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(54) **PLATFORM FOR UNDERWATER TURBINES**

PLATTFORM FÜR UNTERWASSERTURBINEN

PLATE-FORME POUR TURBINES SUBAQUATIQUES

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Description

[0001] This invention relates to an underwater platform for carrying turbines capable of generating electrical power in a stream flow, and in particular to deep water turbines operable in fast-flowing tidal streams.

[0002] GB-A-2348249 discloses a tethered device consisting of a buoyancy chamber having underwater turbines mounted on a cross arm thereof. By varying the buoyancy of the chamber, the device can be rolled over between a generally horizontal floating condition, in which the turbines are accessible for maintenance, and a generally upright submerged condition in which the turbines are capable of generating electricity.

[0003] GB-A-2450624 discloses an improvement whereby auxiliary buoyancy chambers are provided to the side of a single main buoyancy chamber. The auxiliary chambers stabilize the main chamber against roll movement, and can be ballasted preferentially to induce rollover between the horizontal floating condition and the submerged generating condition.

[0004] GB-A-2447774 discloses an underwater turbine array which moves between submerged and surface conditions under control of a sea-bed winch.

[0005] GB-A-2471874 discloses an underwater turbine array pivotable in pitch from a submerged operating condition to a surface maintenance condition.

[0006] One difficulty with the arrangement of GB-A-2450624 is that ballast connections between the main and auxiliary chambers are difficult to make since they have to be above the water line in the horizontal floating condition. These connections also have adverse weight and cost implications.

[0007] According to a first aspect of the invention, there is provided a platform for underwater turbines, and adapted to be tethered to an underwater anchorage, the platform comprising a plurality of elongate spar buoys linked by a plurality of cross arms, the cross arms being adapted to support turbines thereon, characterized in that the platform is adapted for rollover transition between a generally horizontal floating maintenance condition and a submerged upright operating condition by asymmetric ballasting of said spar buoys, the platform further including a rigid tether connected thereto at one end, the other end of said tether comprising an articulating connection for an underwater anchorage.

[0008] The spar buoys may be considered to be buoyancy chambers, and in use are aligned so that the long axes are parallel with each other and the stream flow. In one embodiment the spar buoys comprise a smooth external casing containing buoyancy volumes adapted to be flooded and exhausted to change buoyancy on demand. The spar buoys are substantially tubular and extend substantially fore and aft of the cross arms. The spar buoys comprise the sole or principal means of buoyancy of the platform. In one embodiment the spar buoys extend fore and aft of the cross arms by 25% or more of the length of the spar buoys.

[0009] In the submerged operating condition, turbines are wholly submerged in the stream flow. In one embodiment the elongate buoyancy chambers pierce the surface in the operating condition.

[0010] The spar buoys are substantially identical in a preferred embodiment, and the platform is symmetrical about a longitudinal centreline. The preferred embodiment comprises two spar buoys and two cross arms, thus having a symmetrical cruciform appearance with a clear central space between the spar buoys.

[0011] In a preferred embodiment the cross arms extend laterally on both sides of the platform, and each cross arm supports three turbines; one turbine in between the spar buoys and two turbines are on opposite sides outboard of the spar buoys.

[0012] In the preferred arrangement the cross arms are mounted on one side of the spar buoys, so as to be clear of the water when in the horizontal floating condition. This arrangement reduces drag on the surface, and gives the platform the form of a catamaran. Roll stability is improved in the floating condition due to the lateral spacing of the elongate spar buoys. In one embodiment the spacing between spar buoys is in the range 40-60% of the length thereof.

[0013] In a preferred embodiment the spar buoys of a surface piercing platform are shaped to have toe-in in the upright generating condition with respect to the stream flow, generating inwards lift. Any tendency for the platform to roll in the generating condition creates a greater depth of water in one spar buoy, which generates lift tending to oppose the roll.

[0014] In one embodiment each buoyancy chamber includes a plurality of independent buoyancy chambers along the length thereof.

[0015] The arrangement of the invention provides reliable, safe and predictable transition between the maintenance and operating conditions. Separation of buoyancy control between the spar buoys provides the means of preferentially biasing the attitude of the platform to assist transition between the floating and generating conditions.

