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Description

The invention relates to a method for erecting a wind energy system comprising a tower and a nacelle arranged at the top of the tower, wherein, during a tower body structure construction phase in which no nacelle has yet been placed on top of the tower body structure, a tower body structure is initially erected in one tower body structure construction stage or several tower body structure construction stages by placing one or several tower sections one on top of the other to form a tower body structure, which in the case of several tower sections becomes bigger with each tower section, until a final height of the tower body structure is reached, wherein after the tower body structure has been fully erected from all tower sections, the nacelle is placed on top of the tower body structure and rotatably attached to the tower body structure. The invention further relates to a corresponding wind energy system.

Modern wind energy systems comprise a high tower with a vertical longitudinal axis, frequently consisting of several tower sections, at the top of which is mounted a nacelle or gondola with a rotor having several rotor blades and a horizontal rotor axis rotatably mounted around the tower axis.

Towers of onshore wind energy systems are usually erected on a foundation section by section out of several sections, and directly on location at the construction site. Tower sections for such wind energy systems are most often transported lying flat to the erection site. When erecting a tower of a wind energy system, the as a rule several individual tower sections are sequentially moved out of their lying position and into an erected position using a hoist, and placed on a foundation, an auxiliary foundation or a fixing point and/or a tower section erected last, and attached with the latter. The longitudinal tower axis is here moved from a horizontal into a vertical orientation.

By contrast, towers for offshore wind energy systems are preferably erected section by section on auxiliary foundations at the port of shipment. The towers completely erected for transport or vertically erected tower sections are then loaded
5 onto an installation vessel at the port, and there attached to auxiliary foundations for transport, so-called "grillages". For reasons of space, offshore towers are preferably transported standing erect. Only once tower erection has been completed is the nacelle, the so-called gondola, attached on top of the tower.

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Wind energy system towers involve components that are highly prone to vibrations. However, a freestanding tower without a gondola here has a distinctly different natural frequency than a tower with a nacelle and rotor arranged on the top.

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During the erection of a wind energy system, this means that a freestanding and gondola-less tower or tower body structure, the top of which is still not yet loaded with the weight of the nacelle, vibrates at a higher frequency than it would after
20 placement of the nacelle.

Any structure, and thus also a wind energy system or a wind energy system tower, reacts to an external stimulation, for example wind or waves, of a specific frequency with their own
25 vibrations, depending on the stimulation frequency. In addition, each structure has so-called natural frequencies. These are the frequencies at which the system vibrates when deflected and then left on its own. Relevant in particular for wind energy systems is the first natural frequency, whose accompanying first
30 intrinsic shape essentially consists of a bending deformation of the tower. Therefore, it is also referred to as the "first natural bending frequency". This frequency changes when other components are added, e.g., when a wind energy system tower gets higher. It thus depends considerably on the stage of
35 construction.

Within the framework of the present invention, the term natural frequency in the respective conjunction encompasses the natural

frequency of a wind energy system tower in itself or the natural frequency of a combination of tower and (auxiliary) foundation or clamping, i.e., essentially the natural frequency of the unilaterally clamped or attached tower.

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A vibration stimulation becomes critical in particular if it overlaps the natural frequency of the structure within the frequency range, and thus results in resonance vibrations that can destroy the structure.

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Wind energy systems are stimulated to vibrate primarily by the incident wind. In completely erected, commissioned systems, tower vibrations arise above all in response to the rotor being loaded by the wind. In offshore wind energy systems, stimulation by the ocean movements in the form of arising waves must also be considered.

Vibrations in freestanding tower body structures are caused primarily by vortex shedding, the so-called Karman vortices, which lead to vortex-induced transverse vibrations (WEQ or "vortex induced vibrations" - VIV). Involved here is a sequence of vortex shedding of the wind or wind field streaming around the tower, alternatingly on the left and right side of the tower as viewed in the wind direction. The tower vibration and vortex shedding intensify each other. After placement of the nacelle and commissioning of the wind energy system, the natural frequency of the tower changes in such a way that VIV's only overlap the natural tower frequency at low wind speeds, and are then not that critical. Tower vibrations then arise in particular in response to the rotor being loaded by the wind, and offshore as well through wave stimulation.

The natural frequencies of the gondola-less towers are basically higher than those for the completely mounted systems. There then exist conditions under which Karman vortex stimulations induce VIV's at frequently arising wind speeds. Accordingly, the vibration amplitudes become larger, so that the mechanical and

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structural loads on the wind energy system towers rise accordingly.

5 Since the VIV's are encountered at specific wind speeds and the frequencies of the reciprocal vortex shedding associated therewith, towers of wind energy systems in the shell condition without the nacelle placed on top must either be secured starting at a specific length, for example by bracing elements, or measures must be taken to prevent vortex shedding. Otherwise,
10 VIV's can result in the destruction of the tower. This danger is either nonexistent or exists only to significantly less of an extent below a critical length, since the natural frequencies of the shorter tower stumps with a few tower sections lie in a higher frequency range, the accompanying high wind speeds of
15 which realistically need not be expected.

For a completely erected tower without gondola, a critical wind speed at which the vortex-induced transverse vibrations are dangerous to the tower body structure usually lie between 10 m/s
20 and 25 m/s, depending on its height and stiffness, so that erection is impermissible if these wind speeds are expected and the gondola cannot be directly pulled after the last tower section has been lifted.

