(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
29 October 2015 (29.10.2015)

WIPO | PCT

(10) International Publication Number
WO 2015/164386 A1

(51) International Patent Classification:
B63B 35/44 (2006.01)

(21) International Application Number:
PCT/US2015/026893

(22) International Filing Date:
21 April 2015 (21.04.2015)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/982,258 21 April 2014 (21.04.2014) US

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

(54) Title: FLOATABLE SUPPORT STRUCTURE FOR AN OFFSHORE WIND TURBINE OR OTHER DEVICE

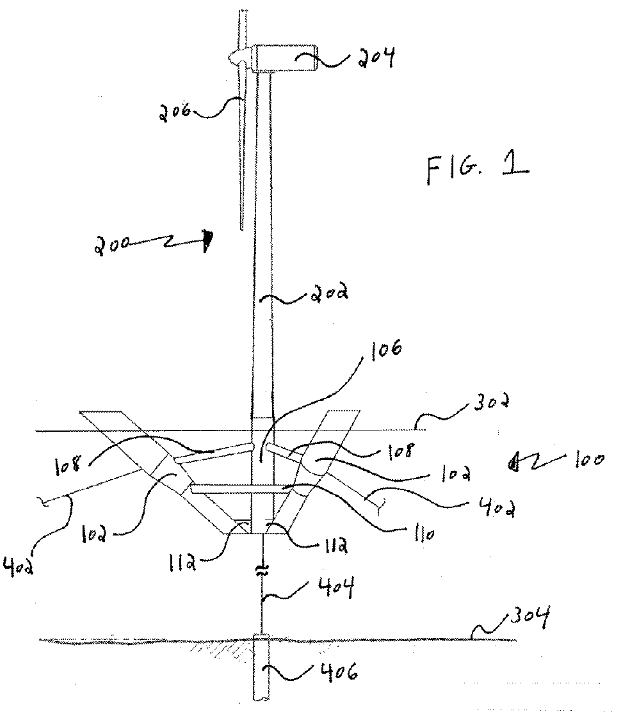

FIG. 1

(57) Abstract: An apparatus for supporting an additional structure near a surface of a body of water, and a system which includes the apparatus and further includes the structure attached to the apparatus. The apparatus and the system are each configured to assume a rest position and orientation when the apparatus or system is floating at the surface and when the body of water is substantially still, where the rest orientation defines a vertical direction extending from the surface to a keel at a lowermost position of the apparatus. The apparatus includes a support member, which, in use, is attached to the additional structure; and buoyant units. Each buoyant unit is attached to the support member at or near the keel and extends from the keel in a longitudinal direction of the buoyant unit, which longitudinal direction defines an angle of approximately 35-65 with respect to the vertical direction.

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FLOATABLE SUPPORT STRUCTURE FOR AN OFFSHORE WIND TURBINE OR OTHER DEVICE

CROSS-REFERENCE TO RELATED APPLICATION

[0001] This application claims priority to US Provisional Application Serial No. 61/982,258, filed April 21, 2014, the disclosure of which is hereby incorporated by reference.

TECHNICAL FIELD

[0002] The present invention relates to a floatable support structure configured to be anchored to the sea floor and to support an additional device such as an offshore wind turbine.

BACKGROUND OF THE INVENTION

[0003] A support structure for an offshore wind turbine must be stable and safe. Wind turbines can operate satisfactorily when motions due to wind current and waves are relatively small. However large motions of surge, sway, pitch, roll, yaw, and heave will result in inefficient operation or shutdown. Therefore, the support structure must have relatively small motions. The support structure motions are affected by the force of wind on the turbine blades, nacelle, and tower, by the wave and current forces on the submerged structure, by the period of the waves, by the period of the rotating turbine blades, and by the natural period of the entire structure, *i.e.* the time it takes to complete one cycle of motion when subjected to an excitation force. This period depends on the mass of the structure including the added mass of surrounding water, the stiffness of the structure itself (*e.g.* tower flexing and blade flexing), and the stiffness of the anchoring system of the structure.

[0004] If the period of the support structure is synchronous with the period of the waves, the wave forces will be amplified, leading to disruption of operations and/or structural failure. Therefore it is desirable to ensure that the natural period of the support structure differs substantially from the wave periods for all reasonably expected waves.

[0005] Vortex Induced Motions (VIMs) are another factor affecting the motions of a floating wind turbine support structure. VIMs are defined as motions caused by vortexes that form from current moving past a structure.

SUMMARY

[0006] The disclosure relates to an apparatus for supporting an additional structure near a surface of a body of water. Also disclosed is a system which includes the apparatus and further includes the structure attached to the apparatus. The apparatus and the system are each configured to assume a rest position and orientation when the apparatus or system is floating at the surface and when the body of water is substantially still, where the rest orientation defines a vertical direction extending from the surface to a keel at a lowermost position of the apparatus. The apparatus includes a support member, which, in use, is attached to the additional structure; and buoyant units. Each buoyant unit is attached to the support member at or near the keel and extends from the keel in a longitudinal direction of the buoyant unit, which longitudinal direction defines an angle of approximately 35°-65° with respect to the vertical direction.

[0007] Each of the buoyant units may have a certain cross-sectional area at a first position along the longitudinal direction, and a different cross-sectional area at a second position along the longitudinal direction. For example, each of the buoyant units may have a certain cross-sectional area at a first portion of the buoyant unit that is distal from the keel, and a smaller cross-sectional area at a second portion of the buoyant unit that is proximal to the keel. There may be a transitional portion of the buoyant unit between the first portion and the second portion, such as a tapered transitional portion.

[0008] Alternatively, each of the buoyant units may have a cross-sectional area that is substantially constant along the longitudinal direction.

[0009] The buoyant units may be symmetrically disposed around the vertical direction.

[0010] The buoyant units may be three buoyant units, four buoyant units, or more than four buoyant units.

[0011] At least a portion of each buoyant unit that is distal from the keel may include a buoyant material, whose density is lower than the density of the body of water. At least a portion of each buoyant unit that is proximal to the keel may include a ballast material, whose density is equal to or higher than the density of the body of water.

[0012] The apparatus or system may further include at least one anchor line or tether, configured to attach the apparatus to a substantially stationary position within the body of water. The anchor line or tether may include one or more catenary anchor lines, each attached to one of the buoyant units. The anchor line or tether may include one or more tendons, each attached to one of the buoyant units, and configured to assume a substantially vertical orientation to anchor the apparatus or system to the floor of the body of water.

