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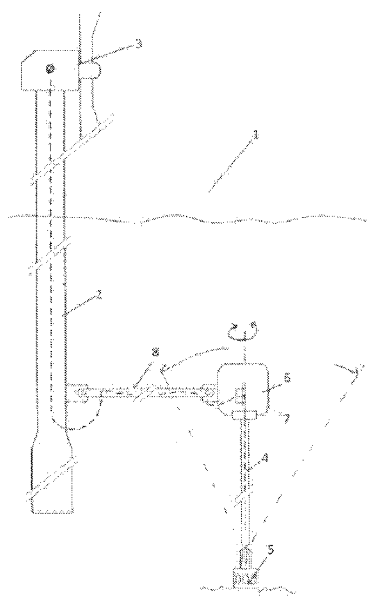

Fig. 1

(57) Abstract: The invention provides a floating windmill, comprising a floating element and a wind turbine. The floating windmill is distinguished in that it further comprises: a tension leg, an anchoring, a buoyancy element, a swivel and a cross bar, wherein the swivel is arranged in the buoyancy element. In operation, the floating windmill in operation is configured with the wind turbine in an upper end of the floating element extending up above the sea level, with a lower end or part of the floating element submerged in the sea, with the cross bar in one end connected to the lower part or end of the floating element and in the opposite end connected to the buoyancy element, with the buoyancy element fully submerged, preferably at safe draught depth below surface for service vessels and/or marine transport ships, with the tension leg arranged between the buoyancy element and the anchoring on the seabed. The floating windmill configured with the wind turbine in the upper end can weathervane freely around the buoyancy element, wherein in a low force condition when the forces by ocean current, wind and waves are low the floating element, the buoyancy element and the tension leg is oriented in substance in vertical direction and the cross bar is oriented in substance in horizontal direction, wherein in a high force condition when the forces by ocean current, wind and waves are high the shape of the floating element, cross bar, buoyancy element and tension leg is stretched by the forces to provide a shape like a lazy-s configuration, which change in shape and dynamic behavior reduce extreme stress levels.

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FLOATING WINDMILL

Technical Field

The present invention relates to anchored floating structures, such as floating windmills, also termed floating wind turbines. More specifically, the invention relates to a floating windmill with reduced cost compared to produced electric energy, if fabrication, transport, installation and maintenance is included in the cost and leveled out over the estimated lifespan of at least 20 – 30 years.

Background Art

The shift towards greener energy will be facilitated if the cost for floating wind energy can be reduced. Enormous areas offshore can thereby be available for electric energy produced by floating windmills. Floating energy islands or floating infrastructure hubs can also facilitate the shift towards greener energy.

The state-of-the-art with respect to floating windmills are presumably Hywind, WindFloat and Sway. However, cost is a limiting factor for the utilization of floating wind, and economic subsidizing is still required for the concepts to be economically viable.

New windmills leading to reduced cost would benefit the shift towards greener energy. The objective of the present invention is to provide one such new windmill. New floating energy islands or infrastructure hubs can also facilitate the shift towards greener energy. A further objective of the present invention is to provide said floating energy islands or infrastructure hubs.

Summary of invention

The invention provides a floating windmill, comprising a floating element and a wind turbine. The floating windmill is distinguished in that it further comprises:

a tension leg, an anchoring, a buoyancy element, a swivel and a cross bar, wherein the swivel is arranged in the buoyancy element,

wherein the floating windmill in operation is configured with the wind turbine in an upper end of the floating element extending up above the sea level, with a lower end or part of the floating element submerged in the sea, with the cross bar in one end connected to the lower part or end of the floating element and in the opposite end connected to the buoyancy element, with the buoyancy element fully submerged, preferably at safe draught depth below surface for service vessels and/or marine transport ships, with the tension leg arranged between the buoyancy element and the anchoring on the seabed,

wherein the floating element with the wind turbine in the upper end can weathervane freely around the buoyancy element, wherein in a low force condition when the forces by ocean current, wind and waves are low the floating element, the buoyancy element and the tension leg is oriented in substance in vertical direction and the cross bar is oriented in substance in horizontal direction, wherein in a high force condition when the forces by ocean current, wind and waves are high the shape of the floating element, cross bar, buoyancy element and tension leg is stretched by the forces to provide a shape like a lazy-s configuration, which change in shape and dynamic behavior reduce extreme stress levels.