[0016] In one embodiment, the platform includes on-board buoyancy control means whereby buoyancy of the individual buoyancy chambers is controlled. The control means may include a processor and programmable memory whereby one or more transition characteristics may be pre-programmed to give optimum transition behaviour in prevailing stream flow conditions. Such characteristics may be determined empirically, and with the benefit of experience.

[0017] According to a second aspect of the invention there is provided a method of rollover transition of a platform of a stream flow turbine, from a substantially horizontally maintenance condition to a substantially upright generating condition, the method comprising the steps of providing a platform consisting of a plurality of spaced elongate spar buoys linked by cross arms, connecting the platform to an underwater anchorage by means of

an articulating tether, and transitioning the platform by asymmetric ballasting of said spar buoys.

[0018] The way that the individual chambers are ballasted from the floating condition will affect the behaviour of the platform in transition. If the chambers are ballasted substantially together transition will be abrupt, and the direction of rollover will be unpredictable as one bi-stable state of equilibrium gives way to the other. Ballasting one side first, or progressively in advance of the other side gives a transition which is more controllable and predictable.

[0019] Preferably the method includes the step of providing a rate of transition which increases with increasing speed of stream flow. This arrangement is desirable to reduce the chance that a platform will be held in an undesirable transition state by competing buoyancy and hydrodynamic forces. The rate of transition may be proportional to the speed of stream flow.

[0020] In particular it may be desirable that the transition is unstable rather than progressive, so that having advanced beyond a certain point, the remainder of the transition is completed automatically, that is to say without the need of further control input. For example failure of a pump should not cause the platform to remain in a partially transitioned condition, or be caught in an undesirable attitude in a rising flow speed where it may be pushed too far downwards.

[0021] In a preferred embodiment, one or more elongate spar buoys incorporates longitudinally arranged buoyancy compartments adapted to be separately ballasted. Such an arrangement permits the leading or trailing end to be differently ballasted in the floating condition, or the upper and lower ends to be differently ballasted in the generating condition. The advantage of differential ballasting is to ensure preferred rollover characteristics.

[0022] For example if it is desired to move from the generating condition to the maintenance condition, it is desirable to de-ballast the side of the platform which is to lead the rollover. Rollover can be encouraged by transferring ballast from the bottom to the top of a spar buoy which trails in transition, before de-ballasting as a critical point of rollover is reached.

[0023] In the same way, the rollover transition from the horizontal to the upright condition can be facilitated by ballasting first the upstream end of the spar buoy which is to roll downwards first. It is an additional feature of the method of the invention that the desired transition characteristic is achieved by adjusting optimally both differential ballasting between the spar buoys, and the centre of buoyancy of each spar buoy in order to give a desired transition behaviour appropriate for the prevailing conditions.

[0024] In one embodiment, one or more of the plurality of spar buoys incorporates an equipment space for containing control and operating devices, such as a micro-processor, pump control(s), pump(s), transformer and the like. A similarly located equivalent space in another spar buoy may contain an equivalent permanent ballast,

to ensure that the platform is evenly loaded.

[0025] In a preferred arrangement the direction of rollover is predetermined to ensure that the same spar buoy leads transition to the operating condition, and trails transition to the floating condition. Thus a spar buoy trailing the transition to the operating condition can have an equipment space (in particular an access opening) in a surface piercing location which is substantially out of the water at all times. Likewise devices having a significant mass, for example a transformer, can be located in a space which is low down in a spar buoy leading transition to the operating condition, and thus assist rollover to the operating condition.

[0026] As noted above, turbines are preferably located on cross arms which lie above the water surface. In a preferred embodiment the method of the invention comprises partially ballasting a spar buoy on one side of the longitudinal axis of symmetry and/or partially de-ballasting a spar buoy the other side of the longitudinal axis of symmetry so as to change the relative height of turbines above the surface. Such an arrangement allows a turbine to be raised to introduce a service barge underneath, or allows a turbine to be lowered to introduce a crane overhead.