[0013] The apparatus or system may further include a heave plate at the keel.

[0014] The floatable structure may include a wind turbine and associated tower. The support member may be attached to the tower.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Exemplary embodiments will be described in more detail with reference to the accompanying drawings, in which:

[0016] **FIG. 1** is an elevation view of an exemplary floatable support structure with a tower and turbine attached, and anchored to the sea floor with a vertical tendon at the keel and taut catenary anchors.

[0017] **FIG. 2A** is an enlarged elevation view of the support structure of **FIG. 1** without the tower and turbine attached, and with additional vertical tendons.

[0018] **FIG. 2B** is a view similar to **FIG. 2A**, showing an alternative embodiment of the shape of buoyant units.

[0019] **FIG. 3** is a plan view of the support structure of **FIGs. 1**, **2A**, and **2B** without the tower and turbine attached.

[0020] **FIGs. 4A-4D** are schematic illustrations showing the water plane area of an exemplary buoyant unit and its distance from the centroid of the structure, where:

[0021] **FIG. 4A** is a side view of a buoyant unit when the support structure is in its upright position;

[0022] **FIG. 4B** is a cross-sectional view showing the water plane area of the buoyant unit of **FIG. 4A** and the distance of the water plane area from the centroid of the structure;

[0023] **FIG. 4C** is a side view of the buoyant unit when the support structure is tilted significantly; and

[0024] **FIG. 4D** is a cross-sectional view showing the water plane area of the buoyant unit in the configuration of **FIG. 4C** and the distance of the water plane area from the centroid of the structure.

[0025] **FIG. 5** is an elevation view, similar to that of **FIG. 2**, showing a further embodiment of the support structure.

[0026] **FIG. 6** is a plan view of the support structure of **FIG. 5.**

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0027] Exemplary embodiments described herein provide a floatable support structure configured to be anchored to the sea floor and to support an offshore wind turbine or other device. Some embodiments are considered particularly useful for deep waters, such as in water depths greater than about 40 meters, and some embodiments can be used in depths of over one thousand meters.

[0028] Turning to **FIG. 1**, a floatable support structure **100** is shown supporting a wind turbine **200** and floating the wind turbine **200** on a water surface **302**. The floatable structure **100** is attached to the sea floor **304** by catenary anchor lines **402** or vertical tendons **404** or, as illustrated, by both catenary anchor lines **402** and a vertical tendon **404**.

[0029] With further reference to **FIGs. 2A**, **2B**, and **3**, the structure **100** includes buoyant units **102** which meet at the keel **104** of the structure and extend slopingly upward from the keel **104**. (As used herein, the keel **104** should be understood to be the bottommost point or area of the structure **100** when the structure **100** is in its upright position, which position is seen in **FIGs. 1**, **2A**, and **2B**. In other words, the horizontal line at the bottom of the structure **100** near where the tendon **404** attaches to the structure **100** in **FIGs. 1**, **2A**, and **2B** is the keel.) The structure **100** also includes a generally central support member **106** which attaches to the buoyant units **102** at the keel **104** and extends generally vertically therefrom. The support member **106** is configured to attach to and to support a tower **202** of the turbine **200**. The buoyant units **102** and the support member **106** are connected to one another by various braces **108**, **110** and connecting members **112**.

[0030] The buoyant units **102** are partly submerged in use, *i.e.* partly below the water surface **302**, as shown. The illustrated embodiments include three such buoyant units **102**, which slope outward from at or near the keel **104** to above the water surface **302**. In some presently preferred embodiments, three or more buoyant units **102** are provided. Each buoyant unit **102** is a generally tubular member whose diameter may vary along its length, as will be discussed in detail later. Each buoyant unit **102** intersects the support member **106** at an angle **θ** of approximately 35-65°. In other words, the longitudinal direction of each buoyant unit **102** is about 35-65° from the longitudinal direction of the support member **106**, which is vertical when the structure is in its upright position, *i.e.* not being rocked by waves or wind.

[0031] In the embodiment illustrated in **FIG. 2A**, each buoyant unit **102** is a generally tubular member whose diameter varies along its length to provide a larger cross-sectional area at the top portion of the buoyant unit **102** than at the bottom. In the alternative embodiment illustrated in **FIG. 2B**, the diameter is substantially constant along the length. Each buoyant unit **102** includes several compartments **102a**, **102b**, **102c**, separated by water-tight bulkheads **114**, along its length. There may also be smaller sub-compartments (not illustrated) within these compartments **102a**, **102b**, **102c**. The upper compartments **102a** may contain buoyant material, and the lower compartments **102c** may contain ballast material. The diameter and length of the upper compartment **102a** of each buoyant unit can be selected to achieve the required buoyant force and water plane area and resulting moment of inertia of the structure **100**'s cross section at the waterline **302**. An intermediate, or "transition" section **102b** connects the upper part **102a** of each buoyant unit **102** to the lower part **102c** of the buoyant unit **102**. In the embodiment illustrated in **FIG. 2A**, the lower part **102c** has a smaller cross-sectional area than the upper part **102a**. Depending on requirements for stability, a large portion of each buoyant unit **102** will be filled with ballast. Therefore ballast requirements as well as buoyancy requirements will dictate the length and cross-sectional area of each part **102a**, **102b**, **102c** of each buoyant unit **102**.

[0032] In a presently preferred embodiment, both the buoyant units **102** and the support member **106** are steel tubular members, which may include ring stiffeners and/or longitudinal stiffeners on the interior to hold the round shape and to resist hydrostatic pressure. In a presently particularly preferred embodiment, the units **102** and member **106** include ring stiffeners, and may additionally include longitudinal stiffeners.

[0033] The tower **202** is supported by the support member **106**. The tower **202** extends from the support member **106** to high above the water surface **302** to support the wind turbine **200**. In more detail, the tower **202** supports the nacelle **204** which supports the turbine rotor blades **206**, and which contains the controls, the generator, and other required components.

[0034] The buoyant units **102** are connected to the support member **106** by braces **108**. The buoyant units **102** are connected to one another by braces **110**. Near the keel **104**, the buoyant units **102** are further connected to the support member **106** by connecting members **112**.

[0035] The support structure **100** is mounted to the sea floor **304** by catenary anchor lines **402**, which may include, for example, chain and/or wire rope, and/or polyester.

