The rotor is rotational about its centre axis. The area swept by said at least one blade when the rotor is rotating is called the rotor plane.

The purpose of the blade airfoil section is to convert the wind force acting on the blade into a lift force applied to the blade. The lift force comprises two force components in relation to the rotor plane, where one force component (the torque component) is acting in the rotor plane, and the other force component (the thrust component) is acting perpendicularly to the rotor plane. The skilled person will be able to devise an appropriate blade airfoil section for generating lift. The blade may have a transitional zone adjacent the root to gradually transfer from a shape corresponding to the hub to a shape corresponding to the blade airfoil section. This transitional zone may or may not provide lift.

In the current application, the term blade airfoil section is used as a matter of simplification. The blade may have a plurality of different blade airfoil sections along its length for adapting to the different speed of the various blade airfoil sections due to their distance from the centre of rotation of the rotor. However, the blade airfoil sections of the blade must provide a net lift, regardless of how the airfoil is laid out in general along the length of the blade.

The blade comprises an inverted lift zone section with inverted lift means. The inverted lift means apply an inverted lift force to the inverted lift zone section. The inverted lift force has an inverted torque component which is directed opposite the torque component from the blade airfoil section. The resulting torque component of the blade, composed of the combined torque component and inverted torque component, is lower than the torque component of the blade would be without the inverted lift zone section. The rotor torque is, thereby, reduced by the application of the inverted lift force because the inverted torque component acts against the torque component of the blade compared to a rotor driven by the torque component alone.

Power production of a rotor having blades according to the invention will be slightly less as compared to a rotor of the same diameter because the inverted torque component developed by the at least one inverted lift zone section will deduct from the torque component of the blade and thereby lower the net torque of the rotor. The blade shall however be designed such that the net torque is positive in order to turn the rotor. The benefit from lowering the axial and bending loads on the hub and blade by applying the invention will outweigh the lower power production. Alternatively, the lower efficiency may be balanced by enlarging the blade, which is possible due to the reduced thrust. The invention offers a significant advantage on the blade design as the invention allows for either longer blades with the same axial and bending load on the hub or a lighter blade and hub construction for the same length of the blade.

When the wind speed is insufficient for turning the rotor, the wind turbine is not operating. The blade does not produce enough lift, and the inverted lift zone section does not produce inverted lift. When the wind speed increases, the blade airfoil section begins to generate sufficient lift and, thereby, generates the torque and thrust components. The inverted lift zone section begins to generate inverted lift and, thereby, the inverted torque and inverted thrust components are generated. The torque component is larger than the inverted torque component, why the rotor turns. When the wind speed increases, the thrust component increases as well; because the inverted thrust component acts against the thrust component, the blade will be subject to a smaller bending load as compared to a conventional blade. This is so because the inverted lift zone section works to alleviate some of the loading caused by the lift.

The inverted lift zone section provides an advantageous effect when reaching the rated rotational speed of the rotor, as this is where the bending loads are highest and, thus, where the highest benefit is reached with respect to load alleviation.

The inverted lift zone section has a significant influence on reducing the effect of gust and other sudden changes in wind speed. A gust will momentarily increase the lift and thereby the torque and thrust components. However, the torque and thrust components will be counteracted by the inverted torque and inverted thrust components of the inverted lift zone section, such that the loading on the blade due to gust or sudden change in wind speed is reduced compared to a blade not having the invention. If the magnitude of the gust or sudden change in wind speed is high, the loading will be high due to the increase of the torque and thrust components. On the other hand, the inverted torque and inverted thrust components will increase correspondingly. Thus, the invention has a dampening influence on the effects of gust and sudden changes in wind speed. This is an advantage for wind turbines having the rotor upwind as well as downwind of the tower.

The at least one inverted lift zone section may be located largely at any position along the blade. There may be a further transitional zone between the blade and said at least one inverted lift zone section to gradually transfer from a shape corresponding to the blade airfoil section to a shape corresponding to the inverted lift zone section. Alternatively the transition between the blade airfoil section and the inverted lift zone section may be abrupt.

According to a further embodiment, the inverted lift means comprises a twist of the blade in the inverted lift zone section as compared to the blade airfoil section, for example a twist of at least 30 degrees or at least 45 degrees or at least 60 degrees or between 80 and 100 degrees. Thereby, the inverted lift zone section may be identical to the blade airfoil section with respect to shape but having a different orientation. The blade twist is set such that the airfoil of the inverted lift zone section provides an inverted lift in relation to the blade airfoil section.

The term twist is used here as an angular offset about the longitudinal axis of the blade relatively to the orientation of the remaining part of the blade.

According to a further embodiment, the inverted lift means comprise an inverted lift zone section in the form of an airfoil but having inverted suction and pressure sides. The inverted lift zone section may be provided in a particularly simple way by providing it with a shape of an airfoil that is inverted as compared to the blade airfoil section.

According to a further embodiment, the blade comprises a blade fence at each transition between the blade airfoil section and the at least one inverted lift zone section, for preventing flow in the longitudinal direction of the blade between the blade airfoil section and the inverted lift zone section. Thereby, the losses caused by flow in the longitudinal direction of the blade between the at least one inverted lift zone section and the remainder of the blade are reduced. The fence may be provided as a plate that is oriented perpendicular to the longitudinal direction of the blade. The plate extends above the surface of the blade. Alternatively, the fence may be provided as an aerodynamic fence by intentionally disturbing the flow in the transition between the two adjacent sections. The means for providing the aerodynamic fence may be vortex generators, turbulators, or turbulators, or forced air being blown across the blade.

According to a further embodiment, the blade according to the invention is peculiar in that at least one inverted lift zone section is located at the tip. Thereby, a force component is applied to the tip of the blade in a direction opposite to the direction of the forces from the wind. In the case of a wind turbine having the rotor located upwind in relation to the tower, the tip is pulled forward and away from the tower by the inverted thrust component. The bending moment acting on the blade and the axial forces acting on the hub are hereby reduced. In the case of a wind turbine having the rotor located downwind in relation to the tower, the tip deflections due to tower wake effects is reduced. The inverted lift zone section may be positioned near the tip; or it may be provided at the tip and extending a fixed distance from the tip, for example extending to a fixed distance from the tip that is less than 25%, 15%, or 10% of the blade length. For example, this distance is independent or largely independent of the wind load when in operation on the wind turbine, which is in contrast to the earlier mentioned WO 2008/052677. Surprisingly, simulations have shown that the deflections of the tip during operation of the wind turbine are lowered significantly compared to a reference blade without an inverted lift zone section. The embodiment has a dampening effect on the tip with regards to deflections. This has an advantageous effect on the useful life of the wind turbine and in particular the blade and the hub as the deflections are lowered and thereby causing less fatigue.

According to a further embodiment, the blade according to the invention is peculiar in that said at least one inverted lift zone section is located between the tip and the root at a distance from the tip. For example, the distance from the tip is between 25% and 75% of the blade length. Optionally, the inverted lift zone section is located between to two blade airfoil sections that are adapted for applying a lift force to the blade when in operation on the wind turbine. For example, the two blade airfoil sections are adjacent to each side of the inverted lift zone section. Advantageously, the inverted lift zone section has a length of less than 25%, 15%, or 10% of the blade length. As the inverted lift zone section act as a support for the blade against the force applied by the thrust component, it is possible to design the load curve of the blade according to structural requirements of the blade, by applying one or more inverted lift zone sections inboard of of the tip. This allows production of long blades without having to rely solely on the structural stiffness of the blade to withstand forces applied by the thrust component. The inverted lift zone sections will assist the structure in the blade against large deformation by providing an inverted thrust component, thus providing load alleviation for the blade and the hub.

In an advantageous embodiment, the blade comprises a first inverted lift zone section, for example at the tip of the blade, and at least one second inverted lift zone section between the root and the tip of the blade at a fixed distance from the tip. Between the first and the second inverted lift zone section, there is provided a blade airfoil section adapted for applying a lift force to the blade. In case that the first inverted lift zone section is provided at the tip of the blade and the second inverted lift zone section is provided between the root and the tip at a distance from the tip, for example around the middle of the blade, the tip of the blade is supported as well as a section between the tip and the root. The deflections are reduced at the tip of the blade as well as further inboard of the tip.

In further embodiments, the blade has a blade airfoil section with a first length along the longitudinal axis of the blade and the blade has an inverted lift zone section with a second length along the longitudinal axis of the blade, wherein the first length is larger than the second length, and advantageously at least two times larger than the second length. In case that the blade has a plurality of separate blade airfoil sections, the following applies. In this case, each blade airfoil section has a first length along the longitude of the blade, and the first lengths of the plurality of separate airfoil sections sums up to a first sum of lengths; this would have to be larger than the second length, if there is only one inverted lift zone section. In case that the blade has a plurality of inverted lift zone sections, each inverted lift zone section having a second length along the longitude of the blade, the second lengths of the plurality of inverted lift zone sections sums up to a second sum of lengths; this would have to be larger than the first length, if there is only one airfoil section, or should be larger than the first sum of lengths if there are multiple airfoil sections. In the latter case, the first sum of lengths is larger, and advantageously at least two times larger, than the second sum of lengths. In other words, the total length of the parts that have lift should be substantially larger than the total length of the total length of the parts that have inverted lift, advantageously more than twice as large.