[0027] Aspects of the invention relate to a platform having turbines mounted thereon, and to a platform tethered to an underwater anchorage in a manner which permits rollover thereof. According to the present invention the tether is a rigid tether having three axis articulation at the anchorage.

[0028] These and other features of the invention will be apparent from the following description of a preferred embodiment illustrated, by way of example only, in the accompanying drawings in which:

Figure 1 is a schematic showing a tidal turbine platform in the upright operating position with turbine units mounted on hydrofoil-shaped cross arms supported by twin surface-piercing spar buoys.

Figure 2 shows the same tidal turbine platform in the horizontal floating position with the turbines raised above the water surface where they may be accessed for maintenance.

[0029] With reference to the drawings, Fig. 1 illustrates a platform having two buoyancy chambers (or spar buoys), 1, 2 in the upright generating condition. The water surface is indicated by dotted line 9. The platform is restrained by a rigid tether 5 having triangulation struts 6 at the upper end (in the form of a wishbone) so as to provide fore and aft connections to the spar buoys. The tether has an arm for each buoyancy chamber, and an articulating joint 7 connected to an underwater bed anchorage 8 in the form of a pin.

[0030] Two generally horizontal cross arms 4 each carry three underwater turbines 3 of conventional type; these turbines generate electricity from the stream flow passing over the anchorage 8 towards the turbines 3. The struts

6 may provide for angular trimming control of the platform.

[0031] It will be understood that the water surface will rise and fall with respect to the level 9, both due to waves and due to hydrodynamic forces on the platform; such forces may be due to drag on the structure, thrust from the turbines, and lift generated by the cross arms. An opening or door 10 provides access in conning tower style to an equipment room in the upper end of one spar buoy.

[0032] In use the turbine blades rotate to generate power, and the platform maintains an approximately steady station trailing the anchorage 8.

[0033] The platform is adapted to be raised to a generally horizontal floating condition, illustrated in Fig. 2; common reference numerals indicate the same feature.

[0034] To raise the platform water (as ballast) is pumped out of one spar buoy 1, 2 preferentially, and air is admitted via one or more vent pipes in the surface piercing portion. The platform pitches up and rolls over to the position shown in Fig. 2. As soon as the direction of rollover is set, water is pumped out of both spar buoys 1, 2 in order to achieve the desired degree of buoyancy.

[0035] As illustrated in Fig. 2, the turbines are raised out of the water in the floating condition of the platform by virtue of the topside connection of the cross arms 4, and may be accessed for maintenance, repair and substitution. In this embodiment ballasting is arranged so that spar buoy 2 always moves upwards first, and rolls downward last, so that the access opening 10 is not submerged.

[0036] In the drawings, the ends of the spar buoys are marked 'A' and 'B'. In addition to preferential change of buoyancy to determine the direction of rollover, the spar buoys may also be preferentially ballasted end to end in order to give a desirable transition characteristic. For this purpose several ballast compartments are provided in each spar buoy.

[0037] For example, to transition from the generating condition of Fig. 1 to the maintenance condition of Fig. 2, ballast water is first pumped out of spar buoy 2. As the platform rises and begins to roll, the roll angle may be increased by pumping ballast water from the bottom B of spar buoy 1 to the top A. Once the critical rollover point is reached and passed, the remaining ballast water may be removed from the top A of spar buoy 1, and the platform adopts the floating condition.

[0038] Providing for separate ballasting of the spar buoys 1, 2, and providing for preferential end to end ballasting has other advantages. For example one spar buoy may be ballasted to raise a turbine so that a maintenance barge may be floated underneath. Alternatively a turbine may be lowered so that a barge crane may be positioned overhead. Likewise the adjacent ends of both spar buoys may be ballasted to lower the adjacent turbines, and to raise the turbines at the unballasted ends. Instead of increasing ballast in one location, ballast may be removed from another location, or both techniques may be used in conjunction.