In one preferable embodiment, the floating element is a spar buoy.

In other preferable embodiments, the floating element is a rectangular or triangular, polygonal, elliptic or circular floating or semi-submersible structure with one, two, three, four or more windmill towers.

The submerged part of the floating element can extend far below the point where the cross bar is connected, which is preferable for reducing or eliminating tilting of the floating element in downwind direction by the load of the wind on the turbine blades. Retaining an angle of the turbine blade plane in substance perpendicular to the wind direction increases efficiency.

The terms “vertical direction” of the floating element and “the cross bar is oriented in substance in horizontal direction between the buoyancy element and the floating element" are relative terms, not necessarily meaning literally vertical within a small margin or horizontal within a small margin. With a spar buoy as the floating element, and low force condition, the terminology will typically be literally as described, with other floating elements the terminology is relative, but the dynamic "stretching out" more or less to a lazy-s like shape by the forces at higher force condition is retained as an essential feature. This is correct also for embodiments with floating element retaining a vertical orientation even far into high force condition since the orientation change of the cross bar opens up the angle above the cross bar towards the floating element. If the floating element is a triangular, polygonal, quadratic, rectangular or otherwise shaped floating structure with one, two, three or more windmills, the vertical orientation of the floating element may be literally correct only for the windmill towers.

The axial movements by said stretching, combined with lateral movements by orientation change and position change, contribute in reducing the extreme stress in the structural elements. Said movements of the elements take up a significant part of the energy that else had resulted in higher stress levels in the structural elements. Said movements also reduce acceleration on the elements, since the dynamic flexibility works with the forces and strain. The effect, compared to a stiff rigid structure, apparently reduces the extreme stress level by at least 10%, 20%, 30% or 50%, depending on several factors and the prevailing conditions.

Preferably, the floating windmill comprises a releasable coupling between the cross bar and the buoyancy element. Preferably, the floating windmill also comprises a releasable coupling between the cross bar and the floating element. Releasable coupling in this respect means a coupling that can be coupled and decoupled/released at the windmill site offshore. Releasable couplings can preferably comprise guide funnels or guide structures and/or guidelines, for facilitates coupling and decoupling/release with or without assistance by an ROV (Remotely Operated Vehicle).

Preferably, the floating windmill includes no gear rim in the wind turbine/nacelle of the floating element. The swivel in the buoyancy element is sufficient to take up the rotation when weathervaning.

The invention also provides a method of fabrication, transport, installation and/or maintenance of the floating windmill, comprising to fabricate, transport, install or maintain the windmill in components.

Prefabrication of elements of the windmill, or parts of elements, preferably takes place at a fabrication site. The elements, or parts thereof are transported to a preassembly site or a transport position, from where transport to installation site takes place, where final assembly of parts of elements and/or the elements take place.

In one preferable embodiment, the method comprises that installation takes place by transporting the floating element and the wind turbine to the windmill site, where said components are coupled to the buoyancy element that has been preinstalled with an anchor on the seabed. Preferably, the floating element has the crossbar connected, wherein the installation involves connecting the crossbar to the buoyancy element. Alternatively, the buoyancy element has the crossbar connected, wherein the installation involves connecting the floating element to the crossbar. Preferably, the buoyancy element and/or the vessel used for the operation includes a buoyancy system allowing to bring the buoyancy element up and down between a surface position and a submerged position, whereby the coupling can take place near or at the surface position.