25 During the erection of a wind energy system, this circumstance is taken into account by installing or placing the last tower section or potentially the last sections of the tower and the nacelle onto the tower given a weather window with calm conditions, preferably at wind speeds of at most 9 m/s. Such
30 weather windows must last for at least several hours or days. Therefore, waiting for a suitable weather window can significantly delay the erection of a wind energy system, and thereby result in high costs.

35 The consequences of the vibration problem are more keenly felt offshore than onshore due to the on average stronger winds offshore. As opposed to the section-by-section erection of onshore towers, offshore towers are as a rule already assembled

at the port out of several tower sections with a perpendicularly aligned longitudinal axis, and for reasons of space are preferably transported standing upright on an installation vessel. During transport, the towers or tower sections are exposed to wind or wave stimulation. VIV's can arise here already. Furthermore, the weather windows suitable for erection are shorter offshore due to the generally more constant and higher wind speeds, so that the required wait for a weather window suitable for erection is as a rule longer than onshore, which is once again associated with correspondingly high extra costs for the offshore construction site.

During transport on an installation vessel, the airstream can further intensify the already prevailing wind, so that even stronger VIV's can arise. In addition, a tower or tower section can also be stimulated to vibrate by the rolling motions of the ship, which are caused by the swells. Installation vessels are usually not equipped with a separate liquid rolling moment damper that dampens these rolling motions, especially since loading with the vertical towers or tower sections would shift the rolling frequency in a way that such a damper could exert little effect. The rolling motion also leads to a certain draft at the tops of the towers or tower sections.

As a rule, towers for offshore wind energy systems are currently transported in two preassembled sections, which are subsequently placed one after the other on a foundation structure in the ocean or on the lower tower section in two lifts and connected. Because of the divided tower transport, the critical wind speeds for VIV stimulation are so high for the lower section as not to arise to a critical extent.

However, if complete towers are to be installed to shorten the time for offshore operations, the critical wind speeds then lie below 20 m/s owing to the elevated tower height, meaning they can be realistically encountered. In this case, it is mandatory that measures be taken against VIV's.

Since towers for offshore wind energy systems as a rule are preinstalled to yield an upright standing tower body structure and/or transported standing upright on an installation vessel, they have to date been secured by bracing elements starting at
5 a specific length due to the VIV's, or coils are temporarily secured in the upper tower area to prevent or suppress the vortex shedding, for example as known from WO 2006/106162 A2 or EP 1 881 195 A1. However, the practicable use of coils requires compliance with specific criteria regarding coil thickness and
10 winding pitch. The outlay for installing and uninstalling these coils offshore is significant.

Known from WO 2008/000265 A1 is a tower-internal bracing system, with which the tower stiffness can be adjusted to reflect the
15 construction progress, so as to prevent the natural frequency of the tower from dropping too low.

Vibration dampers that remain temporarily on the top of the tower have also already been proposed, for example in WO
20 2014/040598 A1, according to which several sandbags are each pendulum mounted in the upper area of the respective uppermost tower section.

US 2012/063915 A1 discloses a wind energy system with a vibration damper suspended on a strut of a tower segment in the form of a
25 pendulum damper with a vibrating rod loaded with weights. US 2012/0267207 A1 discloses a wind energy system having a vibration control device with an inverted pendulum-type vibration system.

30 By contrast, the object of the present invention is to make erecting a wind energy system simpler and safer.

This object is achieved by a method for erecting a wind energy
35 system comprising a tower and a nacelle arranged at the top of the tower, wherein, during a tower body structure construction phase in which no nacelle has yet been placed on top of the tower body structure, a tower body structure is initially

erected in one tower body structure construction stage or several tower body structure construction stages by placing one or several tower sections one on top of the other to form a tower body structure, which in the case of several tower sections becomes bigger with each tower section, until a final height of the tower body structure is reached, wherein after the tower body structure has been fully erected out of all tower sections, the nacelle is placed on top of the tower body structure and rotatably attached to the tower body structure, wherein at least one vibration damper designed as a pendulum damper is arranged in a tower section placed last for completing the tower body structure, whose damping frequency is adjusted to a first fundamental frequency of the tower body structure without the nacelle placed on top, wherein the at least one pendulum damper remains in the tower after the nacelle has been placed on top of the tower body structure, and the damping frequency of the at least one pendulum damper is or has been adjusted to a second fundamental frequency of the completely erected wind energy system, which is further developed in the process of erecting the tower body structure in order to adjust the natural frequency of the at least one pendulum damper by increasing the pendulum length, wherein the pendulum length is set by bending at support beams or at a temporary platform in the tower, or by fixing chain links.

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A vibration damper draws energy from the tower vibration, which flows into a vibration of a vibrating mass movably suspended or mounted relative to the tower. The vibrating mass can be a pendulum mass or a mass suspended on springs. At a specific frequency that corresponds to approaching a first bending mode or intrinsic bending shape of a tower, a tower stump or a tower section, the vibration of the vibrating mass ideally has a phase shift of 180° relative to the vibration of the tower itself. As a result, the vibrating energy derived from the tower in the vibration dampers and the corresponding damping of the tower vibration are at a maximum. Above and below the maximum damping frequency, the phase shift is more or less than 180° , so that the damping effect tapers.

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The presently used terms damping frequency, natural frequency and fundamental frequency have the following meaning within the framework of the present patent application. Vibrating bodies, 5 for example an unloaded tower or tower stump without a vibration damper, has various natural frequencies for different bending modes or intrinsic bending shapes. The first intrinsic bending shape of a vertically erected tower fastened at its lower end has no vibration nodes, while higher intrinsic bending shapes 10 have one, two or more vibration nodes. These have increasingly higher natural frequencies, and in reality are stimulated less and less as the ordinal number increases. Technically the most important is the first intrinsic bending mode, which has the lowest natural frequency, and is therefore referred to as the 15 fundamental frequency within the framework of the present application.