In some embodiments, the dimension of each inverted lift zone section, or even the total dimensions of all inverted lift zone sections, along the longitudinal axis of the blade is shorter than 25% of the blade length, for example less than 15% or even less than 10% of the blade length. Thus, in contrast to the system of WO2008/052677, where a central spar pitch flexes the blade substantially along the entire length of the blade, the inverted lift according to the invention is achieved by a local zone or several local zones having dimensions substantially less than the length of the blade.

The inverted lift sections can be provided in various ways. A first way is to mould a blade with various sections of blade shapes; a first section is shaped or a first group of sections are shaped and configured such that it/they provide lift to the rotor when in operation; a second section is shaped or a second group of sections are shaped and configured such that it/they provide inverted lift when in operation. In the first way, the inverted lift zone sections are static in the sense that they are shaped once for all during production and do not change shape later, apart from some minor distortion due to the customary bending and pitch flexing of a few degrees (typically less than 5 degrees) of the blade under wind load. In contrast to the first way, there is also the possibility of providing the inverted lift sections by a second way, where inverted lift zone sections are configured for changing shape during operation, for example by implementing mechanics that actively by actuators or passively due to wind load or motion changes the shape of the inverted lift zone section. The principle is in some aspects similar to the system as disclosed in WO 2008/052677, where, however, the entire blade pitch flexes and a deformation of the blade is not restricted to certain inverted lift zone sections. A third way is to produce a blade with various inverted lift zone sections that are pitch-adjusted relatively to the remaining part of the blade in order to provide inverted lift. The principle is in some aspects similar to the system disclosed in WO2010/046760, where however, the inverted lift zone section or the plurality of inverted lift zone sections are shaped and configured for inverted lift and a counteracting thrust component.

In relation to the first way of providing the inverted lift zone sections, the following applies. In this case, the blade airfoil section (or the plurality of blade airfoil sections) and the inverted lift zone section (or the plurality of inverted lift zone sections) are mutually distinct longitudinal sections of the blade when the blade is in a pre-mounted state, the pre-mounted state is a state before mount of the blade to the wind turbine. Thus, the at least one blade airfoil section and the at least one inverted lift zone section are inherent in the shape of the blade. The blade can be shaped, for example in a mould arrangement, and configured with the inherent feature of the inverted lift zone section providing inverted lift. There may occur some minor distortion of the inverted lift zone sections due to the customary bending of the blade under wind load, however, this does not change the overall function of the inverted lift zone section. For example, the blade may be shaped with a stability and rigidity such that the wind-induced pitch flexing of the blade is less than 10 degrees or even less than 7 degrees or less than 5 degrees during operation. It should be mentioned here that wind turbines may have pitch control systems for controlling the angle of attack of the blades. In some related embodiments for a wind turbine having pitch control of the blades, the relation between the angle of attack on the blade airfoil section and the angle of attack on the inverted lift zone section may be such that the inverted lift zone section provides an inverted lift during certain operational regimes of the wind turbine and lift during other operational regimes of the wind turbine. This is especially important with respect to providing the inverted lift at strong winds. Alternatively, the inverted lift zone sections can be shaped and configured to provide inverted lift independently of the pitch orientation of the blade on the rotor. Although, the invention focuses on the first way, the other two ways are also options for providing improved blades for wind turbines or even water turbines.

In relation to the second way of providing inverted lift zone sections, the following applies. According to a further embodiment, the inverted lift means comprise a deployable lift regulating device. Optionally, such deployable structure is a local, flexible deformation of the outer skin of the blade. Alternatively, the blade may comprise parts that are moved in order to change the shape and/or size of the blade in the inverted lift zone section. The deployable lift regulating device may comprise an extendable and retractable device that is actuated by an actuator. Alternatively, the device may be actuated

tuated automatically, for example by a spring mechanism that deploys the inverted lift zone section or parts thereof when the rotational speed of the rotor exceeds a certain threshold. For example the inverted lift zone section may provide lift during start-up and low wind speed operation and may turning into inverted lift function as the wind speed increases to nominal operation. As the wind speed increases above nominal operation, the magnitude of the inverted lift contribution by the inverted lift zone section will further increase and thereby reduce the effect of the higher wind speed.

In relation to the third way of providing inverted lift zone sections, the following applies. According to a further embodiment, the blade according to the invention is peculiar in that, the deployable lift regulating device comprises a symmetric airfoil section and an actuation means for adjusting the angle of attack of the symmetric airfoil section for selectively applying an inverted lift during operation of the wind turbine. For example, the actuation means will adjust the pitch of the symmetric airfoil such that the inverted lift zone section produces an inverted lift during operation in the low wind speed regimes, rated and high wind speed, thus alleviating the load on the blade. Alternatively, the actuation means may adjust the pitch of the symmetric airfoil section such that the inverted lift zone section produces lift during start-up of the wind turbine and during low wind speed operation. The use of a symmetric airfoil is beneficial because the lift characteristic is identical for positive as well as negative angles of attack. In a further alternative embodiment, the deployable lift regulating device comprises a non-symmetrical airfoil section and an actuation means for adjusting the angle of attack of the non-symmetric airfoil section for selectively applying an inverted lift during operation of the wind turbine. The lift characteristics is non identical for positive and negative angles of attack. This may be required for the purpose of performance adaptation.

It is herewith achieved that the inverted lift zone section may provide an inverted lift only during certain operational regimes of the wind turbine and lift during other operational regimes of the wind turbine. Thus, the inverted lift zone section may add to the net lift of the blade during low wind speed operation. During low speed operation the loading on the blade is comparatively smaller than during high speed operation. Therefore the need for load alleviation is not as pronounced during low speed operation.

Preferably, the blade has a fixed length, which is in contrast to the above mentioned WO2010/046760, where blades can be telescopically changed in length.

Optionally, the blade comprises a central spar with a central spar configured for providing torsional stiffness for counteracting a pitch flexing of the blade. For example, the spar has a polygonal cross section having edges, wherein the edges are rigid for counteracting a pitch flexing of the blade.

Optionally, the blade is free of a rotation apparatus between sections of the blade, the rotation apparatus being configured for rotating one section of a blade relatively to another section of the blade about a longitudinal axis of the blade. An example of such a pitch mechanism is disclosed in WO2010/046760.

Optionally, the blade is free from a blade pitch flexing mechanism, wherein the blade pitch flexing mechanism is configured for continuously changing the blade pitch from the root end to the tip as a result of increased wind load. An example of such a pitch mechanism is disclosed in WO2008/052677.

Optionally, the blade airfoil section has a stationary location on the blade and is configured for only providing lift force to the blade. Although the lift force may be dependent on the wind load, the aspect of providing lift and not inverted lift is independent or substantially independent of the wind load. The term substantially has to be understood such that the characteristic of the lift may change under extreme wind load outside the nominal operation regime.

The invention also comprises a method of manufacturing a blade for a rotor of a wind turbine. The method comprises manufacturing a blade with at least two differently shaped sections along the blade comprising at least one airfoil section and at least one inverted lift zone section configured for mutually opposite thrust components when in operation as part of a wind turbine. Thus, the method takes into account that the sections for providing the opposite thrust components are shaped from the onset and are therefore, inherent sections of the blade.

Thus, the blade airfoil section and the inverted lift zone section are mutually distinct longitudinal sections of the blade when the blade is in a pre-mounted state, the pre-mounted state is a state before mount of the blade to the wind turbine. Also, the blade comprises at least one inverted lift zone section when the blade is free from applied torsion forces along the blade.

Especially, the inverted lift zone sections may be of a kind that are not changing shape during operation for providing inverted lift and are not rotating relatively to a remaining part of the blade. These two aspects were above described as the second and third way of providing inverted lift zone sections.

In a further embodiment, the method comprises providing a shell mould with a first section with first shaping means and a second section with second shaping means, and shaping an airfoil section with the first shaping means and an inverted lift zone section with the second shaping means.

The term “a blade airfoil section” does not exclude a plurality of blade airfoil sections and should be read as “at least one airfoil section”. The term “an inverted lift zone section” does not exclude a plurality of inverted lift zone sections and should be read as “at least one inverted lift zone section”. The term “a” and “an” in this connection are solely chosen for simplicity and ease of understanding and can imply the numbers one, two, three, four, or five or even optionally a plurality larger than five. In this sense, the term “a” and “an” and the term “at least one” may optionally be substituted by the term “one or a plurality of”.