A variable, or no-rigid tension leg can be preferable, or combinations of rigid and flexible tension legs, as will be described in more detail below. More specifically, the tension leg can be one or more wires, such as three or four wires, or one or more rigid tension legs, such as three or four rigid tension legs. However, a combination of rigid and flexible tension legs is preferable, with the rigid tension legs, for example three rigid tension legs, extending from the anchor to an operation position of the buoyancy element at the largest operational depth of the buoyancy element, in which position the rigid elements can be fixedly coupled or decoupled to the buoyancy element, wherein a wire winch system preferably is integrated in the buoyancy element, operable to allow the buoyancy element to float controlled up to the surface and down to the operation position. Installation, coupling and decoupling of the crossbar are thereby facilitated. The rigid part or lower part of the tension legs preferably comprises truss structure, for increased torsional stiffness and/or for retaining relative positions. The coupling to the anchor may include a swivel, to reduce or eliminate torsional forces on the anchor.

In a preferable embodiment, the method comprises that only the anchor is preinstalled, and the rest of the structure, in one or several parts, are prefabricated and towed out to the position of the preinstalled anchor, where the anchor is coupled to the tension legs and any further separate elements are coupled together. A guideline with funnel and transponder is preferably arranged to the anchor for facilitating the operation.

In another preferable embodiment, the method comprises that maintenance takes place by replacing components on the windmill field, by installing a new component and transporting away the part that is damaged or need maintenance or repair, as one combined operation, preferably with by a single trip with a single vessel.

Some advantages of the floating windmill of the invention are:
Lower weight in the wind turbine/nacelle, due to no gear rim, which saves at least 3-5 times the corresponding floating element structure weight subsea.
Only one anchoring point is required, reducing safe zone area.
Self-directing orientation by weathervaning.
Self-dampening effect by shape variation, reducing extreme tensions.
Simplified cable routing, no swivel required in wind turbine/nacelle.
Simplified logistics, by fabrication into parts, transport into parts or partly preassembled structure, facilitating fabrication, transport and installation, allowing fewer and/or smaller vessels at lower rate than for larger structures.
Simplified maintenance, by replacing/maintenance of only the element requiring maintenance, on the field site, reducing windmill downtime and vessel operations time.

The total cost savings are roughly estimated to be more than 30%, 40% or even 50% per MWh produced, if fabrication, transport, installation and maintenance are included in the cost and leveled out over a lifespan of at least 20 or 30 years.

In some embodiments, the floating windmill of the invention is not only a floating windmill but also a floating energy island or a floating infrastructure hub, comprising one, two, three or more of the anchoring systems of claim 1. Embodiments with two or more anchoring systems as prescribed will have reduced or eliminated functionality for weathervaning but the essential reduction of extreme stress levels will be retained.

Brief description of drawings

Figure 1 illustrates an embodiment of a floating windmill of the invention.

Figure 2 illustrates an embodiment of a floating windmill of the invention, as viewed from the side, and

Figure 3 illustrates the embodiment of Figure 2 as viewed from an angle.

Detailed description of the invention

Reference is made to Figure 1, illustrating an embodiment of a floating windmill 1 of the invention, comprising a floating element 2 and a wind turbine 3. The floating windmill further comprises: a tension leg 4, an anchoring 5, a buoyancy element 6, a swivel 7 and a cross bar 8, wherein the swivel is arranged in the buoyancy element.

The illustrated floating windmill comprises a spar buoy as the floating element 2, with the wind turbine 3 in the upper end above the sea level. The lower end of the floating element is submerged in the sea and is connected to one end of the cross bar 8 and the opposite end of the cross bar is connected to the buoyancy element 6. The buoyancy element 6 is fully submerged and in a lower end is connected to the upper end or part of tension leg 4, which lower end or part of the tension leg is connected to the anchoring 5.

The anchoring preferably is a weight anchor or a suction anchor or a combination of a weight anchor and a suction anchor. Other anchors, such as pile anchors, can be used.

The floating element 2 can weathervane freely around the buoyancy element 6, as indicated by a rotation symbol above the buoyancy element.

The operation state as illustrated is a low force condition, meaning that the forces by ocean current, wind and waves are low, not forcing the components/elements significantly out of an equilibrium condition or orientation taken when no current, wind or waves are present. Not significantly out of an equilibrium condition or orientation means less than 5° out of orientation for elements oriented vertical or horizontal, as defined.