Claims

1. A platform for underwater turbines, and adapted to be tethered to an underwater anchorage, the platform comprising a plurality of elongate spar buoys (1, 2) linked by a plurality of cross arms (4), the cross arms being adapted to support turbines (3) thereon, **characterized in that** the platform is adapted for rollover transition between a generally horizontal floating maintenance condition and a submerged upright operating condition by asymmetric ballasting of said spar buoys, the platform further including a rigid tether (5) connected thereto at one end, the other end of said tether comprising an articulating connection (7) for an underwater anchorage (8).
2. A platform according to claim 1, wherein one or more of said spar buoys (1, 2) includes a plurality of independent buoyancy chambers along the length thereof.
3. A platform according to claim 1 or claim 2, and comprising two spar buoys (1, 2).
4. A platform according to claim 3, wherein the spar buoys (1, 2) are substantially identical.
5. A platform according to claim 3 or claim 4, wherein the spar buoys (1, 2) are disposed symmetrically about a longitudinal centreline.
6. A platform according to any preceding claim, wherein each spar buoy (1, 2) includes a surface piercing portion in the operating condition thereof.
7. A platform according to claim 6, wherein one or both of said surface piercing portions includes an access hatch (10).
8. A platform according to claim 6 or claim 7, wherein said surface piercing portions toe-in with respect to the stream flow direction.
9. A platform according to any preceding claim, wherein said cross arms (4) are substantially orthogonal to said spar buoys (1, 2).
10. A platform according to claim 9, wherein said cross arms (4) are substantially above said spar buoys (1, 2) in the floating maintenance condition.
11. A platform according to claim 10, wherein said cross arms (4) extend laterally outboard of said spar buoys (1, 2).
12. A platform according to claim 11, wherein said cross arms (4) support turbines (3) thereon between said spar buoys (1, 2), and outboard thereof.

13. A platform according to any preceding claim, and further including ballast control means whereby said spar buoys (1, 2) may be a ballasted differentially to initiate rollover transition.
14. A platform according to claim 13, wherein said ballast control means is operable to change the attitude of said platform in the floating condition.
15. A method of transitioning the platform of any preceding claim, and comprising the steps of initiating rollover transition by preferentially altering the ballast of one of said spar buoys (1, 2).
16. A method according to claim 15, and further comprising the step of controlling transition behaviour by differential ballasting of said spar buoys (1, 2) during rollover transition.
17. A method according to claim 15 or claim 16, and including the step of preferentially alternating the ballast of one of said spar buoys (1, 2) to ensure rollover transition only from one side of said platform.
18. A method of changing the attitude of the platform of any of claim 1-14 in the floating condition, comprising differential ballasting of said spar buoys (1, 2).
19. A method of changing the height of a turbine (3) mounted on a platform according to any of claims 1-14, the method comprising differentially ballasting one of said spar buoys (1, 2) to change the attitude of said platform.

Patentansprüche

1. Plattform für Unterwasserturbinen, wobei die Plattform in der Lage ist, an einer Unterwasserverankerung angebunden zu werden, wobei die Plattform mehrere längliche Spierenbojen (1,2) aufweist, die durch mehrere Querarme (4) verbunden sind, wobei die Querarme (4) in der Lage sind, Turbinen (3) zu halten,
dadurch gekennzeichnet, dass die Plattform zu einer Überroll-Überführung zwischen einem im Wesentlichen horizontalen Floating-Wartungszustand und einem eingetauchten vertikalen Betriebszustand mittels asymmetrischer Ballastierung der Spierenbojen in der Lage sind, wobei die Plattform ferner einen starren Strang (5) aufweist, der an einem Ende mit ihr verbunden ist, wobei das andere Ende des Strangs eine Gelenkverbindung (7) für eine Unterwasserverankerung (8) aufweist.
2. Plattform nach Anspruch 1, bei der eine oder mehrere der Spierenbojen (1,2) entlang ihrer Länge mehrere unabhängige Auftriebskammern aufweisen.