[0036] The support structure **100** may additionally or alternatively be attached to the sea floor **304** by a vertical tether such as a tendon or tendons **404**. In some embodiments, the tether or tethers may be wire ropes, chains, polyester ropes, or steel or metal tubes. By selecting an appropriate length, modulus of elasticity, and/or cross-sectional area of the tendon or tendons (in addition to further design considerations which will be discussed later with reference to **FIGs. 4A-4D**), the natural period of the structure **100** in heave, surge, sway, pitch, roll, and yaw can be made not to coincide with the wave period of any waves that can be expected in the particular area at which the support structure **100** is installed. As is further seen in **FIGs. 2A** and **2B**, the tendon or tendons **404** can be attached to the structure **100** at or near the keel **104** and/or at one or more of the buoyant units **102**. In a presently preferred embodiment, one tendon **404** is attached at each of the buoyant units **102**. In practice, it is unlikely that three anchor lines **402** would be used in conjunction with three tendons **404** at the buoyant units **102** and an additional tendon **404** at the keel **104**, as is illustrated. These illustrations are provided for the sake of completeness, to illustrate many possible attachment locations of anchor lines and tendons.

[0037] The tendon or tendons **404** may be attached to the sea floor **304** via an anchor or anchors **406**. Depending on the applied force from the tendon **404** and the sea floor conditions, each anchor may be a suction pile, a driven pile, a drilled and grouted pile, a gravity anchor, or any anchor with the capacity to transmit the tendon forces to the sea floor.

[0038] It will be appreciated that the support structure **100** can be fabricated, assembled, and launched at a quay, uprighted, then outfitted with the tower **202** and wind turbine **200** all at quay site. The assembled wind turbine **200** and support structure **100** can then be towed in upright position to its installation site and then be attached to previously installed anchors **406** or catenary anchor lines **402**.

[0039] In the illustrated embodiments, the support structure **100** is shown supporting an offshore wind turbine **200** and associated tower **202**. The structure **100** can also be used to support any other device, such as an electrical substation, or for oil and gas exploration and production.

[0040] In some unillustrated embodiments, the support structure **100** is used to support a platform for a support station rather than a turbine **200**. Since these platforms are generally rectangular in plan view, the structure will typically have four buoyant units **102** rather than the three buoyant units **102** illustrated, each of which will attach to the platform at or near a corner thereof. In a presently preferred embodiment, the support member **106** extends through a blind hole or a through hole at the center of the platform to provide further support.

[0041] Turning now to **FIGs. 4A-4D**, the stability of the exemplary structure **100** will now be discussed. It will be appreciated that the stability of the structure **100** is proportional to **I / V**, where **I** is the moment of inertia of the water plane area (for the hydrodynamic definition of moment of inertia, as opposed to the mass moment of inertia), and **V** is the volume of water displaced by the structure 100. For the sake of simplicity, **FIGs. 4A-4D** illustrate the stability of a single one of the buoyant units **102**. It will further be appreciated that the moment of inertia **I** is proportional to $\mathbf{A}\boldsymbol{\ell}^2$, where **A** is the water plane area of the buoyant unit **102**, in other words, the cross-sectional area of the buoyant unit **102** that is presented to the surface of the water (*i.e.* the cross-section taken vertically, as opposed to along the longitudinal axis of the buoyant unit **102**), and $\boldsymbol{\ell}$ is the horizontal distance from the centroid of the water plane area of the buoyant unit **102** to the centroid of the water plane area of the entire structure **100**.

[0042] Turning to **FIG. 4A**, one of the buoyant units **102** is shown along with the support member **106**, when the structure **100** is upright, *i.e.* not being rocked by waves or wind. The additional buoyant units **102** are omitted from these **FIGs.** for simplicity. The orientation of the buoyant unit **102** in **FIG. 4A** is the same as that illustrated in **FIGs. 1**, **2A**, and **2B**. Assuming a circular cross-section for the upper part **102a** of the buoyant unit **102** (taken along the longitudinal direction of the buoyant unit **102**), the water plane area, *i.e.* the cross-section presented to the water surface **302**, is elliptical, as seen in **FIG. 4B**. The minor diameter $\mathbf{d_{minor}}$ of the ellipse is equal to the cross-sectional (along the longitudinal axis) diameter of the unit **102**, $\mathbf{d_{minor}} = \mathbf{d_{unit}}$. The major diameter $\mathbf{d_{major,1}}$ is the distance between where the left and right edges of the unit **102** intersect the waterline **302** in **FIG. 4A**.

Elementary trigonometry tells us that this distance $\mathbf{d}_{\mathbf{major,1}} = \mathbf{d}_{\mathbf{unit}} / \sin \boldsymbol{\alpha}$, where $\boldsymbol{\alpha}$ is the angle at which the unit **102** intersects the water line **302**, *i.e.* $\boldsymbol{\alpha} = \mathbf{90° - \theta}$. The horizontal distance ℓ_1 from the center of the ellipse to the centroid of the structure **100**, which in this case is the center of the water plane area of the support unit **106**, is also shown in **FIG. 4B**.

[0043] Turning now to **FIG. 4C**, the structure **100** is shown tilted dramatically to the left. Again, the water plane area of the buoyant unit **102** is elliptical, as seen in **FIG. 4D**. The minor diameter $\mathbf{d}_{\mathbf{minor}}$ is again equal to $\mathbf{d}_{\mathbf{unit}}$. However, $\mathbf{d}_{\mathbf{major,2}}$ is now much larger. $\mathbf{d}_{\mathbf{major,2}} = \mathbf{d}_{\mathbf{unit}} / \sin \boldsymbol{\beta}$, where $\boldsymbol{\beta}$ is the new angle at which the unit **102** intersects the water line **302**. The horizontal distance ℓ_2 from the centroid of the water plane area of the buoyant unit **102** to the centroid of the structure **100** is also larger than that of **FIG. 4B**, since the center of the water plane area of the buoyant unit **102** is farther to the left due to the larger major diameter $\mathbf{d}_{\mathbf{major,2}}$. Note that in this case, the centroid of the water plane area of the entire structure **100** is no longer coincident with the centroid of the water plane area of the support member **106**, but is shifted slightly to the left. However, in practice, $\ell_2 > \ell_1$. Thus, the contribution of each buoyant unit **102** to the moment of inertia **I** of the structure **100**, which is proportional to $\mathbf{A}\ell^2$, increases when the respective unit **102** tips, providing increased stability when the structure **100** is impacted by waves or wind.