As the skilled person will understand, the equilibrium condition is deviated from by more than 5° in a high force condition, drawing out the shape of the configuration of the elements towards a lazy s shape. This is illustrated by a turning angle of the tensioning leg and buoyancy element by dashed line, exceeding 5°. For clarity, such dashed line deviation is indicated only for the buoyancy element as being pulled out of vertical orientation by high forces. The skilled person will understand that also the angular orientation of the cross bar and for many embodiments also the angular orientation of the floating element will change when stretched towards a lazy s shape.

As mentioned, Figure 2 illustrates an embodiment of a floating windmill of the invention, as viewed from the side in a low force condition, wherein the s-like shape of the structures is clear. Figure 3 illustrates the embodiment of Figure 2 as viewed from an angle. The numeric references are as for Figure 1, however, Figure 2 also refer to the waterline by numeric reference 9. Figures 2 and 3 are more to scale for a larger depth embodiment than the embodiment illustrated in Figure 1. The figures are in general but not necessarily out of scale, in order to illustrate features clearly.

Preferably, the anchor, the tension leg and the buoyancy element are preinstalled, whilst the floating element with the cross bar is coupled to the buoyancy element on the windmill site, wherein the cables are preinstalled out from the swivel, arranged on the cross bar and is pulled into the inner part of the floating element, with or without a coupling in dry location inside the floating element. Preassembling can be in alternative configurations, preferably involving coupling at least two preassembled groups of components with the cross bar in one or both ends.

The tension leg can be a flexible wire or a number of flexible wires, preferably combined with a buoyancy system in the buoyancy element or connectable from a vessel, such as a pump and required piping and valves for adjusting a ballast water level in the buoyancy element, for moving the buoyancy element up to or near the surface when coupling to the cross bar and down to operation position. The tension leg can also be or comprise a rigid element, or several rigid elements, such as three elements in triangular configuration, providing torsional stiffness. Rigid elements can have a cone and a guideline in the upper end, for allowing controlled deployment when installing, retrieving, and ballasting the buoyancy element with combined ballasting and hoisting. The buoyancy element preferably comprises a retrievable transponder with electrical and/or hydraulic coupling for controlled ballasting and controlled winching, wherein the buoyancy element comprises an electric or hydraulic winch and/or an electric or hydraulic pump or a hydraulic coupling to a ballast pump on the ship.

Preferably, also the buoyancy element comprises a releasable coupling, towards the tension leg.

Preferably, also the floating element comprises a buoyancy system and/or facilities for connecting to a buoyancy system on a vessel. The buoyancy system can be a pump, in the floating element or in a vessel, and required piping and valves for adjusting a ballast water level in the floating element. Thereby, installation, replacement or maintenance of the wind turbine, nacelle or parts thereof can be simplified by submerging more of the floating element.

Preferably, the submerging can be down to a level where the nacelle is reachable by a ship crane on the ship used for installation.

As the skilled person will know, the anchor can be a single anchor vertically below the buoyancy element in equilibrium position. However, also several anchors, such as suction anchors are possible embodiments within the term one anchor, arranged in substance close together as one unit below the buoyancy element but positioned apart as the soil conditions dictate for sufficient strength. One big weight anchor that can be weighted on site to sufficient weight/strength is a preferable embodiment in many shallow areas with relatively rigid bottom.

The invention also provides energy islands or energy hubs with or without windmills but with one or more of the maximum stress level reducing structure; a tension leg, an anchoring, a buoyancy element, preferably a swivel, and a cross bar, wherein the swivel, if present, is arranged in the buoyancy element, and wherein said structure is arranged as a dynamic s - lazy s structure stretched out from s to lazy s shape in high force conditions as defined in claim 1.

The floating windmill or energy island of the invention can preferably comprise vertical axis windmills since such windmills can be arranged closer together than horizontal axis windmills. No wind shadow, resulting in no requirement for weathervaning and no requirement for gear rim are further advantages by vertical axis windmills.