A vibration damper has its own natural frequencies. The preferably first or lowermost natural frequency selected for the 20 vibration of the vibration damper is preferably equal to or close to the fundamental frequency of the tower, i.e., the natural frequency of the first intrinsic bending shape of the tower.

25 By contrast, the damping frequency is a property of the coupled system comprised of the tower and vibration damper. In the coupled system, there arises a damping spectrum with a maximum damping at a specific frequency, and a tapering damping above and below this maximum damping frequency. The frequency of 30 maximum damping is referred to as damping frequency within the framework of the present application. This coupled system has its own natural frequencies, among other things the damping frequency, which is close, but not identical to the natural frequencies of the uncoupled constituents. Therefore, a 35 vibration damper built into a tower does not vibrate at its own natural frequency at maximum damping.

As a consequence, adjusting the natural frequency of the vibration damper also leads directly to an adjustment of the damping frequency, i.e., to a shift in the damping spectrum.

5 As opposed to prior art, the vibration damper(s) used for the shell condition of the tower in the completed wind energy system remain(s) in the uppermost tower section or in the tower below the nacelle. The vibration damper(s) is/are here configured in such a way that the damping frequencies of the vibration damper
10 or vibration dampers can be adjusted to the various arising fundamental frequencies of a gondola-less tower body structure and a complete wind energy system. These vibration frequencies differ between the shell and completely erected wind energy system by factors ranging between 2 and 10, depending on the
15 type of wind energy system. The arising natural tower frequencies during the construction stage, i.e., given a tower shell, lie between 0.2 Hz and 1 Hz, but range between below 0.1 Hz and 0.3 Hz in the final stage. Such a change requires a strong configurability and changeability of the vibration damper or
20 vibration dampers.

Also known from prior art are vibration dampers for the final stage of the wind energy system. However, the damper mass and natural frequency are not adjusted for the tower body structure
25 condition.

Several vibration dampers with the same natural frequency or differing natural frequencies can also be used within the framework of the present invention.

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The method according to the invention makes it possible to leave the vibration damper already used in the construction stage in the uppermost tower section with only slight modifications, so that the vibration damper no longer has to be removed from the
35 uppermost tower section before or after placement of the nacelle. In addition, this improves the structural integrity of the wind energy system, and thus the stability and safety of the wind energy system. The maximum structural loads to be expected on

the tower of the wind energy system are already diminished by the vibration damping in the tower body structure phase, so that the tower can be constructed more easily and inexpensively. Conversely, it is thus also possible to modify vibration dampers rated for normal operation only for the stage of construction, and to again eliminate this modification for the final stage of the wind energy system.

In an advantageous further development, the natural frequency of the at least one vibration damper is adjusted to the fundamental frequency of the completely erected wind energy system after or shortly before the nacelle has been placed on top of the tower or tower body structure. This procedural step takes little time, most often less than an hour, so that even relatively short time windows or weather windows allow this operation. Since nacelle placement already results in VIV suppression, the vibration damper is preferably adjusted after nacelle placement, so that no critical time window with unadjusted vibration damper arises in the VIV-prone tower body structure.

The natural frequency of the at least one pendulum damper can preferably be varied between at least one first frequency ranging from 0.2 to 1 Hz and at least one second frequency ranging from 0.1 to 0.3 Hz, wherein the first frequency and second frequency differ from each other by a factor of 2 or more, in particular by at least a factor of 3. The factor effectively bridges the difference between the fundamental frequency of the tower in the shell condition and after nacelle placement.

The at least one vibration damper is advantageously designed as a pendulum damper in combination with springs on the pendulum mass and/or with a viscous pendulum damping. Several vibration dampers of the same or different type are also advantageously provided.

Masses are suspended from vertical cables or chains of the pendulum dampers, and oscillate at their own vibration frequency

corresponding to their pendulum length. Spring-mass dampers and pendulum dampers can freely oscillate or move in a viscous liquid, thereby damping the pendulum motion. The pendulum mass can also be laterally suspended with springs, and thus be a hybrid
5 comprised of a pendulum damper and spring-mass damper.

The advantage to vibration dampers with a low vertical expansion for use in tower sections or towers is that they economize on space. Undamped pendulums are only conditionally suitable, since
10 a pendulum length of over 6 mm is already necessary for a frequency of 0.2 Hz, for example, and of approx. 25 m at 0.1 Hz. The necessary pendulum length is decreased by damping the pendulum mass with a viscous liquid, i.e., through viscous pendulum damping.

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Within the framework of the present invention, for example, a combination of springs on the pendulum mass and viscous pendulum damping can involve the pendulum mass initially oscillating and being fixed in place with springs in the tower body structure
20 stage, omitting the springs as the height of the tower body structure increases, so as to modify the pendulum frequency, and in a last section installing a damping bath with viscous liquid to achieve the fundamental frequency of the complete wind energy system. Alternatively, the damping bath with viscous liquid can
25 already be present, and either remain at the respectively same immersion depth or be brought closer to the pendulum mass with each section, so that a portion being immersed in the viscous liquid is exposed to a resistance that rises with each lifting into a different tower section, and is thus decelerated more
30 strongly. The reverse case is also possible. The energy dissipation can be individually set to increase or decrease with a rising tower height. This can be combined with a spring suspension, but not necessarily.