3. Plattform nach Anspruch 1 oder Anspruch 2, und mit zwei Spierenbojen (1,2).
4. Plattform nach Anspruch 3, bei der die Spierenbojen (1,2) im Wesentlichen identisch sind.
5. Plattform nach Anspruch 3 oder Anspruch 4, bei der die Spierenbojen (1,2) symmetrisch um eine Längsmittellinie angeordnet sind.
6. Plattform nach einem der vorhergehenden Ansprüche, bei der jede Spierenboje (1,2) in ihrem Betriebszustand einen Oberflächen-Durchdringungsabschnitt aufweist.
7. Plattform nach Anspruch 6, bei der einer oder beide der Oberflächen-Durchdringungsabschnitte eine Zugangsklappe (10) aufweisen.
8. Plattform nach Anspruch 6 oder Anspruch 7, bei der die Oberflächen-Durchdringungsabschnitte hinsichtlich der Strömungsrichtung eine Vorspur bilden.
9. Plattform nach einem der vorhergehenden Ansprüche, bei der die Querarme (4) im Wesentlichen rechtwinklig zu den Spierenbojen (1,2) verlaufen.
10. Plattform nach Anspruch 9, bei der die Querarme (4) im Floating-Wartungszustand im Wesentlichen über den Spierenbojen (1,2) verlaufen.
11. Plattform nach Anspruch 10, bei der die sich die Querarme (4) seitlich außerbords der Spierenbojen (1,2) erstrecken.
12. Plattform nach Anspruch 11, bei der die Querarme (4) zwischen den Spierenbojen (1,2) sowie außerbords derselben Turbinen (3) tragen.
13. Plattform nach einem der vorhergehenden Ansprüche, und ferner mit einer Ballaststeuervorrichtung, mittels derer die Spierenbojen (1,2) unterschiedlich ballastiert werden können, um die Überroll-Überführung zu initiieren.
14. Plattform nach Anspruch 13, bei der die Ballaststeuervorrichtung zum Ändern der Lage der Plattform im Floating-Zustand betätigbar ist.
15. Verfahren zum Überführen der Plattform nach einem der vorhergehenden Ansprüche, und mit dem Schritt des Initiierens einer Überroll-Überführung vorzugsweise durch Verändern des Ballasts einer der Spierenbojen (1,2).
16. Verfahren nach Anspruch 15, und ferner mit dem Schritt des Steuerns des Überführungsverhaltens durch unterschiedliche Ballastierung der Spierenbo-

jen (1,2) während der Überroll-Überführung.

17. Verfahren nach Anspruch 15 oder Anspruch 16, und mit dem Schritt des vorzugsweisen Alternierens des Ballasts einer der Spierenbojen (1,2) zur Gewährleistung der Überroll-Überführung nur von einer Seite der Plattform. 5
18. Verfahren zum Verändern der Lage der Plattform nach einem der Ansprüche 1-14 in den Floating-Zustand, mit unterschiedlicher Ballastierung der Spierenbojen (1,2). 10
19. Verfahren zum Verändern der Höhe einer an einer Plattform nach einem der Ansprüche 1-14 montierten Turbine (3), wobei das Verfahren ein unterschiedliches Ballastieren der Spierenbojen (1,2) zwecks Veränderns der Lage der Plattform umfasst. 15

Revendications

1. Plateforme pour turbines subaquatiques, et adaptée pour être attachée à un ancrage subaquatique, la plateforme comprenant une pluralité de bouées à espar allongés (1, 2) liées par une pluralité de traverses (4), les traverses étant adaptées pour supporter des turbines (3) sur celles-ci, **caractérisée en ce que** la plateforme est adaptée pour transition de basculement entre une condition de maintenance flottante généralement horizontale et une condition de fonctionnement verticale immergée par ballastage asymétrique desdites bouées à espar, la plateforme incluant en outre une attache rigide (5) raccordée à celle-ci à une extrémité, l'autre extrémité de ladite attache comprenant un raccord articulé (7) pour un ancrage subaquatique (8). 25
2. Plateforme selon la revendication 1, dans laquelle une ou plusieurs desdites bouées à espar (1, 2) incluent une pluralité de chambres de flottaison indépendantes sur la longueur de celle-ci/celles-ci. 30
3. Plateforme selon la revendication 1 ou la revendication 2, et comprenant deux bouées à espar (1, 2). 35
4. Plateforme selon la revendication 3, dans laquelle les bouées à espar (1, 2) sont sensiblement identiques. 40
5. Plateforme selon la revendication 3 ou la revendication 4, dans laquelle les bouées à espar (1, 2) sont disposées symétriquement autour d'une ligne centrale longitudinale. 45
6. Plateforme selon une quelconque revendication précédente, dans laquelle chaque bouée à espar (1, 2) inclut une portion de perçage de surface dans la con-

dition de fonctionnement de celle-ci.