The floating windmill or energy island of the invention can preferably comprise a frame with numerous windmills that are self-aligning against the eye of the wind, preferably on a non-weathervaning energy island, or the frame itself weathervanes as a single floating windmill, wherein the frame preferably is arranged on a triangular floater or semi-submerged floater anchored according to the invention.

The floating windmill or energy island of the invention can preferably comprise water current turbines, suspended from the floating windmill or/and anchored, preferably retrievable for facilitating installation and maintenance.

The floating windmill or energy island of the invention can preferably comprise solar panels.
The floating windmill or energy island of the invention can preferably comprise batteries.

The floating windmill or energy island of the invention can preferably comprise any of the energy-producing structures herein described, in any combination, and/or coupling to standalone equipment in the surrounding area, thereby expanding the floating windmill of the invention into an energy island and/or an energy hub.

Claims

1.

Floating windmill, comprising a floating element and a wind turbine, c h a r a c t e r i s e d i n that the floating windmill further comprises:

a tension leg, an anchoring, a buoyancy element, a swivel and a cross bar, wherein the swivel is arranged in the buoyancy element,

wherein the floating windmill in operation is configured with the wind turbine in an upper end of the floating element extending up above the sea level, with a lower end or part of the floating element submerged in the sea, with the cross bar in one end connected to the lower part or end of the floating element and in the opposite end connected to the buoyancy element, with the buoyancy element fully submerged, preferably at safe draught depth below surface for service vessels and/or marine transport ships, with the tension leg arranged between the buoyancy element and the anchoring on the seabed,

wherein the floating element with the wind turbine in the upper end can weathervane freely around the buoyancy element, wherein in a low force condition when the forces by ocean current, wind and waves are low the floating element, the buoyancy element and the tension leg is oriented in substance in vertical direction and the cross bar is oriented in substance in horizontal direction, wherein in a high force condition when the forces by ocean current, wind and waves are high the shape of the floating element, cross bar, buoyancy element and tension leg is stretched by the forces to provide a shape like a lazy-s configuration, which change in shape and dynamic behavior reduce extreme stress levels.

2.

Floating windmill according to claim 1, comprising a releasable coupling between the cross bar and the buoyancy element.

3.

Floating windmill according to claim 1 or 2, comprising a releasable coupling between the cross bar and the floating element.

4.
Floating windmill according to claim 1, 2 or 3, including no gear rim in the upper end of the floating element, in the nacelle and/or wind turbine.

5.
Method of fabrication, transport, installation or maintenance of the floating windmill of any one of claim 1 - 4, comprising to fabricate, transport, install or maintain the windmill in components.

6.
Method according to claim 5, whereby installation takes place by transporting the floating element and the wind turbine to the windmill site, where said components are coupled to the buoyancy element that has been preinstalled with an anchor on the seabed, preferably the buoyancy element includes a buoyancy system allowing to bring the buoyancy element up and down between a surface position and a submerged position, whereby the coupling can take place near or at the surface position.

7.
Method according to claim 5, whereby maintenance takes place by replacing components on the windmill field, by installing a new component and transporting away the part that is damaged or need maintenance or repair, as one combined operation, preferably by a single trip with a single vessel.

8.
Method according to claim 5 or 6, whereby the anchor, the tension leg and the buoyancy element are preinstalled, whilst the floating element with the cross bar is coupled to the buoyancy element on the windmill site, wherein the cables are preinstalled out from the swivel, arranged on the cross bar and is pulled into the inner part of the floating element, with or without a coupling in dry location inside the floating element.