35 The vibration damper preferably comprises a viscous damping. This is inherently the case in liquid dampers such as the sloshing damper or TLCD, since the vibrating liquid has a viscosity, so that energy dissipation takes place. In the case

of the spring-mass damper and pendulum damper, viscous damping is accompanied by an energy dissipation in the manner described above through movement in a viscous liquid.

5 Given a case where a pendulum damper is used in combination with springs on the pendulum mass, it is preferably provided that the number of springs be reduced and/or that used springs be replaced by springs with a lower spring force during the course of erecting the tower body structure in order to adjust the natural
10 frequency of the at least one damper.

In the pendulum damper, the pendulum length is increased according to the invention during the course of erecting the tower body structure in order to adjust the natural frequency
15 of the at least one damper, wherein the pendulum length is set by bending at support beams, which are arranged on the tower wall or suspended from a platform in the tower, or by fixing chain links.

20 Different vibration damper types, meaning various liquid dampers, spring-mass dampers and pendulum dampers, damped or undamped, can also be combined with each other within the framework of the invention.

25 Fundamental frequencies of a tower body structure are advantageously calculated or determined in at least one tower body structure stage and the completely erected wind energy system already before erection of the wind energy system begins, and the natural frequencies of the at least one pendulum damper
30 are adjusted thereto.

The object underlying the invention is also resolved by a vibration damper for a wind energy system that can be attached in a tower section to be placed last for completing the tower
35 body structure, wherein a natural frequency of the vibration damper can be adjusted to a first fundamental frequency of a tower body structure of the wind energy system without the nacelle placed on top, and to a second fundamental frequency of

the wind energy system with the nacelle placed on top, wherein in particular the natural frequency of the at least one vibration damper can be varied between at least one first frequency ranging from 0.2 to 1 Hz and at least one second frequency ranging from 0.1 to 0.3 Hz, wherein the first frequency and second frequency differ from each other by a factor of 2 or more, in particular by at least a factor of 3, wherein the vibration damper is designed as a pendulum damper, in particular as a pendulum damper in combination with springs on the pendulum mass, in particular with viscous damping, wherein the pendulum length is increased or decreased for adjusting the natural frequency in a pendulum damper, wherein the pendulum length is set by bending at support beams or at a temporary platform in the tower, or by fixing chain links. As described above with respect to the method according to the invention, viscous damping either involves the type of damper as a liquid damper with inherent viscous damping, or mixing a portion of the vibrating mass or an immersion body protruding from the latter into a viscous liquid.

In order to adjust the natural frequency in a pendulum damper in combination with springs to the pendulum mass, it is preferable that the number of springs be decreased or increased, and/or that the used springs be replaced by springs with a lower or higher spring force.

According to the invention, in order to adjust the natural frequency in a pendulum damper, the pendulum length (L_1 , L_2) is increased or decreased, wherein the pendulum length (L_1 , L_2) is set by bending at support beams or at a temporary platform in the tower, or by fixing chain links.

The measures for reducing the natural frequency mentioned for the damper types are advantageously reversible, so as to increase the natural frequency once again.

The object underlying the invention is also resolved by a wind energy system with a tower comprised of several tower sections and a nacelle arranged on the top of the tower and a rotor with

an essentially horizontal rotor axis, which is erected based on the method according to the invention described above, comprising at least one vibration damper according to the invention as mentioned above designed as a pendulum damper, 5 which is arranged in the tower below the nacelle in an upper area of an uppermost tower section of the tower, and whose natural frequency can be adjusted to a fundamental frequency of the tower body structure without the gondola placed on top, and to a fundamental frequency of the completely erected wind energy 10 system.

This wind energy system was already given a better structural integrity in the tower body structure by using a corresponding vibration damper, making it possible to dimension the tower 15 sections and tower for smaller load demands. Alternatively, the stability and resilience are increased.

The corresponding wind energy system realizes the features, characteristics and advantages of the method according to the 20 invention described above in relation to the result of the method.

Additional features of the invention are made evident by the description of inventive embodiments in conjunction with the claims and attached drawings. Embodiments according to the 25 invention can satisfy individual features or a combination of several features.

The invention will be described below based on exemplary embodiments with reference to the drawings without limiting the 30 general inventive idea, wherein reference is made expressly to the drawings with regard to all inventive details not explained in more detail in the text: Shown on:

Fig. 1a), b) are schematic views of a wind energy system and a 35 tower body structure,

Fig. 2 is a schematic view of a wind energy system according to the invention,

Fig. 3 is a schematic view of another vibration damper,
and

5 Fig. 4a), b) Are schematic views of additional vibration dampers.

Because the same or similar elements and/or parts in the drawings
are each provided with the same reference numbers, they will not
be introduced again.

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Fig. 1a) shows a generic wind energy system 10, in this case an
onshore wind energy system which stands on an underlying surface
2. In offshore wind energy systems, the underlying surface 2 is
underwater, so that a substructure in the form of a foundation
15 structure is present, which is grounded in the underlying
surface 2 and ends above the water level. A tower 20 is then
erected on this substructure.