[0044] As was mentioned in the background section, a floating support structure should be subjected to relatively small motions when affected by wind, waves, and current in the directions of surge, sway, pitch, roll, yaw, and heave. The natural period depends on, among other parameters, the mass of the structure. The sloping buoyant units **102** of the above-described exemplary embodiments have a plan view that presents a large area exposed to water above and below the units. This results in a large added mass when considering heave, *i.e.* vertical motions, of the floatable structure.

[0045] Turning now to **FIGs. 5** and **6**, in a further alternative embodiment, the structure **100** further includes a heave plate **150**. It will be appreciated that, in embodiments with a vertical tendon or tendons **404**, heave may not be much of a concern once the structure **100** is anchored to the sea floor **304** with the tendon or tendons **404**, but heave can be a problem when the structure **100** is being towed from the quay to the installation site. Furthermore, in embodiments without a vertical tendon or tendons **404**, such as embodiments in which the structure **100** is secured with catenary anchor lines **402** and not tendons **404**, heave may be a concern even once the structure **100** is installed. Therefore, in some embodiments, the structure **100** further includes the heave plate **150**, which minimizes heave while the structure **100** is being towed to the installation site and/or after installation.

[0046] A heave plate is typically generally plate-shaped; *i.e.* has two roughly parallel planar surfaces and is relatively thin in the direction perpendicular to these planes. The planar surfaces are typically disposed perpendicular to the direction of heave (*i.e.* roughly horizontal, parallel to the surface of the water **302** and to the sea floor **304**) for increasing the effective mass of the structure to which they are attached (in this case the structure **100**). A plate so attached affects the dynamic behavior of the structure **100** by increasing the effective mass and the viscous drag in the heave (vertical) direction. The heave plate **150** can be any relatively thin square, circular, rectangular, or any other shape of plate, and can either be solid or have holes punched in it.

[0047] In the illustrated embodiment, the heave plate **150** is circular, and is strengthened by hexagonal ridges **152**. The shape of the plate **150** and ridges **152** are exemplary only and are in no way intended to be limiting. The heave plate **150** may have any shape in plan view and may have any number and configuration of ridges and/or holes on or in it.

[0048] To ensure that the period of the support structure differs substantially from all expected wave periods, the stiffness of the lines **402**, **404** can be selected accordingly, for example, by selecting an appropriate material. Additionally or alternatively, the mass of the structure can be selected, for example, by adding or subtracting ballast.

[0049] Since VIMs are particularly pronounced on current moving past vertical, column-like elements, in presently preferred embodiments, the buoyant units are sloped. The result is that the formation of vortexes are disrupted and VIMs are diminished.

[0050] Another feature of some of the above-described exemplary embodiments is that the very large cost of offshore construction can mostly be avoided. Except for the preset anchors and their attachment to the floatable structure, the fabrication, assembly, launching and outfitting of the complete wind turbine structure can be accomplished at or near the quay. This will, however, require reasonably deep water at the quay and no overhead obstructions that would interfere with towing to the installation site. This feature is aided by the sloping buoyant units and the fact that they intersect the water surface with a large elliptical waterplane area at a large distance from the centerline of the structure. A requirement for stability for a floating body is that the body's metacenter be above the center of gravity of the body. The metacentric height (*i.e.* the distance between the center of gravity and the metacenter) is equal to the moment of inertia of the waterplane area divided by the volume of displaced water plus or minus the distance between the centers of buoyancy and gravity when the body is in equilibrium. The configuration of the embodiments described herein, with a large separation between each buoyant unit's waterplane area, results in a high metacenter and good stability both when free floating while being towed and also when anchored.

[0051] The combination of small motions (due to the structure having a natural period that is not synchronous with wave periods), reduced vortex induced motions, and good stability due to a high metacenter, results in a safe and stable floating structure. The fact that most offshore construction can be avoided results in an economical installation.

[0052] As will be understood by those skilled in the art, the present invention may be embodied in other specific forms without departing from the essential characteristics thereof. Many other embodiments are possible without departing from the essential characteristics thereof. Many other embodiments are possible without deviating from the spirit and scope of the invention. These other embodiments are intended to be included within the scope of the present invention, which is set forth in the following claims.

WHAT IS CLAIMED IS:

1. An apparatus for supporting an additional structure near a surface of a body of water,

wherein the apparatus is configured to assume a rest position and orientation when the apparatus is floating at the surface and when the body of water is substantially still, wherein the rest orientation defines a vertical direction extending from the surface to a keel at a lowermost position of the apparatus,

the apparatus comprising:

a support member configured to be attached to the additional structure; and

a plurality of buoyant units, wherein each buoyant unit is attached to the support member at or near the keel and extends from the keel in a generally longitudinal direction of the buoyant unit, wherein the longitudinal direction of each buoyant unit defines an angle of approximately 35°-65° with respect to the vertical direction.

2. The apparatus of claim 1, wherein each of the buoyant units comprises a first cross-sectional area at a first position along the longitudinal direction, and a second, different cross-sectional area at a second position along the longitudinal direction.

3. The apparatus of claim 1, wherein each of the buoyant units comprises a first cross-sectional area at a first portion of the buoyant unit disposed distal from the keel, and a second, smaller cross-sectional area at a second portion of the buoyant unit disposed proximal to the keel.

4. The apparatus of claim 3, wherein each of the buoyant units further comprises a transitional portion of the buoyant unit disposed between the first portion and the second portion.

5. The apparatus of claim 4, wherein a cross-section at the transitional portion is tapered.

6. The apparatus of claim 1, wherein each of the buoyant units comprises a cross-sectional area that is substantially constant along the longitudinal direction.

7. The apparatus of claim 1, wherein the buoyant units are symmetrically disposed around the vertical direction.

8. The apparatus of claim 1, wherein the plurality of buoyant units comprises three buoyant units.

9. The apparatus of claim 1, wherein the plurality of buoyant units comprises at least four buoyant units.

10. The apparatus of claim 1, wherein at least a portion of each buoyant unit that is distal from the keel comprises a buoyant material, wherein a density of the buoyant material is lower than a density of the body of water.

11. The apparatus of claim 1, wherein at least a portion of each buoyant unit that is proximal to the keel comprises a ballast material, wherein a density of the ballast material is equal to or higher than a density of the body of water.