Description of the Drawing

The invention will be explained in more detail below with reference to the accompanying drawing, where:

Fig. 1 shows an illustration of a thrust/inverted thrust component curve along a blade according to the invention on a wind turbine, the blade being subject to the wind forces,

Fig. 2 shows an illustration of a thrust/inverted thrust component curve along a blade according to the invention on a wind turbine, the blade being subject to the wind forces and a gust force,

Fig. 3a shows a conventional blade, without an inverted lift zone section,

Fig. 3b-g shows blades with different embodiments of the inverted lift means,

Fig. 4 shows the heave blade deflections at the blade tip as a function of lead-lag motion compared for a tip section without inverted lift and a tip section according to the invention,

Fig. 5 shows the mean heave blade deflections at the blade tip as a function of lead-lag motion compared for a tip section without inverted lift and a tip section according to the invention,

Fig. 6 shows torsion pitch flexing due to blade loading compared for a tip section without inverted lift and a tip section according to the invention,

Fig. 7 shows aerodynamic power production as a function of time compared for a tip section without inverted lift and a tip section according to the invention,

Fig. 8 shows aerodynamic rotor efficiency (C_p) as a function of time compared for a tip section without inverted lift and a tip section according to the invention, and

Fig. 9 shows an airfoil section for an embodiment of the blade having a deployable lift regulating device.

Detailed Description of the Invention

In the explanation of the figures, identical or corresponding elements will be provided with the same designations in different figures. Therefore, no explanation of all details will be given in connection with each single figure/embodiment.

Fig. 1 shows an illustration of a thrust/inverted thrust component curve along a blade 2 according to the invention on a wind turbine 4, the blade 2 being subject to the wind forces 6. The wind turbine 4 comprise a rotor 8 attached to a hub 10 that is suspended from a nacelle 12 which is supported by a tower 14. The rotor 8 is located upwind in relation to the tower 14. The blade 2 has a blade airfoil section 16 (see FIG. 3c) adapted for applying a lift force to the blade 2. The lift force comprises a torque component acting in the rotor plane of the rotor 8 for generating torque and a thrust component 18 acting perpendicularly to the rotor plane for generating thrust. The blade 2 has an inverted lift zone section 20 having inverted lift means 22. The inverted lift means 22 is adapted for applying an inverted lift force to the inverted lift zone section 20. The inverted lift force comprises an inverted torque component which is directed opposite the torque component and an inverted thrust component 24 which is directed opposite the thrust component 18.

As can be seen in Fig. 2, the inverted thrust component 24 of the inverted lift zone section 20 works against the thrust component 18 of the blade and, thereby, forces the tip 26 away from the tower 14. Fig. 2 shows also a curve illustrating a thrust component 18 and an inverted thrust component 24 along a blade 2 according to the invention on a wind turbine 4, the blade 2 being subject to the wind forces 6 and a gust force 6'. The thrust component 18 and the inverted thrust component 24 on the curve is divided into a contribution 18, 24 from the wind force 6 and an additional contribution 18', 24' from the gust force 6'. The thrust component 18, 18' and the inverted thrust component 24, 24' is increased when the blade is subject to gust. As can be seen from Fig. 2, the inverted lift zone section 20 reduces the effect of the gust because the inverted thrust component 24, 24' increases proportionally with the thrust component 18, 18'.

Fig. 3a shows a conventional blade 2 without the inverted lift zone section 20. The blade 2 has a tip 26 and a root 34, the root being configured for attachment to a nacelle of a wind turbine. Fig. 3b-g shows blades 2 with different embodiments of the inverted lift means 22. FIG. 3a-g may be understood such that the blade is in a pre-mounted state, where the pre-mounted state is a state before mount of the blade (2) to the wind turbine (4).

The blades 2 of the embodiments shown in Fig. 3b-g have inverted lift zone sections with increased cross sectional area as compared to the blade 2 in Fig. 3a. The blades 2 have an inverted lift zone section 20 and inverted lift means 22 in different locations and configurations. The inverted lift zone sections section 20 provide a negative lift during operation of the wind turbine 4, specifically when passing a threshold at low wind speed and continuing through to high speed operation.

The inverted lift zone section 20 of the blade 2 in Fig. 3b is located at the tip 26 and extends to a predetermined distance from the tip. The inverted lift means 22 is provided in the inverted lift zone section 20 by a twist of a part of the blade 2 as compared to the remaining part of the blade.

The blade 2 in Fig. 3c has an inverted lift means 22 that is shaped as an airfoil 28 at the tip 26 and which extends to a predetermined distance from the tip. The chord 30 of the inverted lift zone section airfoil section 28 is increased in relation to the blade 2. A transition zone 32 is provided where the chord 30 is gradually increasing. The transition zone 32 provides a blade fence 33 that act as an aerodynamic fence between the blade airfoil section 16 and the inverted lift zone section airfoil section 28. The inverted lift means 22 has its aerodynamic centre in front of the torsion axis of the blade 2.

The blade 2 in Fig. 3d has an inverted lift means 22 that is provided by an airfoil shape 28 in the inverted lift zone section at the tip 26 and which extends to a predetermined distance from the tip. The chord 30 of the inverted lift zone section airfoil section 28 is increased in relation to the blade 2. A transition zone 32 is provided where the chord 30 is increasing. The inverted lift means 22 has its aerodynamic centre behind the torsion axis of the blade 2.

The blade 2 in Fig. 3e comprises multiple inverted lift zone sections 20, 20’. One inverted lift zone section 20 is extending a distance inwards from the tip 26, and another inverted lift zone section 20’ is located between the tip 26 and the root 34 at a larger distance from the tip. Inverted lift means 22 are provided in the inverted lift zone sections 20, 20’. The inverted lift means 22 are provided by an airfoil shape 28 of the inverted lift zone section 20. The other inverted lift zone section 20’, located at a distance from the tip, has blade airfoil shapes on either side. At the tip 26, the chord 30 of the airfoil shape 28 in the inverted lift zone section 20 is increased in relation to the blade 2. A transition zone 32 is provided, where the chord 30 is increasing. The transition zone 32 provides a blade fence 33 that acts as an aerodynamic fence between the blade airfoil section 16 and the inverted lift zone section 20 with the airfoil shape 28. The inverted lift means 22 has its aerodynamic centre in front of the torsion axis of the blade 2. The blade 2. The other inverted lift zone section 20’ at a distance from the tip has a slight chord increase. Alternatively it may have a chord 30 that is similar to the adjacent blade chord.

The blade 2 in Fig. 3f comprises an inverted lift zone section 20’ that is located between the tip 26 and the root 34 at a distance from the tip.

The blade 2 in fig 3g comprise two inverted lift zone sections 20’, 20’’ that are located between the tip 26 and the root 34, each having a distance from the tip 26. One inverted lift zone section 20’’ has a first distance to the tip 26, and the other inverted lift zone section 20’ has a second, larger distance to the tip 26.

In the above embodiments, the inverted lift zone section 20’ or sections 20’, 20’’ that is/are provided at a distance from the tip 26 may be located such that the effect of the blade resonance mode shapes is reduced.

Fig. 4-8 shows results of comparing simulations performed on an example blade 2 without an inverted lift zone section, on the one hand, and an example blade 2 with an inverted lift zone section 20, on the other hand. The example blade 2 without an inverted lift zone section has a layout according to Fig. 3a and a length of 47 m. The other example blade 2 with an inverted lift zone section 20 has a layout according to Fig. 3c, a length of 48 m and the inverted lift zone section has a chord of 1 m.

Fig. 4 shows the heave blade deflections at the blade tip as a function of lead-lag motion compared for a tip section without inverted lift and a tip section according to the invention. As can be seen on Fig. 4, the tip section without an inverted lift zone section has flap deflections 36 twice the magnitude of the deflections 38 of the example blade with an inverted lift zone section. This is significant in that the maximum bending loads, to which the blade and hub are subject, are lower when applying the inverted lift zone section. The edge deflection of the two blades is similar.

Fig. 5 shows the mean heave blade deflections at the blade tip 26 as a function of lead-lag motion for a blade without an inverted lift zone section as compared to a blade with an inverted lift zone section at the tip section according to the invention. As can be seen from Fig. 5, the blade without an inverted lift zone section has deflections 36 around a mean value of a much higher magnitude than the deflections 38 of the blade with the inverted lift zone section. This is significant from a fatigue point of view. Fig. 5 clearly shows that the use of the inverted lift zone section dampens the flap deflections of the blade such that the fatigue loading is much less critical in comparison to the blade without the inverted lift zone section.

Fig. 6 shows torsional pitch flexing due to blade loading when comparing a tip section without inverted lift with a tip section according to the invention. The torsional deflections are comparable, but the blade without an inverted lift zone section has a more scattered distribution of torsional deflections 40, whereas the blade with the inverted lift zone section has a distribution of torsional deflections 42 which is dampened by the inverted lift zone section. Therefore, the introduction of the inverted lift zone section does not have a destabilising effect.

Fig. 7 shows aerodynamic power production as a function of time compared for a blade with a tip section without inverted lift and for a blade having an inverted lift zone section at the tip according to the invention. Fig. 7 shows that the characteristics for the example blades are chosen such that the power production 44 of the blade with the inverted lift zone section is comparable to the power production 46 of the blade without the inverted lift zone section. So, for the same power production, the invention provides a blade with flap deflections of a much smaller magnitude than the example blade without the invention. This provide for a less stiff and therefore lighter construction of the blade. The resulting effect is that the hub and other components may be designed for a smaller loading and therefore lighter. Furthermore, the fatigue life of the blade having the invention incorporated is expected to be higher.