In the onshore wind energy system depicted on Fig. 1a), the
20 surface portion of a foundation 5 or base is evident on the
underlying surface 2, upon which a tower 14 with five tower
sections 22^I to 22^V is erected, of which the second uppermost
tower section 22^{IV} is exemplary denoted. The height of the
individual tower sections 22^I to 22^V increases from the bottom
25 up. The tower 20 can taper toward the top, have a constant
diameter or even have kinks in the contour, i.e., the tower can
be designed in such a way as to expand toward the top in the
upper region after tapering in the lower region. This is
especially advantageous if sufficient space is created in a
30 relatively narrow tower for installing a vibration damper. A
nacelle 40 is arranged at the top of the tower 20, wherein Fig.
1a) shows a side view of the nacelle 40 with a rotor 30, which
has a rotor hub 32 with a cover also referred to as a "spinner"
and three rotor blades 34. The side view shows the upper rotor
35 blade 34 in its full length; of the two rotor blades 34 arranged
offset by 120°, only the nearer one is visible in a shortened
perspective view, and covers the third rotor blade arranged
behind it in the image plane.

In the upper part of the uppermost tower section 22^v below the nacelle 40, a vibration damper 50 is arranged between a platform 28 and an ascending platform 29, which makes it possible to climb into the gondola or nacelle 40. The vibration damper 50 dampens tower vibrations during the operation of the wind energy system 10.

Fig. 1b) shows the tower 20 from Fig. 1a) as a tower body structure 24 without the gondola or nacelle 40 placed on top. Depicted on the left next to the tower body structure 24 in curly brackets are the tower body structure stages 24^I to 24^V, which arise by erecting and sitting up the corresponding tower sections 22^I to 22^V. The vibration damper 50 is arranged in the upper tower section 22^v. Also denoted is an upper tower connecting flange 26 for assembling the nacelle 40, in particular an azimuth adjusting unit (not shown).

Fig. 2 shows an exemplary embodiment of a wind energy system according to the invention with a pendulum damper 60. A pendulum 64 with a pendulum mass 62 and a pendulum length L_2 is suspended on a platform 28 in the upper tower section 22^v. The pendulum length L_2 is preferably designed in such a way that the pendulum damper 60 dampens the first intrinsic bending shape of the tower of the completely erected wind energy system. Illustrated for the shell condition is a temporary platform 66 below the platform 28, which comprises a restriction for the pendulum 64. The pendulum bends at the restriction. The effective pendulum length below the restriction still only measures $L_2 - L_1$. In the exemplary embodiment, the length ratio of $L_1:L_2$ is roughly 1:3, so that the pendulum frequency can be reduced by removing the temporary platform by a factor of approx. 2.25.

Fig. 3 is a schematic view of a vibration damper in the form of a sloshing damper 50, for example of the kind denoted on Fig. 1. The latter has outer side walls 52, which enclose an overall sloshing volume. Removable bulkhead plates are inserted into the overall volume, which divide the overall volume into individual

sloshing chambers 54. In order to reduce the natural frequency of the sloshing damper 50, individual or all bulkhead plates 56 are removed, so that the sloshing chambers 54 combine to form expanded sloshing chambers, or the overall volume ultimately serves as the sloshing chamber. This preferably takes place shortly before or after the nacelle is placed on top of the tower.

Fig. 4a) and 4b) present schematic views of additional vibration dampers in the form of TLCD vibration dampers 70, 70'.

The TLCD vibration damper 70 shown on Fig. 4a) has two risers 72, which are connected with each other in the lower region by a horizontal pipe 74. In order to connect the risers 72 with each other, the horizontal pipe 74 is assembled out of two parts, which are connected with each other by a pipe coupling 76. The risers 72 and horizontal pipe 74 together comprise an essentially "U"-shaped pipe, which is partially filled with saltwater 78. If the TLCD 70 is built into a vibrating tower or a vibrating tower body structure 24, the water column 78 is made to vibrate, so that the level 80 of saltwater 78 in the risers (72, 72') inversely rise and fall. The lower water quantity by comparison to a sloshing damper is offset by a higher amplitude or higher lift of the saltwater 78 in the risers 72.

Located above the saltwater 78 are air volumes or air columns 81 in the risers 72. When the latter are sealed to the ambient air, an air spring effect arises, wherein the compression of air in the air column 81 exerts a restoring force on the surface of the water 78 as the level 80 rises. If the air column 81 is also sealed on the opposing side, a negative pressure, i.e., a pressure that again upwardly siphons the water 78, arises as the level falls there. This air spring effect acts opposite the vibrational direction of the saltwater 78, and increases the vibration frequency.

Present in the upper part of the risers 72 are manholes 82 for entering and exiting the risers 72, which during normal

operation are preferably closed, so as to prevent the saltwater
78 from being lost to evaporation over years of wind energy
system 10 operation. In this exemplary embodiment, the air
columns 81 in the risers 72 are connected with each other by a
5 connecting pipe 84, which incorporates a butterfly valve 86.
When the butterfly valve 86 is open, the air columns 81 of the
two risers 72 are connected with each other, and no air spring
effect builds up. If the butterfly valve 87 is closed, the air
columns 81 are separated from each other, and an air spring
10 effect comes about in both risers 72.

Fig. 4b) shows another exemplary embodiment of a TLCD vibration
damper 70'. This one differs from the TLCD vibration damper 70
on Fig. 4a) primarily in that no connecting pipe 84 is present
15 between the risers 72', with at least one riser 72' instead
having a pressure relief valve 88 on its upper side, which opens
if an excessively high pressure or low pressure develops in the
air column 72'.

20 As further evident from Fig. 4b), the TLCD 70' can be combined
crosswise with at least one other TLCD 70. This realizes a
vibration damping for vibrations in varying directions. In order
to initiate the crossing of horizontal pipes 74, 74', they are
vertically staggered. The effective overall height of the risers
25 72 is the same as for the risers 72', since in the latter the
volume under the lower edge of the horizontal pipe 74' does not
participate in the vibration. However, this lower part does
increase the stability of the TLCD vibration damper 70'.