12. The apparatus of claim 1, further comprising at least one anchor line or tether, configured to attach the apparatus to a substantially stationary position within the body of water.

13. The apparatus of claim 12, wherein the anchor line or tether comprises one or more catenary anchor lines, wherein each of the catenary anchor lines is attached to one of the buoyant units.

14. The apparatus of claim 12, wherein the anchor line or tether comprises one or more tendons, wherein each of the tendons is attached to one of the buoyant units, wherein each of the tendons is configured to assume a substantially vertical orientation to anchor the apparatus to a floor of the body of water.

15. The apparatus of claim 1, further comprising a heave plate disposed at the keel.

16. A floatable system, comprising:

a floatable structure; and

an apparatus for supporting the floatable structure near a surface of a body of water,

wherein the system is configured to assume a rest position and orientation when the system is floating at the surface and when the body of water is substantially still, wherein the rest orientation defines a vertical direction extending from the surface to a keel at a lowermost position of the apparatus,

the apparatus comprising:

a support member, wherein the support member is attached to the additional structure; and

a plurality of buoyant units, wherein each buoyant unit is attached to the support member at or near the keel and extends from the keel in a generally longitudinal direction of the buoyant unit, wherein the longitudinal direction of each buoyant unit defines an angle of approximately 35°-65° with respect to the vertical direction.

17. The system of claim 16, wherein each of the buoyant units comprises a first cross-sectional area at a first position along the longitudinal direction, and a second, different cross-sectional area at a second position along the longitudinal direction.

18. The system of claim 16, wherein each of the buoyant units comprises a first cross-sectional area at a first portion of the buoyant unit disposed distal from the keel, and a second, smaller cross-sectional area at a second portion of the buoyant unit disposed proximal to the keel.

19. The system of claim 18, wherein each of the buoyant units further comprises a transitional portion of the buoyant unit disposed between the first portion and the second portion.

20. The system of claim 19, wherein a cross-section at the transitional portion is tapered.

21. The system of claim 16, wherein each of the buoyant units comprises a cross-sectional area that is substantially constant along the longitudinal direction.

22. The system of claim 16, wherein the buoyant units are symmetrically disposed around the vertical direction.

23. The system of claim 16, wherein the plurality of buoyant units comprises three buoyant units.

24. The system of claim 16, wherein the plurality of buoyant units comprises at least four buoyant units.

25. The system of claim 16, wherein at least a portion of each buoyant unit that is distal from the keel comprises a buoyant material, wherein a density of the buoyant material is lower than a density of the body of water.

26. The system of claim 16, wherein at least a portion of each buoyant unit that is proximal to the keel comprises a ballast material, wherein a density of the ballast material is equal to or higher than a density of the body of water.

27. The system of claim 16, further comprising at least one anchor line or tether, configured to attach the apparatus to a substantially stationary position within the body of water.

28. The system of claim 27, wherein the anchor line or tether comprises one or more catenary anchor lines, wherein each of the catenary anchor lines is attached to one of the buoyant units.

29. The system of claim 27, wherein the anchor line or tether comprises one or more tendons, wherein each of the tendons is attached to one of the buoyant units, wherein each of the tendons is configured to assume a substantially vertical orientation to anchor the system to a floor of the body of water.

30. The system of claim 16, wherein the floatable structure comprises a wind turbine and associated tower.

31. The system of claim 30, wherein the support member is attached to the tower.

32. The system of claim 16, further comprising a heave plate disposed at the keel.

33. A support system for supporting a structure adjacent to a surface of a body of water, comprising:

a support member defining a resting axis;

a plurality of buoyant units attached to the support member at or near a keel of the support system for enhancing buoyancy thereof and for reducing vortex induced vibration, wherein each of the buoyant units is at least partially filled with buoyant material such that each of the buoyant units has a net buoyancy which helps support the structure, and wherein each of the buoyant units defines a longitudinal direction, and wherein the longitudinal direction of each buoyant unit defines an angle of approximately 35°-65° with respect to the resting axis of the support member.

34. The support system of claim 33, wherein the longitudinal direction of each buoyant unit is not parallel to the longitudinal direction of any of the other buoyant units.

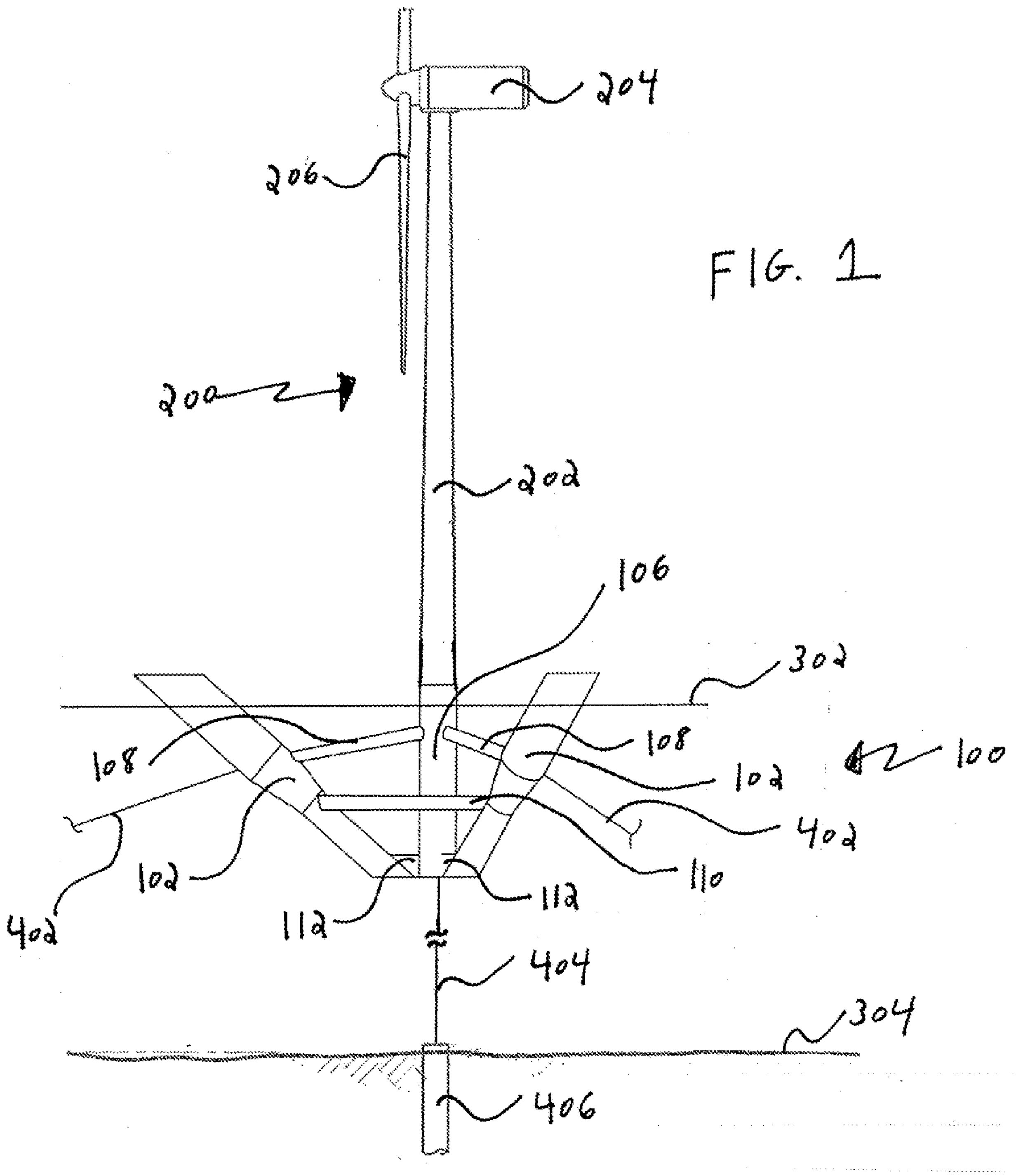
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FIG. 1