Fig. 8 shows aerodynamic rotor efficiency (C_p) as a function of time for a blade with a tip section without inverted lift as compared for a blade having an inverted lift zone section at the tip according to the invention. As can be seen on Fig. 8, the power coefficient 48 of the rotor (Cp) is lower for the blade with the inverted lift zone section than the power coefficient 50 for the blade without the inverted lift zone section. However

ever both blades provide the same power production, as can be seen on Fig. 7, due to the increased length of the blade with the inverted lift zone section and, hence, an increased swept area. The invention provides a decrease of the deflections for the same power production, which decreases the risk of the blade colliding with the tower. Furthermore, the fatigue life of the blade is increased as the magnitude of the variations in deflections during operation is reduced.

Fig. 9 shows an inverted lift zone section airfoil section 28 for an embodiment of the blade 2 having a deployable lift regulating device 52. The deployable lift regulating devise 52 is a flap 54, which deflects to provide an inverted lift.

In the following, some aspects are described for solving the problems and objectives outlined above and on which some of the above features are based. The above features or combinations of the above features may be combined with the below aspects.

Aspect 1. Blade (2) for a rotor (8) of a wind turbine (4), the blade (2) having a blade airfoil section (16) adapted for applying a lift force to the blade (2), wherein the lift force comprise a torque component acting in the rotor plane of the rotor (8) for generating torque and a thrust component (18) acting perpendicularly to the rotor plane for generating thrust, **wherein** the blade (2) comprises at least one inverted lift zone section (20), wherein the inverted lift zone section (20) comprise inverted lift means (22), adapted for applying an inverted lift force to the inverted lift zone section (20), and wherein the inverted lift force comprise an inverted thrust component (24) directed opposite the thrust component (18).

Aspect 2. Blade (2) according to aspect 1, **wherein** the inverted lift means (22) comprise a twist of the blade (2) in the inverted lift zone section (20).

Aspect 3. Blade (2) according to aspect 1 or 2, **wherein** the inverted lift means (22) comprise an inverted lift zone section airfoil section (28) having inverted suction and pressure sides.

Aspect 4. Blade (2) according to any of the preceding aspects **wherein** the inverted lift means (22) comprise a deployable lift regulating device (52).

Aspect 5. Blade (2) according to any of the preceding aspects, **wherein** the deployable lift regulating device (52) comprise a symmetric airfoil section and an actuation means for adjusting the angle of attack of the symmetric airfoil section for selectively applying a inverted lift during operation of the wind turbine (4).

Aspect 6. Blade (2) according to any of the preceding aspects, **wherein** the said at least one inverted lift zone section (20) comprise a blade fence (33) at each transition (32) between the blade airfoil section (16) and said at least one inverted lift zone section (20), for preventing flow in the longitudinal direction of the blade (2) between the blade airfoil section (16) and said at least one inverted lift zone section (20).

Aspect 7. Blade (2) according to any of the preceding aspects, **wherein** said at least one inverted lift zone section (20) is located at the tip (26).

Aspect 8. Blade (2) according to any of the preceding aspects, **wherein** said at least one inverted lift zone section (20) is located between the tip (26) and the root (34).

CLAIMS

1. A blade (2) for a rotor (8) of a wind turbine (4), the blade being elongate and having a root (34) in one end for attachment to a hub (10) of the wind turbine and a tip (26) at an opposite end, the blade (2) having a blade length from the root (34) to the tip (26), the blade (2) having a blade airfoil section (16) adapted for applying a lift force to the blade (2) when in operation on the wind turbine (4), wherein the lift force comprises a torque component acting in a rotor plane of the rotor (8) for generating torque and a thrust component (18) acting perpendicularly to the rotor plane for generating thrust, wherein the blade (2) comprises an inverted lift zone section (20), wherein the inverted lift zone section (20) comprises inverted lift means (22) adapted for applying an inverted lift force to the inverted lift zone section (20) when in operation on the wind turbine (4), and wherein the inverted lift force comprise an inverted thrust component (24) directed opposite the thrust component (18).

2. A blade according to claim 1, wherein the blade airfoil section (16) and the inverted lift zone section (20) are mutually distinct longitudinal sections of the blade (2) when the blade (2) is in a pre-mounted state, the pre-mounted state is a state before mount of the blade (2) to the wind turbine (4).

3. A blade according to any preceding claim, wherein the blade (2) comprises at least one inverted lift zone section (20) when the blade (2) is free from applied torsional pitch flexing forces along the blade (2).

4. A blade according to any preceding claim, wherein the inverted lift zone section (20) extends from a first predetermined and fixed distance from the root (34) end to a second, different predetermined and fixed distance from the root (34).

5. A blade according to any preceding claim, wherein the inverted lift zone section (20) is located at a distance from the tip (26).

6. A blade according claim 5, wherein the distance from the tip is between 25% and 75% of the blade length.

7. A blade according to any preceding claim, wherein the inverted lift zone section (20) is located between two blade airfoil sections (16) that are adapted for applying a lift force to the blade (2) when in operation on the wind turbine (4).

8. A blade according to any one of the claims 5-7, wherein the blade (2) comprises a further inverted lift zone section (20) extending from the tip (26) to a fixed distance from the tip (26).

9. A blade according to any one of the claims 1-4, wherein the inverted lift zone section (20) extends from the tip (26) to a fixed distance from the tip (26).

10. A blade according claim 8 or 9, wherein the distance from the tip (26) is less than 25% of the blade length and independent of the wind load when in operation on the wind turbine (4).

11. A blade according to any preceding claim, wherein the blade (2) has a blade airfoil section (16) with a first length along a longitudinal axis of the blade (2), and wherein the blade (2) has an inverted lift zone section (20) with a second length along the longitudinal axis of the blade (2), wherein the first length is at least two times larger than the second length.

12. A blade according to any preceding claim, wherein the blade (2) has a plurality of separate blade airfoil sections (16), each blade airfoil section (16) having a first length along the longitudinal axis of the blade (2), the first lengths of the plurality of separate airfoil sections (16) summing up to a first sum of lengths, the blade also having a plurality of inverted lift zone sections (20, 20', 20''), each inverted lift zone section (20, 20', 20'') having a second length along the longitudinal axis of the blade, the second lengths of the plurality of inverted lift zone sections summing up to a second sum of lengths, wherein the first sum of lengths is at least two times larger than the second sum of lengths.

13. A blade according to any preceding claim, wherein the inverted lift means (22) in the inverted lift zone section (20) comprise a pitch orientation that is rotated at least 30 degrees relatively to the blade in an adjacent blade airfoil section (16).

14. A blade according to any preceding claim, wherein the inverted lift means (22) in the inverted lift zone section (20) comprise an inverted lift zone section airfoil section (28) having inverted suction and pressure sides relatively to the blade in an adjacent blade airfoil section.

15. A blade according to any preceding claim, wherein a blade fence (33) is provided at a transition (32) between the inverted lift zone section (20) and an adjacent blade airfoil section (16) for preventing flow in the longitudinal direction of the blade (2) between the blade airfoil section (16) and the inverted lift zone section (20).

16. A blade according to any preceding claim, wherein the blade has a fixed length.

17. A blade according to any preceding claim, wherein the blade comprises a central spar configured for providing torsional stiffness for counteracting a pitch flexing of the blade.

18. A blade according to any preceding claim, wherein the blade comprises a central spar with a polygonal cross section having edges, wherein the edges are rigid for

19. A blade according to any preceding claim, wherein the blade is free of a rotation apparatus between sections of the blade, the rotation apparatus being configured for rotating one section of a blade relatively to another section of the blade about a longitudinal axis of the blade.

20. A blade according to any preceding claim, wherein the blade is free from a blade pitch flexing mechanism, wherein the blade pitch flexing mechanism is configured for continuously changing the blade pitch from the root end to the tip as a result of increased wind load.

21. A blade according to any preceding claim, wherein the blade airfoil section (16) has a stationary location on the blade (2) during operation of the blade

22. A blade according to any preceding claim, wherein the length of the blade airfoil section (16) and the length of the inverted lift zone section (20) are fixed.

23. A method of manufacturing a blade (2) for a rotor (8) of a wind turbine (4), wherein the method comprises manufacturing a blade with at least two differently shaped sections along the blade (2) with at least one airfoil section (16) of fixed length and at least one inverted lift zone section (20) with fixed length configured for providing mutually opposite thrust components (24) when in operation as part of a wind turbine.

24. A method according to claim 22, comprising providing a shell mould arrangement comprising a first section with first shaping means and a second section with second shaping means, and shaping an airfoil section with the first shaping means and an inverted lift zone section with the second shaping means.