7. Plateforme selon la revendication 6, dans laquelle l'une ou les deux desdites portions de perçage de surface inclut une trappe d'accès (10). 5
8. Plateforme selon la revendication 6 ou la revendication 7, dans laquelle lesdites portions de perçage de surface convergent par rapport à la direction d'écoulement de courant. 10
9. Plateforme selon une quelconque revendication précédente, dans laquelle lesdites traverses (4) sont sensiblement orthogonales auxdites bouées à espar (1,2). 15
10. Plateforme selon la revendication 9, dans laquelle lesdites traverses (4) sont sensiblement au-dessus desdites bouées à espar (1, 2) dans la condition de maintenance flottante. 20
11. Plateforme selon la revendication 10, dans laquelle lesdites traverses (4) s'étendent latéralement à l'extérieur desdites bouées à espar (1, 2). 25
12. Plateforme selon la revendication 11, dans laquelle lesdites traverses (4) supportent des turbines (3) sur celles-ci entre lesdites bouées à espar (1, 2), et à l'extérieur de celles-ci. 30
13. Plateforme selon une quelconque revendication précédente, et incluant en outre des moyens de commande de ballast moyennant quoi lesdites bouées à espar (1, 2) peuvent être ballastées de façon différentielle pour commencer une transition de basculement. 35
14. Plateforme selon la revendication 13, dans laquelle lesdits moyens de commande de ballast sont utilisables pour changer l'orientation de ladite plateforme dans la condition flottante. 40
15. Procédé de transition de la plateforme selon une quelconque revendication précédente, et comprenant les étapes du commencement d'une transition de basculement en modifiant de façon préférentielle le ballast d'une desdites bouées à espar (1, 2). 45
16. Procédé selon la revendication 15, et comprenant en outre l'étape de la commande du comportement de transition par le ballastage différentiel desdites bouées à espar (1, 2) durant la transition de basculement. 50
17. Procédé selon la revendication 15 ou la revendication 16, et incluant l'étape de la modification préférentielle du ballast d'une desdites bouées à espar (1, 2) pour garantir la transition de basculement seu-

lement à partir d'un côté de ladite plateforme.

- 18.** Procédé de changement de l'orientation de la plateforme selon l'une quelconque des revendications 1 à 14 dans la condition flottante, comprenant le ballastage différentiel desdites bouées à espar (1, 2). 5
- 19.** Procédé de changement de la hauteur d'une turbine (3) montée sur une plateforme selon l'une quelconque des revendications 1 à 14, le procédé comprenant le ballastage différentiel d'une desdites bouées à espar (1, 2) pour changer l'orientation de ladite plateforme. 10