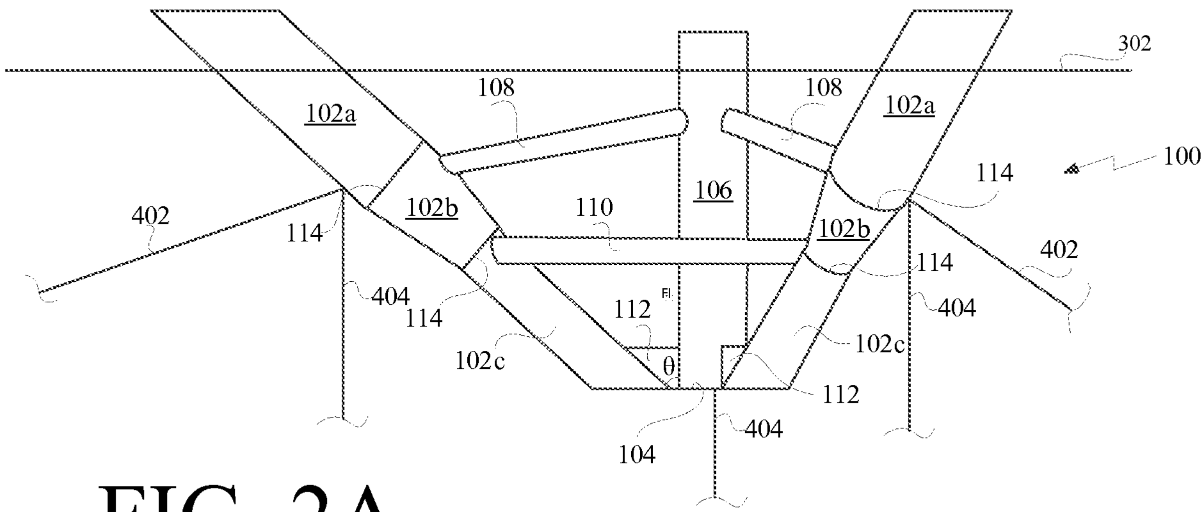

FIG. 2A

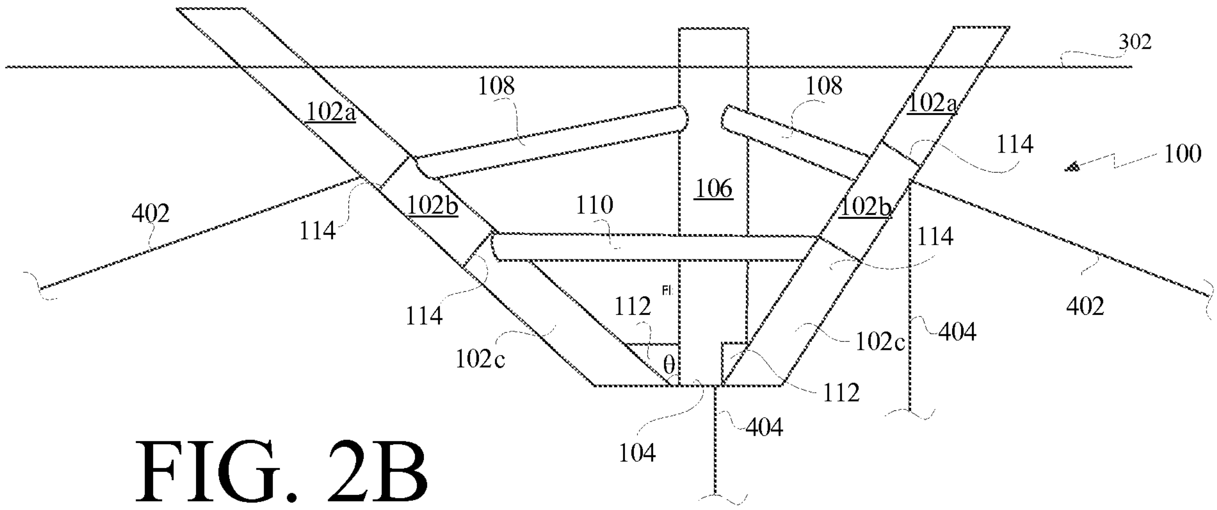

FIG. 2B

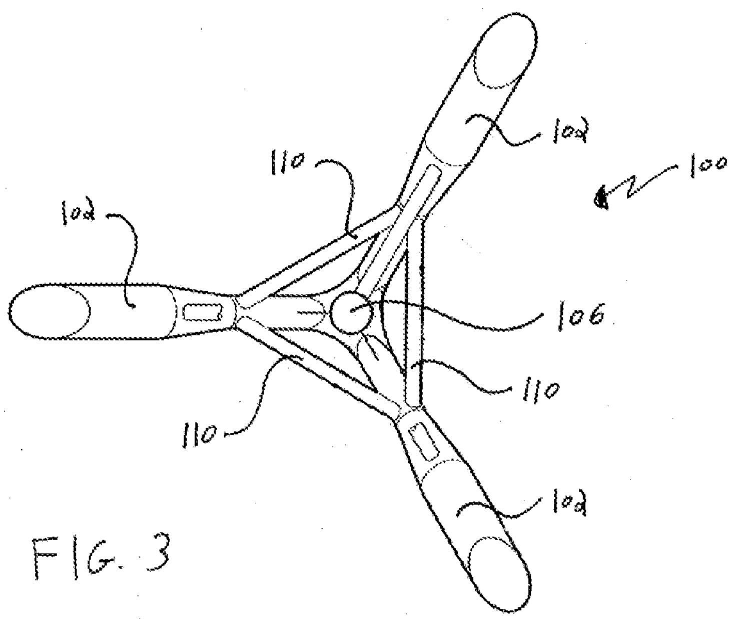

FIG. 3

FIG. 4B

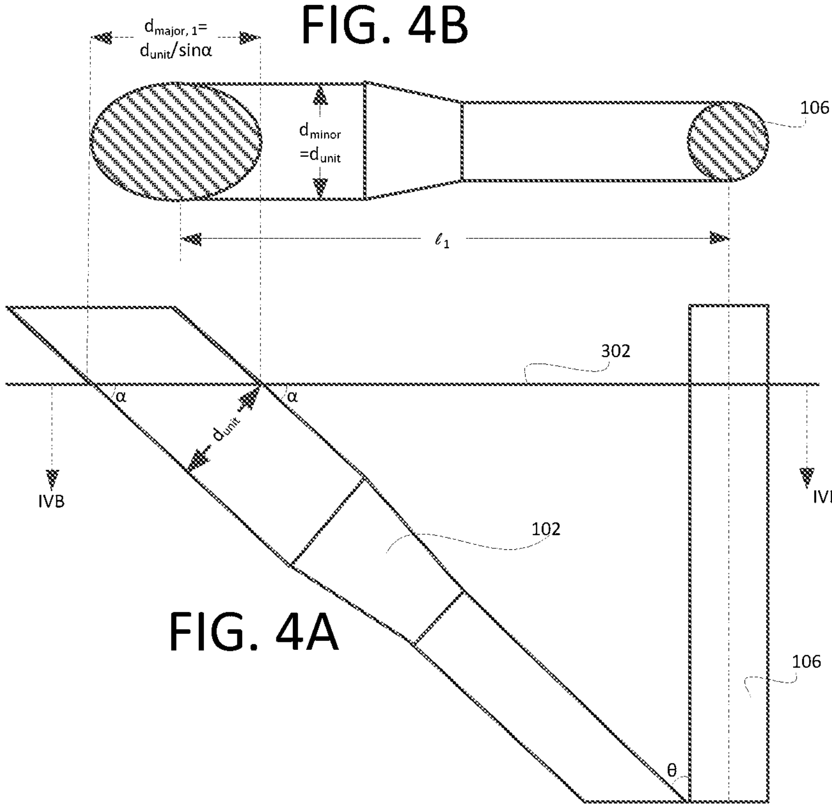

FIG. 4A

FIG. 4D

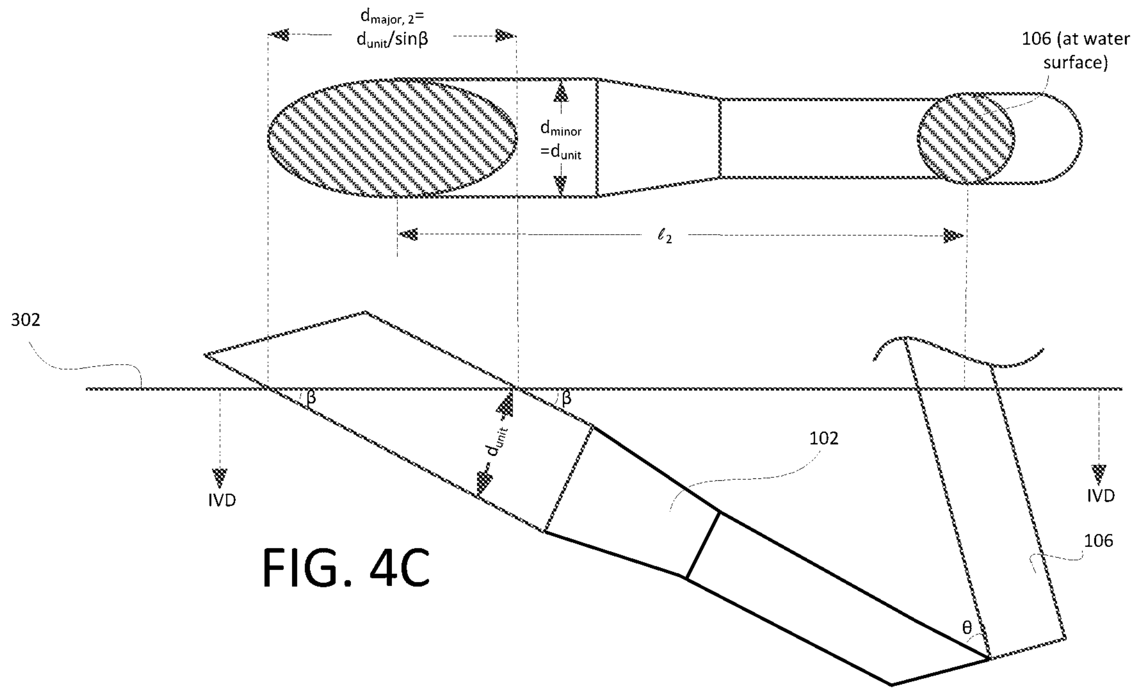

FIG. 4C

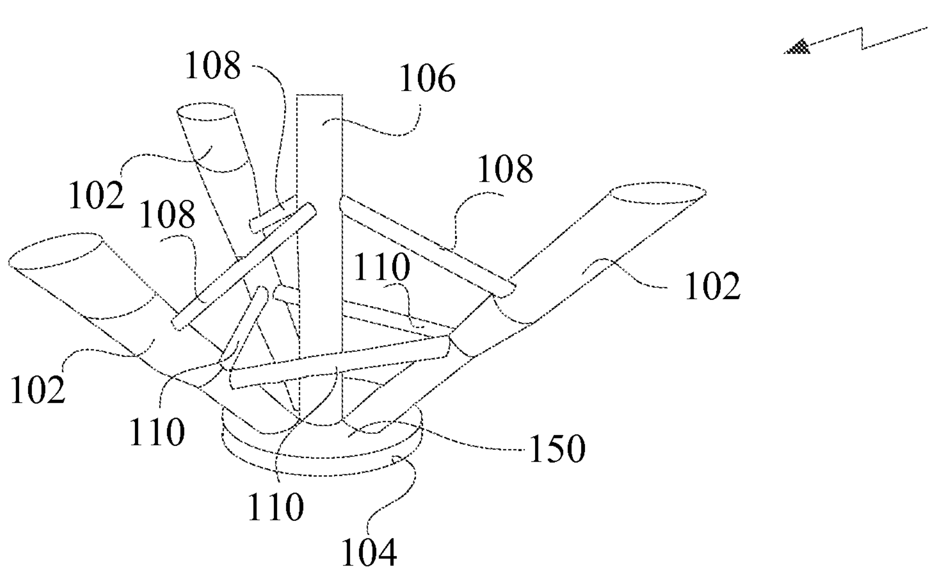
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FIG. 5

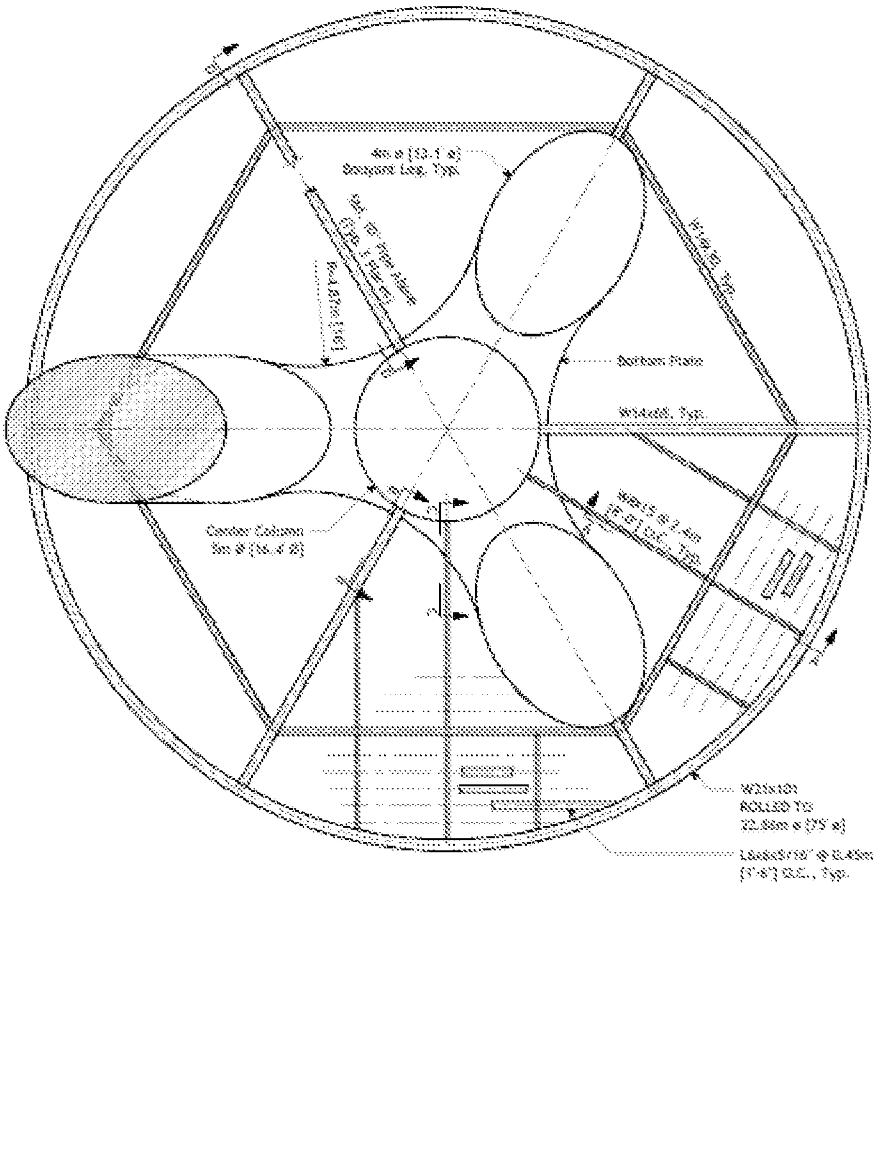
Bottom Plate
Center Column

FIG 6

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2015/026893

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - B63B 35/44 (2015.01)
CPC - B63B 35/44 (2015.05)
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)