30 In the exemplary embodiment shown on Fig. 4a) and 4b), the air
spring pressure can be regulated in several stages. In the final
state of the wind energy system, the butterfly valve 86 can be
open in the connecting pipe 84 during normal operation. The air
spring effect is thus completely omitted. When closing the
35 butterfly valve 86, one riser 72, 72' can remain open, and the
other one that requires a pressure relief valve 88 can be closed,
thereby producing a unilateral air spring effect. In a further
enhancement, both risers 72, 72' can be closed, and possibly be

equipped with pressure relief valves. This case yields a stronger air spring effect, since it is bilateral.

Reference List

	2	Underlying surface
	5	Foundation
5	10	Wind energy system
	20	Tower
	22 ^I -22 ^V	Tower section
	24	Tower body structure
	24 ^I -24 ^V	Tower body structure stage
10	26	Upper tower connecting flange
	28	Platform
	29	Ascending platform
	30	Rotor
	32	Rotor hub
15	34	Rotor blade
	40	Nacelle
	50	Sloshing damper
	52	Side wall
	54	Sloshing chamber
20	55	Expanded sloshing chamber
	56	Removable bulkhead plate
	60	Pendulum damper
	62	Pendulum mass
	64	Pendulum
25	66	Temporary platform
	70, 70'	TLCD vibration damper
	72, 72'	Riser
	74, 74'	Horizontal pipe
	76	Pipe coupling
30	78	Saltwater
	80	Water level
	81	Air column
	82	Manhole
	84	Connecting pipe
35	86	Butterfly valve
	88	Pressure relief valve
	L ₁	Shortened pendulum length
	L ₂	Full pendulum length

Patentkrav

1. Fremgangsmåde til opførelse af en vindmølle (10) med et tårn (20) og et i tårnspidsen placeret maskinhus (40), idet der i første omgang opføres en tårnråbygning (24), idet der i en tårnråbygningsfase, hvor der endnu ikke er påsat noget maskinhus (40) på tårnråbygningen (24), i et tårnråbygningsstadie ($24^I - 24^V$) eller i flere tårnråbygningsstadier ($24^I - 24^V$) sættes en eller flere tårnsektioner ($22^I - 22^V$) oven på hinanden til en, i tilfælde af flere tårnsektioner ($22^I - 22^V$) med hver tårnsektion ($22^I - 22^V$) voksende tårnråbygning (24), til der er nået en sluthøjde på tårnråbygningen (24), idet maskinhuset (40) efter fuldstændig opførelse af tårnråbygningen (24) af alle tårnsektioner ($22^I - 22^V$) sættes på spidsen af tårnråbygningen (24) og forbindes drejeligt med tårnråbygningen (24), idet i det mindste en som penduldæmper (60) udført svingningsdæmper placeres i en til sidst til færdiggørelse af tårnråbygningen (24) påsat tårnsektion (22^V), hvis egenfrekvens er tilpasset til en første grundsvingningsfrekvens i tårnråbygningen (24) uden påsat maskinhus (40), idet den i det mindste ene penduldæmper (60) efter påsætningen af maskinhuset (40) på tårnråbygningen (24) forbliver i tårnet (20), og egenfrekvensen i den i det mindste ene penduldæmper (60) tilpasses eller er tilpasset til en anden grundsvingningsfrekvens i den fuldstændigt opførte vindmølle (10), kendetegnet ved, at pendullængden (L_1, L_2) øges i takt med opførelsen af tårnråbygningen (24) til tilpasning af egenfrekvensen i den i det mindste ene penduldæmper (60), idet pendullængden (L_1, L_2) indstilles ved at bøje den på bærere eller på en temporær platform (66) i tårnet (20) eller ved fiksering af kædeled.

2. Fremgangsmåde ifølge krav 1, kendetegnet ved, at tilpasningen af egenfrekvensen i den i det mindste ene penduldæmper (60) til grundsvingningsfrekvensen i den fuldstændigt opførte vindmølle (10) sker efter eller kort inden påsætningen af maskinhuset (40) på tårnet (20) eller tårnråbygningen (24).

3. Fremgangsmåde ifølge krav 1 eller 2, kendetegnet ved, at egenfrekvensen i den i det mindste ene penduldæmper (60) kan ændres mellem i det mindste en første frekvens i området fra 0,2 til 1 Hz og i det mindste en anden frekvens i området fra 0,1 til 0,3 Hz, idet den første frekvens er forskellig fra den anden frekvens med en faktor 2 eller mere, navnlig i det mindste med en faktor 3.
4. Fremgangsmåde ifølge et af kravene 1 til 3, kendetegnet ved, at den i det mindste ene penduldæmper (60) er udført som penduldæmper i kombination med fjedre på pendulmassen, idet penduldæmperen (60) navnlig omfatter en viskos dæmpning.
5. Fremgangsmåde ifølge et af kravene 1 til 4, kendetegnet ved, at antallet af fjedre i takt med opførelsen af tårnråbygningen (24) til tilpasning af egenfrekvensen i den i det mindste ene penduldæmper (60) ved en penduldæmper (60) i kombination med fjedre på pendulmassen (62) reduceres, og/eller de anvendte fjedre erstattes af fjedre med en lavere fjederkraft.
6. Fremgangsmåde ifølge et af kravene 1 til 5, kendetegnet ved, at grundsvingningsfrekvenser i en tårnråbygning (24) i i det mindste et tårnråbygningsstadiet ($24^I - 24^V$) og i den fuldstændigt opførte vindmølle (10) er beregnet eller bestemt allerede før påbegyndelsen af opførelsen af vindmøllen (10), og egenfrekvenserne i den i det mindste ene penduldæmper (60) er tilpasset hertil.
7. Svingningsdæmpersystem til en vindmølle (10) omfattende en svingningsdæmper og i det mindste en bærer eller en temporær platform, som kan fastgøres i en til sidst til færdiggørelse af tårnråbygningen (24) påsat tårnsektion (22^V), idet en egenfrekvens i svingningsdæmperen kan tilpasses til en første grundsvingningsfrekvens i en tårnråbygning (24) i vindmøllen (10) uden påsat maskinhus (40) og til en anden grundsvingningsfrekvens i vindmøllen (10) med påsat maskinhus (40), idet svingningsdæmperen er udført som penduldæmper (60), kendetegnet ved, at pendullængden (L_1, L_2) til tilpasning