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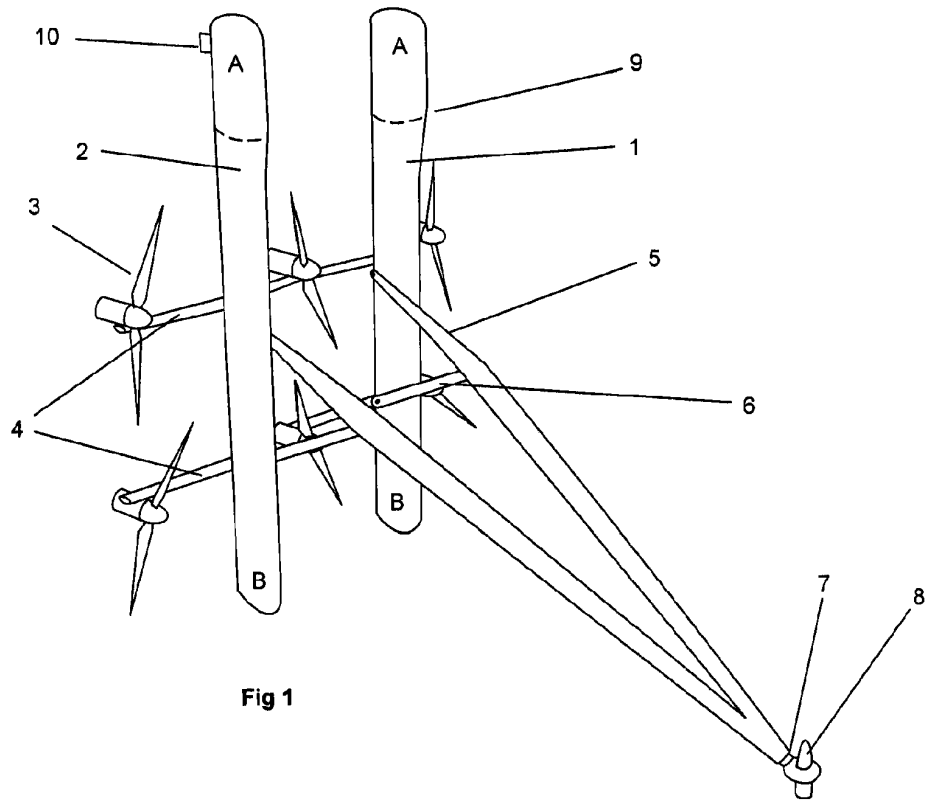


Fig 1

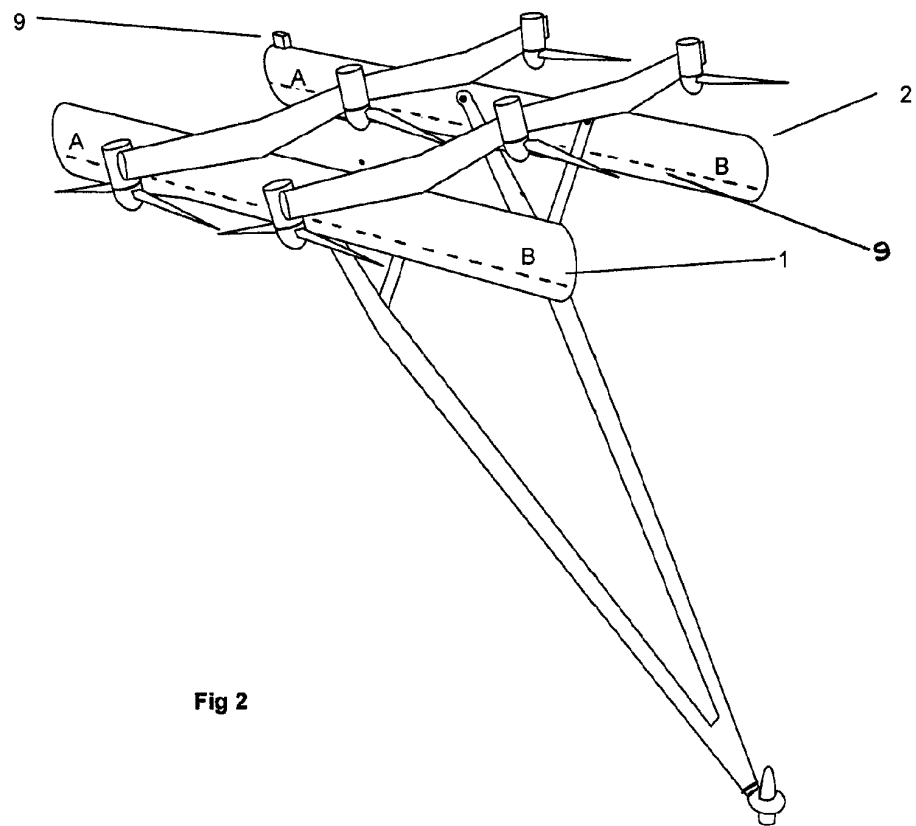


Fig 2

REFERENCES CITED IN THE DESCRIPTION

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