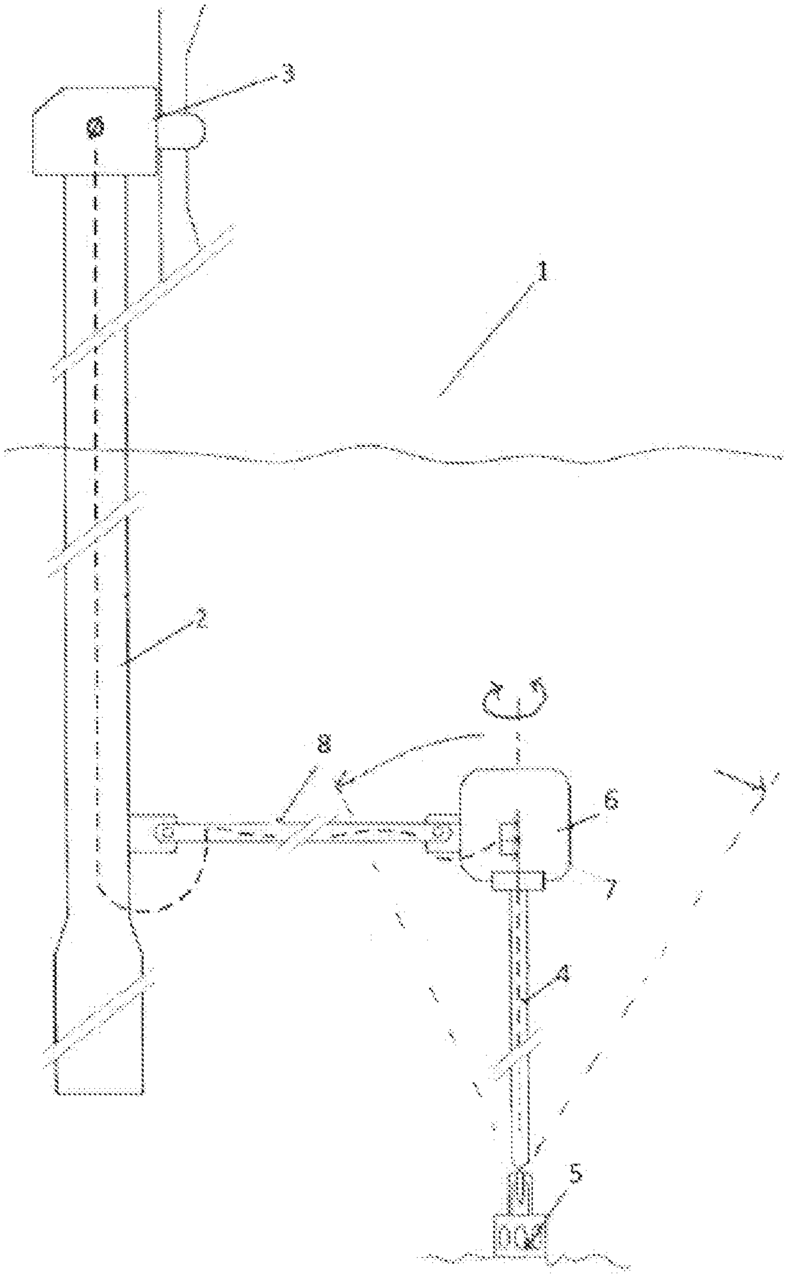

Fig. 1

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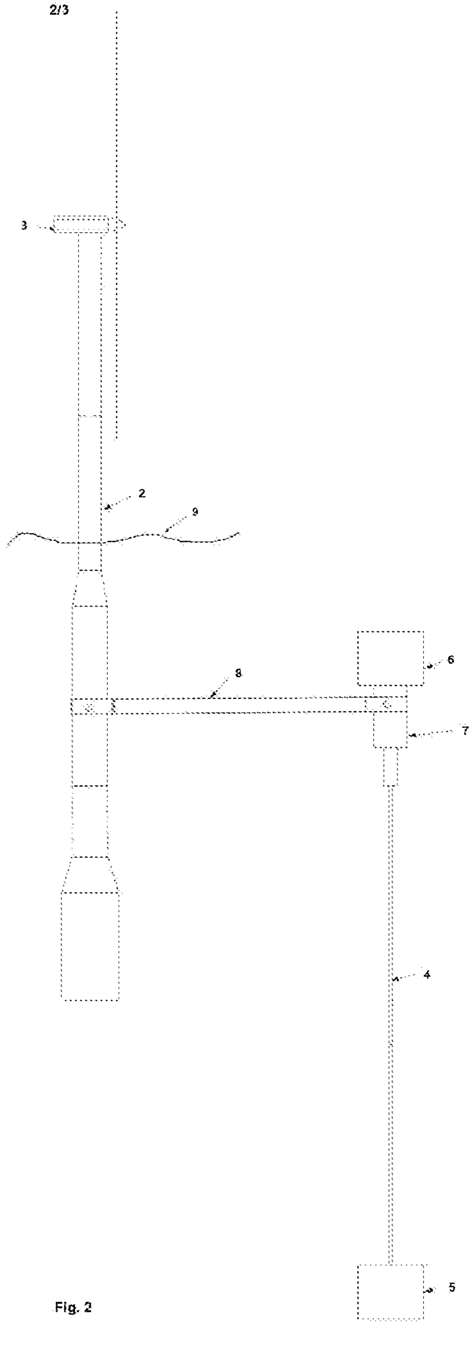