af egenfrekvensen ved en penduldæmper (60) øges eller mindskes, idet pendullængden (L_1 , L_2) indstilles ved at bøje den på bærerne eller på den temporære platform (66) i tårnet (20).

5 8. Svingningsdæmpersystem ifølge krav 7, kendetegnet ved, at egenfrekvensen i den i det mindste ene svingningsdæmper kan ændres mellem i det mindste en første frekvens i området fra 0,2 til 1 Hz og i det mindste en anden frekvens i området fra 0,1 til 0,3 Hz, idet den første frekvens er forskellig fra den anden
10 frekvens med en faktor 2 eller mere, navnlig med i det mindste en faktor 3.

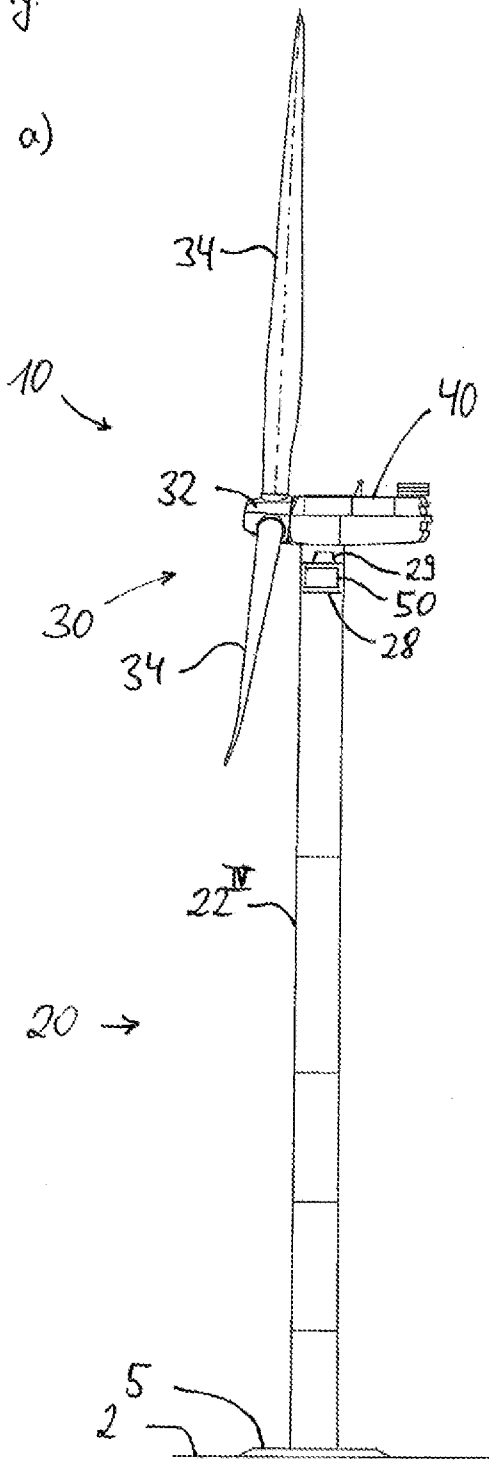
9. Svingningsdæmpersystem ifølge krav 7 eller 8, kendetegnet ved, at penduldæmperen (60) er udført som penduldæmper i
15 kombination med fjedre på pendulmassen, navnlig med viskos dæmpning.

10. Svingningsdæmpersystem ifølge krav 9, kendetegnet ved, at antallet af fjedre til tilpasning af egenfrekvensen ved en
20 penduldæmper (60) i kombination med fjedre på pendulmassen (62) reduceres eller øges, og/eller de anvendte fjedre erstattes med fjedre med en lavere eller større fjederkraft.

11. Vindmølle (10) med et tårn (20) af flere tårnsektioner
25 ($22^I - 22^V$) og et på spidsen af tårnet (20) placeret maskinhus (40) og en rotor (30) med en i det væsentlige horisontal rotoraksel, opført ifølge en fremgangsmåde ifølge et af kravene 1 til 6, omfattende i det mindste et svingningsdæmpersystem ifølge et af kravene 7 til 10, som er placeret i tårnet (20)
30 under maskinhuset (40) i et øvre område i en øverste tårnsektion (22^V) på tårnet (20) og i sin egenfrekvens kan tilpasses til en grundsvingningsfrekvens i tårnråbygningen (24) uden påsat maskinhus (40) og til en grundsvingningsfrekvens i den fuldstændigt opførte vindmølle (10).