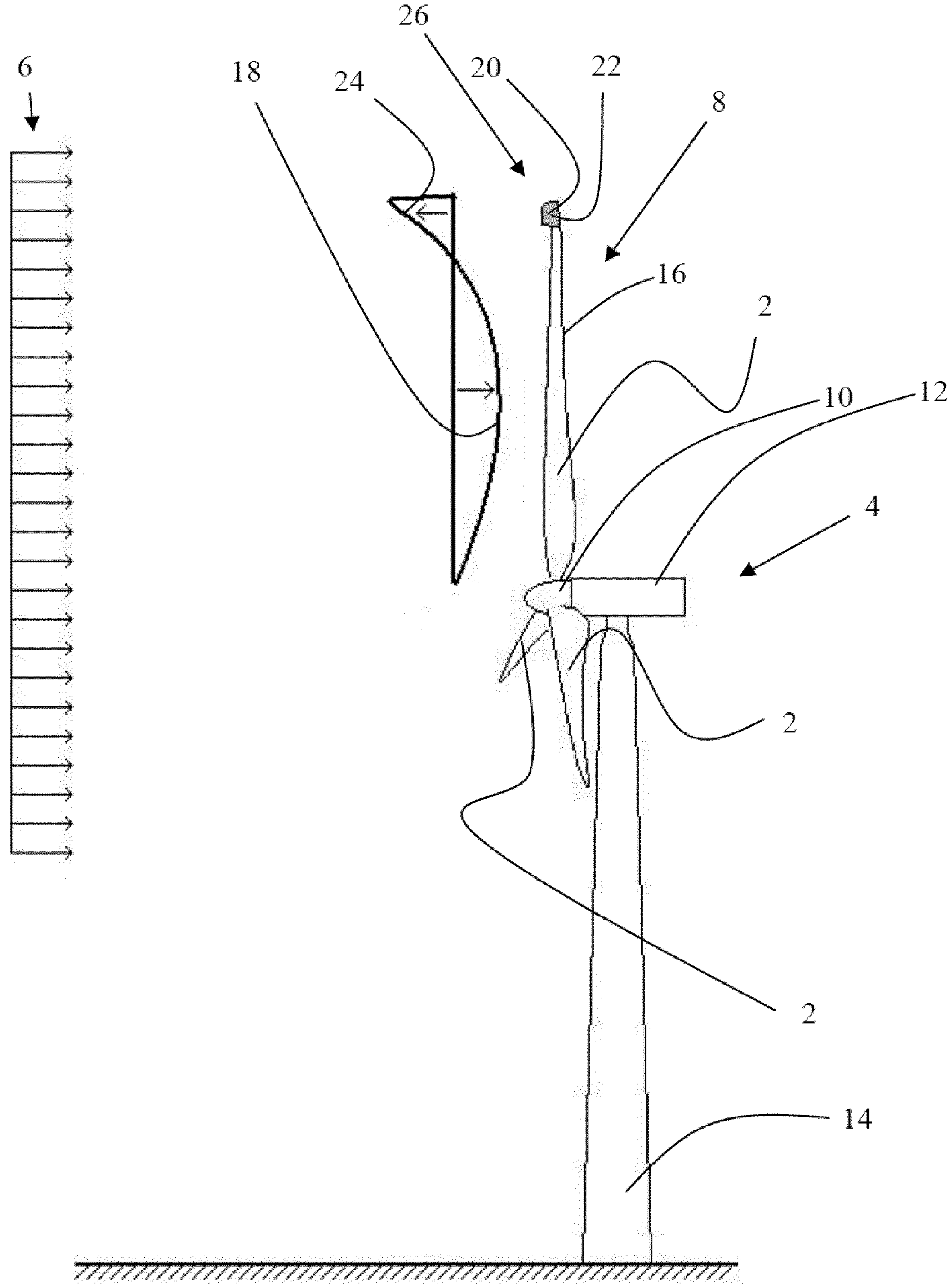


Fig. 1

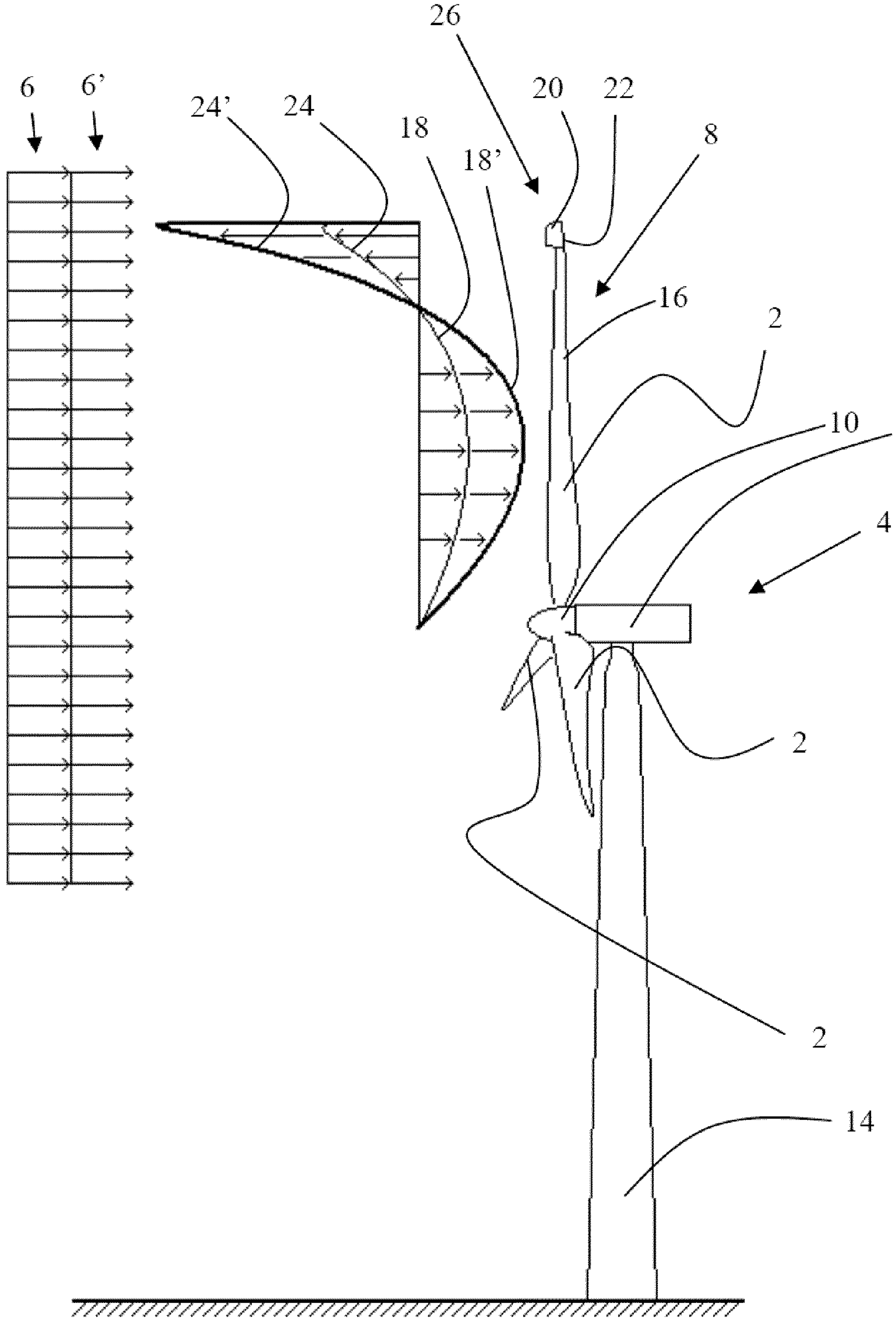


Fig. 2

Fig. 3a

Fig. 3b

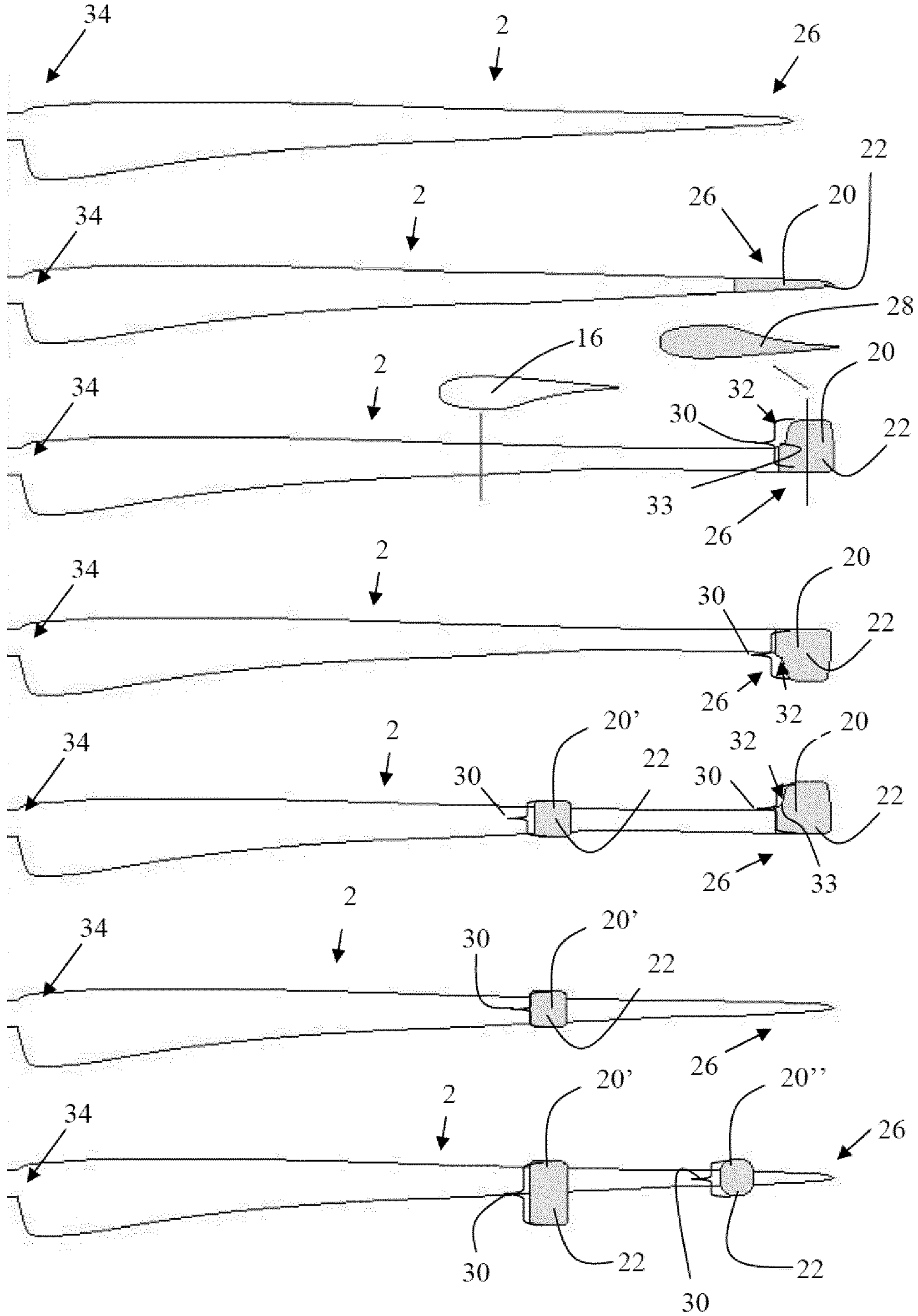
Fig. 3c

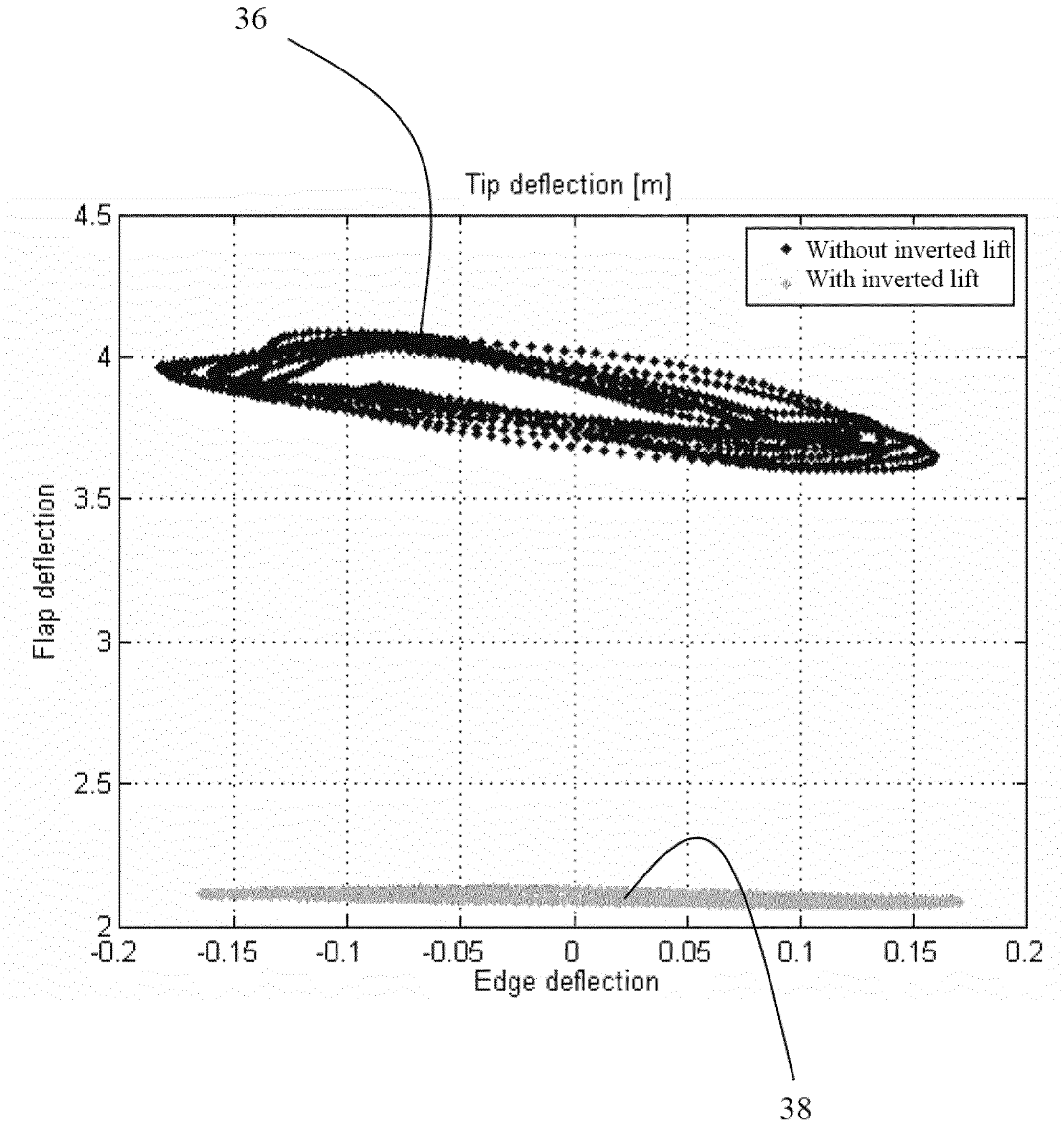
Fig. 3d

Fig. 3e

Fig. 3f

Fig. 3g




36
Tip deflection [m]
Without inverted lift
With inverted lift
Flap deflection
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4
3.5
3
2.5
2
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
Edge deflection
38