Fig. 2

3/3

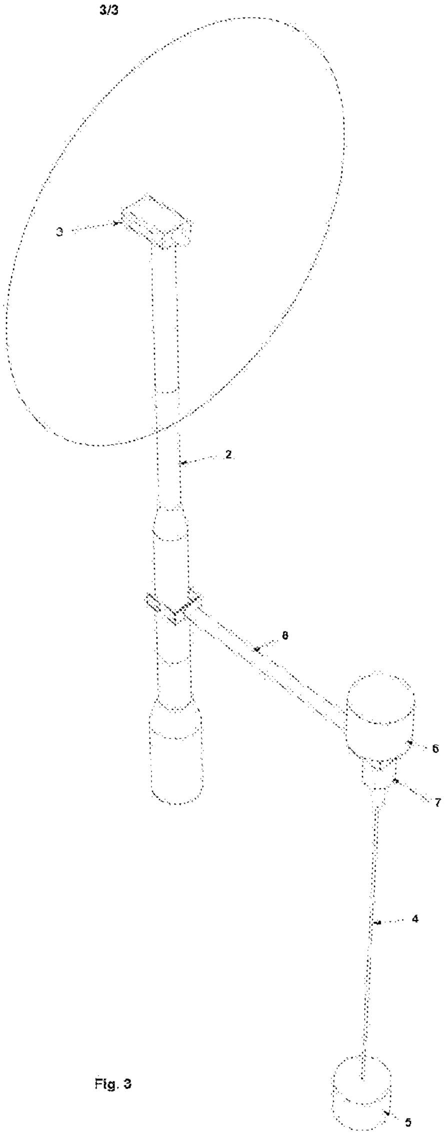

Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO2021/050143

A. CLASSIFICATION OF SUBJECT MATTER

F03D 13/25 (2016.01)i; E02D 27/42 (2006.01)i; B63B 21/50 (2006.01)i; B63B 35/44 (2006.01)i

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; E02D; B63B

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

DK, NO, SE, FI: Classes as above

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

EPODOC, WPI, FULL TEXT: ENGLISH, GERMAN, FRENCH

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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X	Paragraphs [0020], [0025], [0026], [0060]-[0062] and figures 1-8	1, 4, 5
Y		2, 3, 6-8
	WO 2010071433 A2 (SINGLE BUOY MOORINGS ET. AL.) 24 June 2010 (2010-06-24)	
Y	Page 10 line 22 – page 11 line 31, page 15 lines 5-12, claim 22 and figures 8-12 and 17-19	2, 3, 7, 8
	US 3899990 A (LECOMTE, C.) 19 August 1975 (1975-08-19)	
Y	Column 2 line 57 – colum 3 line 8 and figures 1-3, 7 and 8	6, 7, 8
	EP 0287173 A1 (SINGLE BUOY MOORINGS) 19 October 1988 (1988-10-19)	
Y	Column 3 line 58 – column 4 line 19	7, 8
	JP S61155089 A (MITSUI SHIPBUILDING ENG) 14 July 1986 (1986-07-14)	
A	Figures 1-5c	1-8

☐ Further documents are listed in the continuation of Box C. ☑ 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
- "D" document cited by the applicant in the international application
- "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
06 September 2021	**06 September 2021**

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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/NO2021/050143

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