Fig. 1

a)



b)

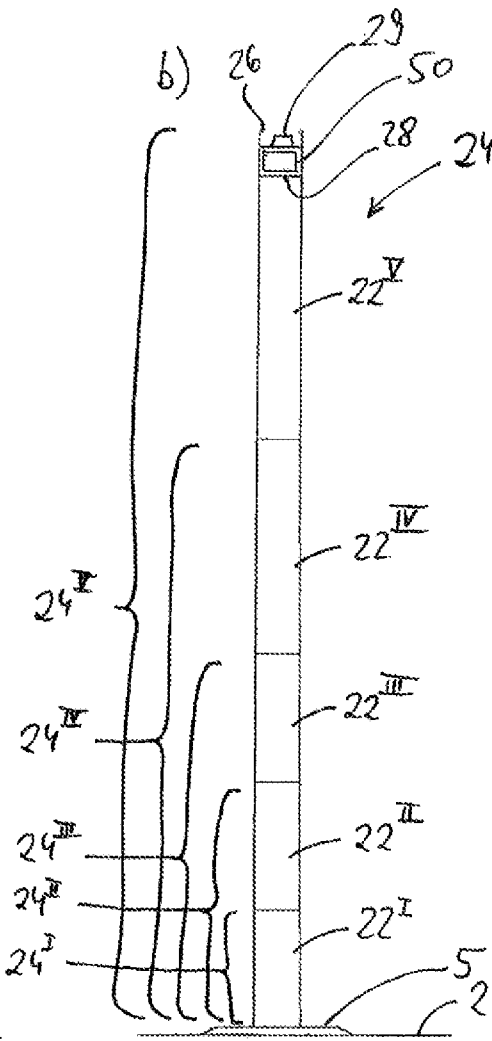


Fig. 2

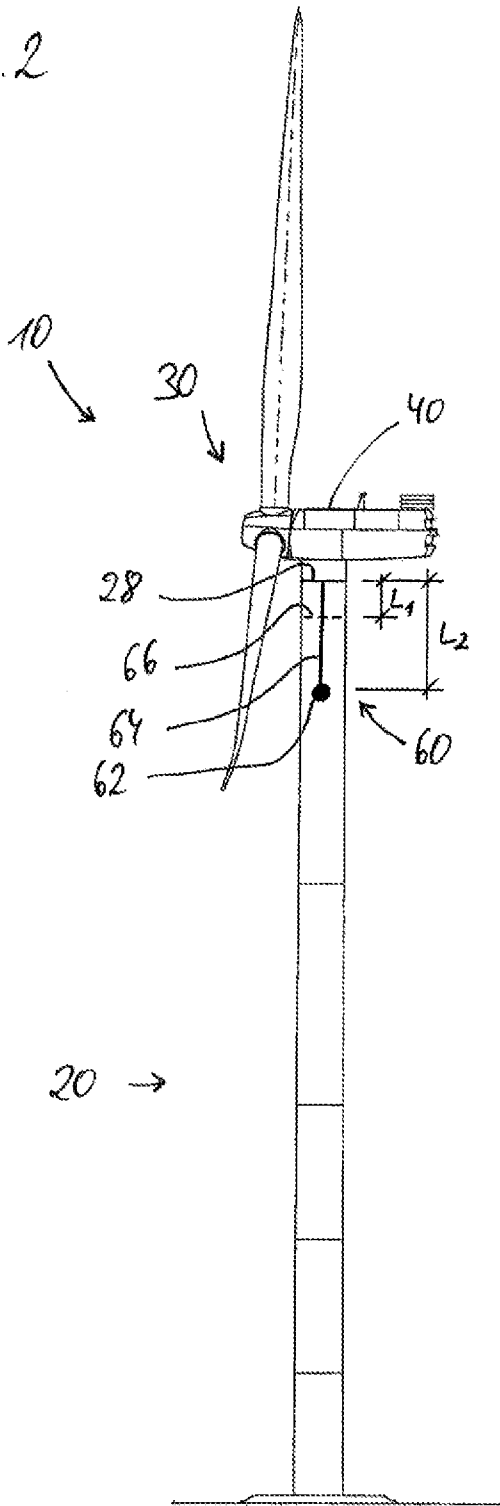


Fig 3

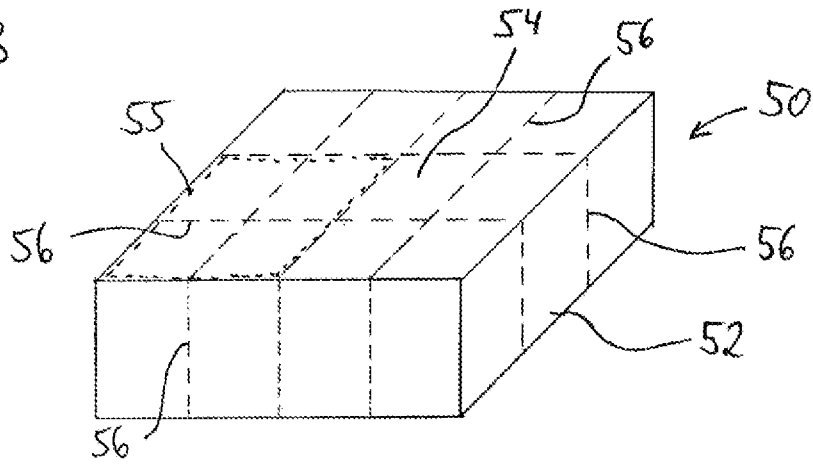


Fig 4