Fig. 4

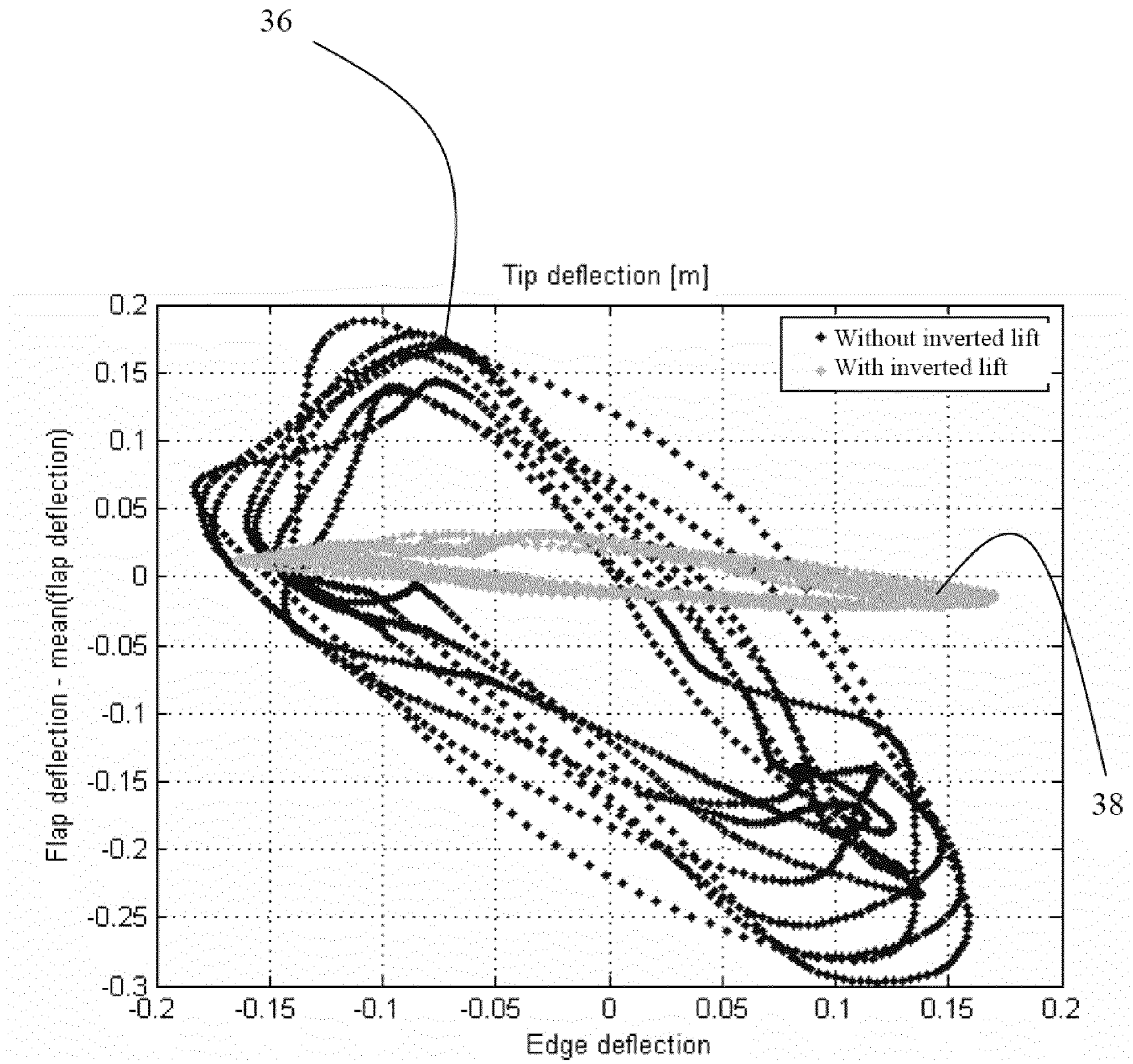

36
Tip deflection [m]
Without inverted lift
With inverted lift
Flap deflection - mean(flap deflection)
Edge deflection
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
-0.2
-0.15
-0.1
-0.05
0
0.05
0.1
0.15
0.2
38

Fig. 5

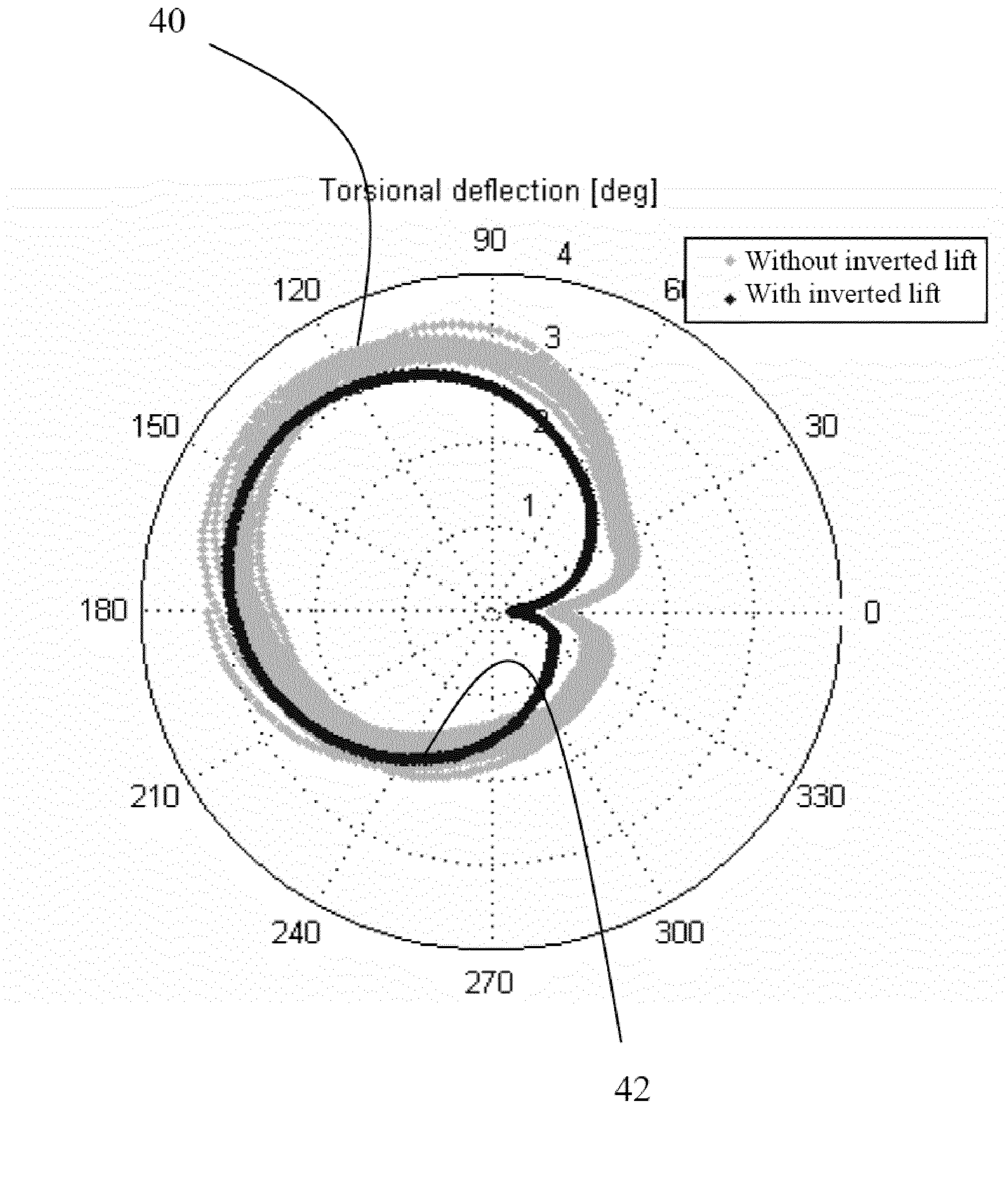
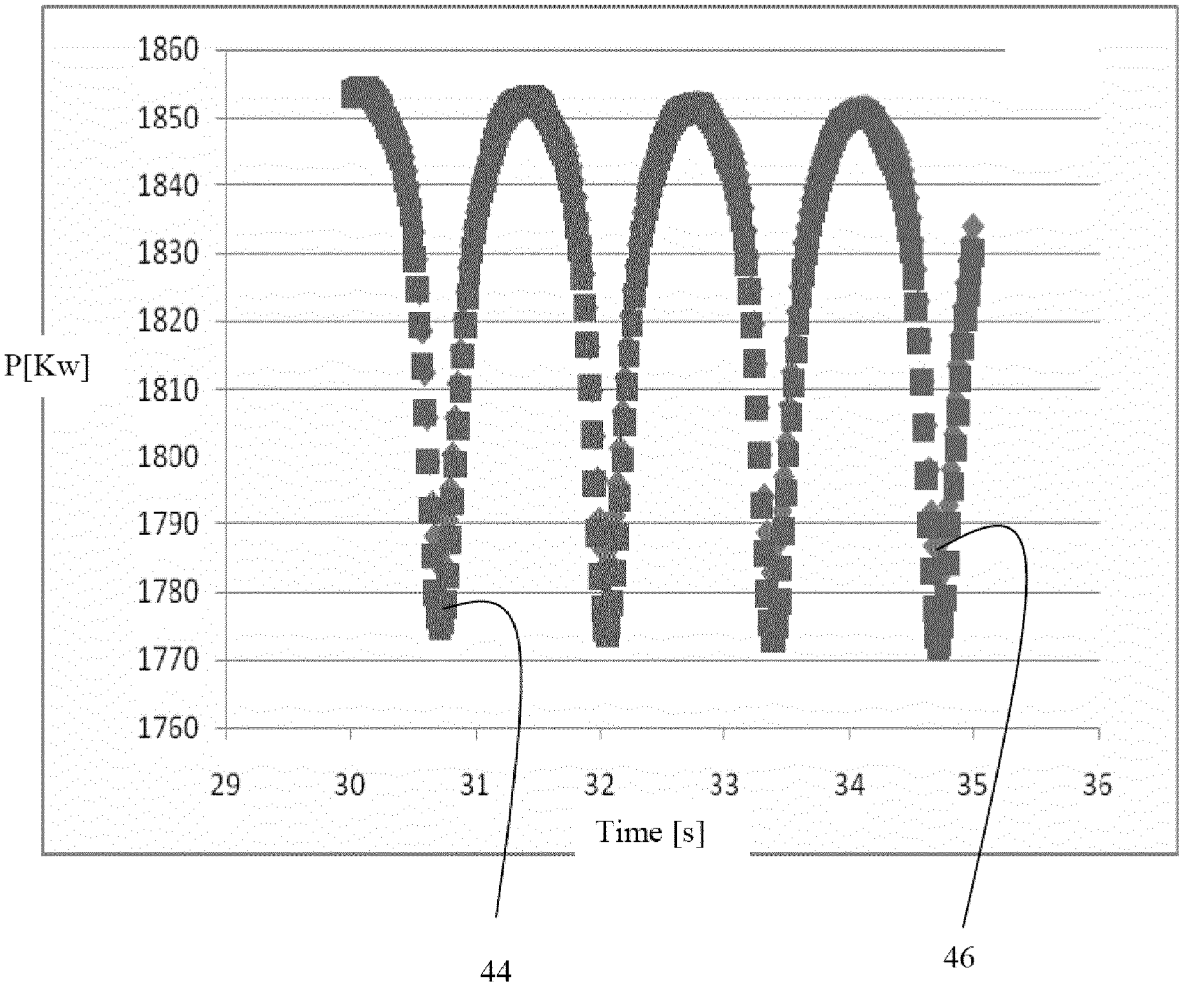