IPC(8) - B63B 1/10, 1/12, 3/26, 9/06, 21/50, 35/00, 35/38, 35/44, 39/00; E02B 17/00, 17/02 (2015.01)
CPC - B63B 1/10, 1/12, 3/26, 9/06, 21/50, 35/00, 35/38, 35/44, 39/00; E02B 17/00, 17/02 (2015.05)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 114/264, 265, 266; 405/195.1, 224 (keyword delimited)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Orbit, Google Patents, Google.
Search terms used: anchor, tether, wind turbine, windmill, float, pontoon, catenary

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2012/0318186 A1 (THIEFFRY) 20 December 2012 (20.12.2012) entire document	1, 6-11, 15, 16, 21-26, 30-34
Y		2-5, 12-14, 17-20, 27-29
Y	US 6,851,894 B1 (PERRET et al) 08 February 2005 (08.02.2005) entire document	2-5, 12, 14, 17-20, 27, 29
Y	WO 2009/068712 A1 (ACCIONA ENERGIA, S.A.) 04 June 2009 (04.06.2009) see machine translation	12, 13, 27, 28
A	US 2012/0294681 A1 (WONG et al) 22 November 2012 (22.11.2012) entire document	1-34
A	US 2013/0276691 A1 (THIEFFRY et al) 24 October 2013 (24.10.2013) entire document	1-34
A	US 2006/0165493 A1 (NIM) 27 July 2006 (27.07.2006) entire document	1-34

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:
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"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
26 June 2015	21 JUL 2015

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