40
Torsional deflection [deg]
90
4
120
60
Without inverted lift
With inverted lift
3
150
30
1
180
0
210
330
240
300
270
42

Fig. 6



P[Kw]
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1820
1810
1800
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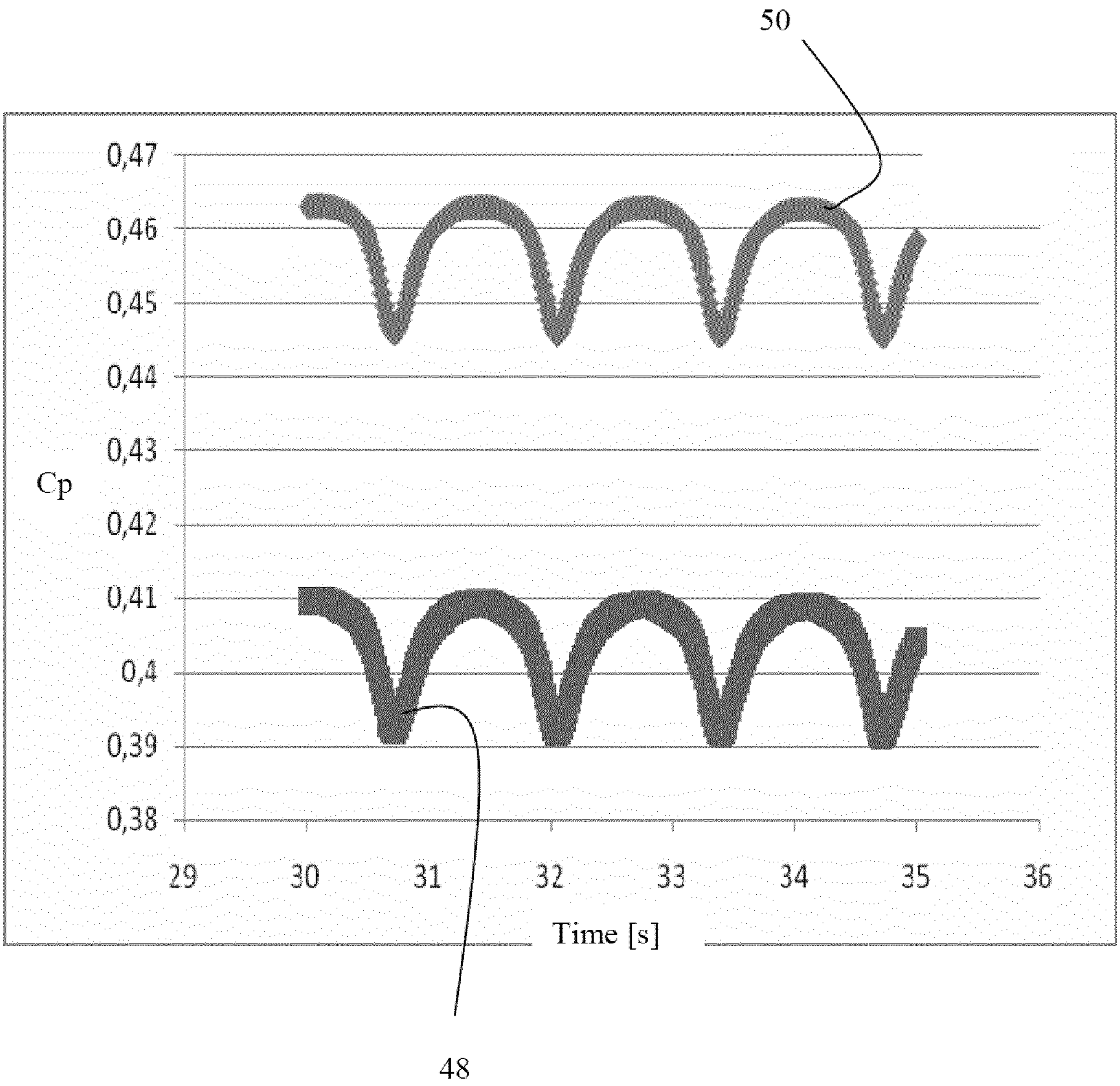
32
33
34
35
36
Time [s]
44
46

Fig. 7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Cp
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34
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36
Time [s]
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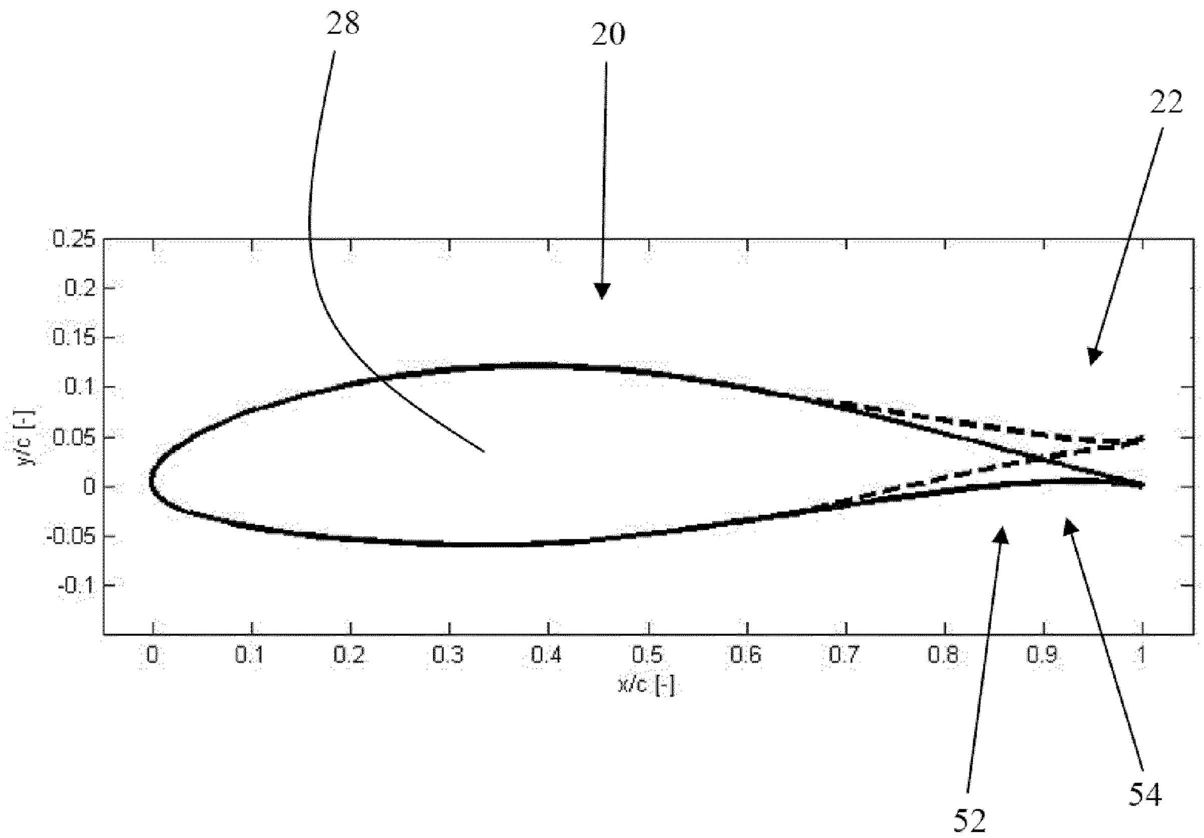
Fig. 8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20
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0.2
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0.05
0
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-0.1
y/c [-]
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0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
x/c [-]
52
54

Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2012/052468

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D1/06 F03D7/02
ADD.

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F03D

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2009/130500 A2 (BRM POWER LTD [GB]; MARSHALL BARRY ROBERT [GB]) 29 October 2009 (2009-10-29) abstract page 1, line 13 - line 33 page 8, line 26 - page 9, line 36 page 11, line 26 - line 29 figures 3-6 -----	1-4,9, 11,14, 16-24
X	GB 2 227 286 A (HOWDEN WIND TURBINES LIMITED [GB]) 25 July 1990 (1990-07-25) abstract page 4, line 9 - page 5, line 33 figures 1-5 -----	1-4, 7-16, 20-24
	-/--	

[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

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

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
8 May 2012	15/05/2012

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Kolby, Lars

2

International application No
PCT/EP2012/052468

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2008/052677 A2 (LIGNUM VITAE LTD [BS]; WAREK MICHAEL B [US]) 8 May 2008 (2008-05-08) cited in the application abstract page 10, paragraph 3 - page 15, paragraph 2 figures 1-3	1,11,13, 14,16, 21,23,24
X	US 5 570 859 A (QUANDT GENE A [US]) 5 November 1996 (1996-11-05) abstract column 2, line 27 - line 40 figures	1-18, 20-24
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2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2012/052468

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