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(54) SPAR BASED MARITIME ACCESS VEHICLE

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B63B 43/02	(2006.01)

(52) **U.S. Cl.** **114/274**; 114/121; 114/271

(57) **ABSTRACT**

The invention relates to a spar based vessel for accessing offshore installations and vessels, including wind farm turbines, in which the centre of gravity of the vessel is positioned below the centre of buoyancy, which is positioned below the operational waterline, the operational waterline occurs at low cross-sectional area vertical struts, and the vertical struts support a topside structure for passengers. Active ballast control system and location of the propulsive elements permits the vessel to travel in spar orientation by positioning the vector of propulsion to lie in the same horizontal plane as the transverse centre of drag of the vessel. A docking system permits safe connection of the vessel to offshore installations, including wind turbines of generic design.

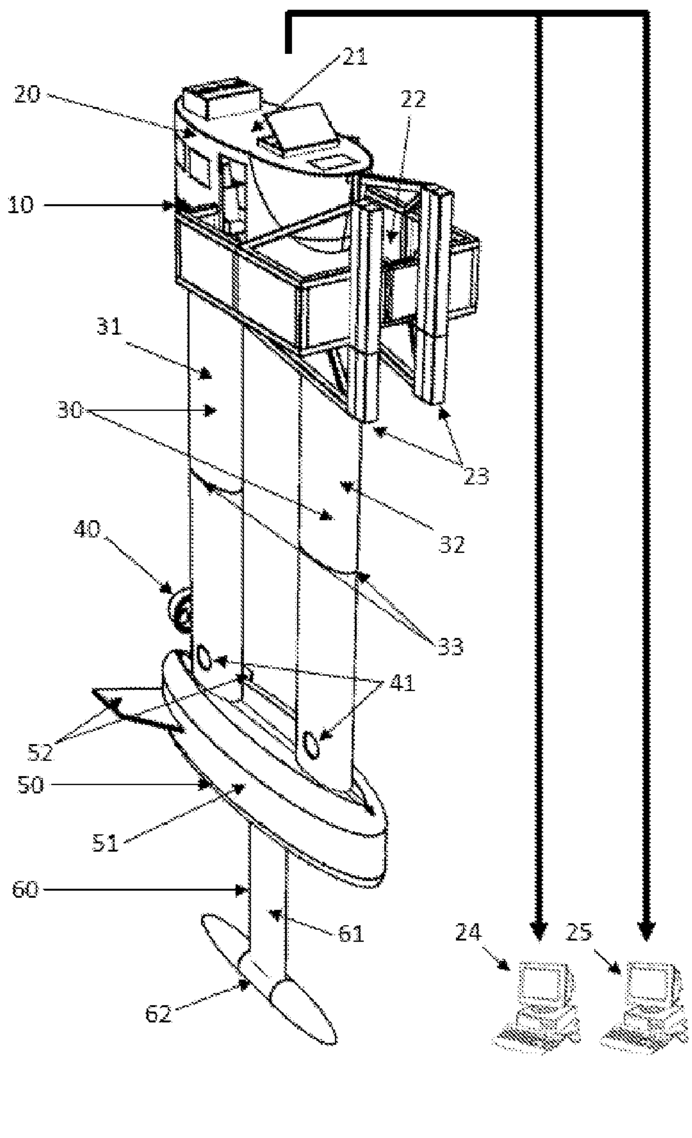

FIGURE 1

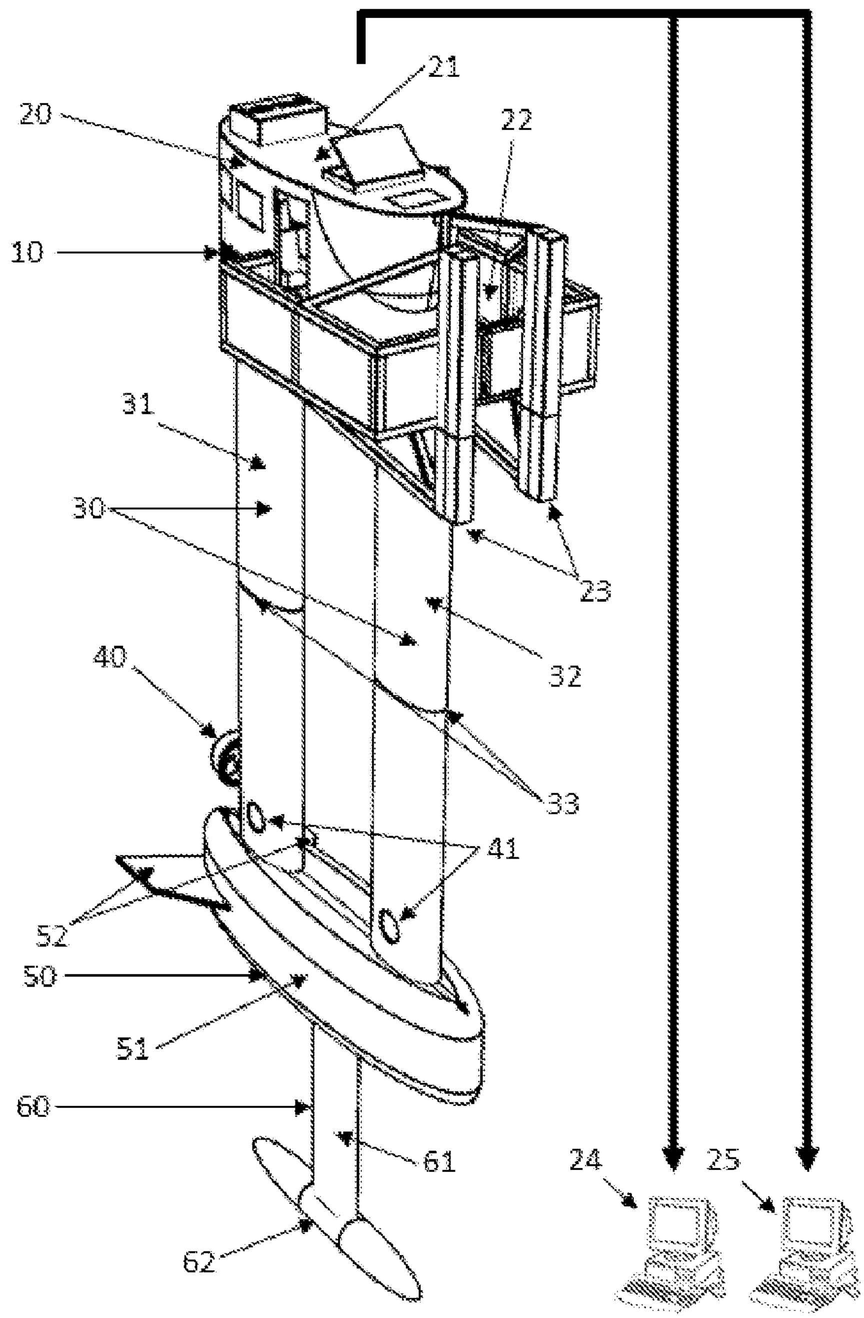

FIGURE 2

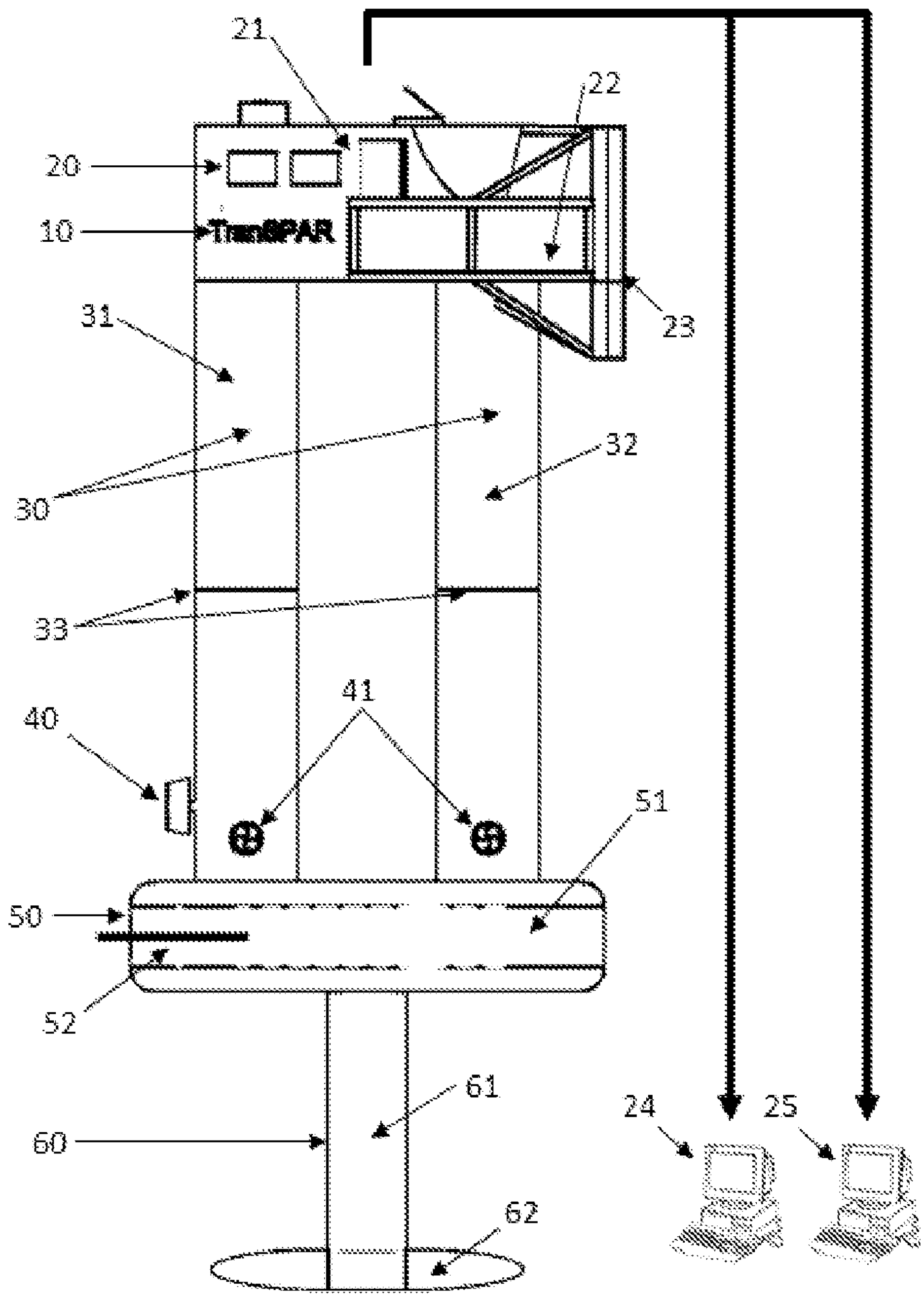

FIGURE 3

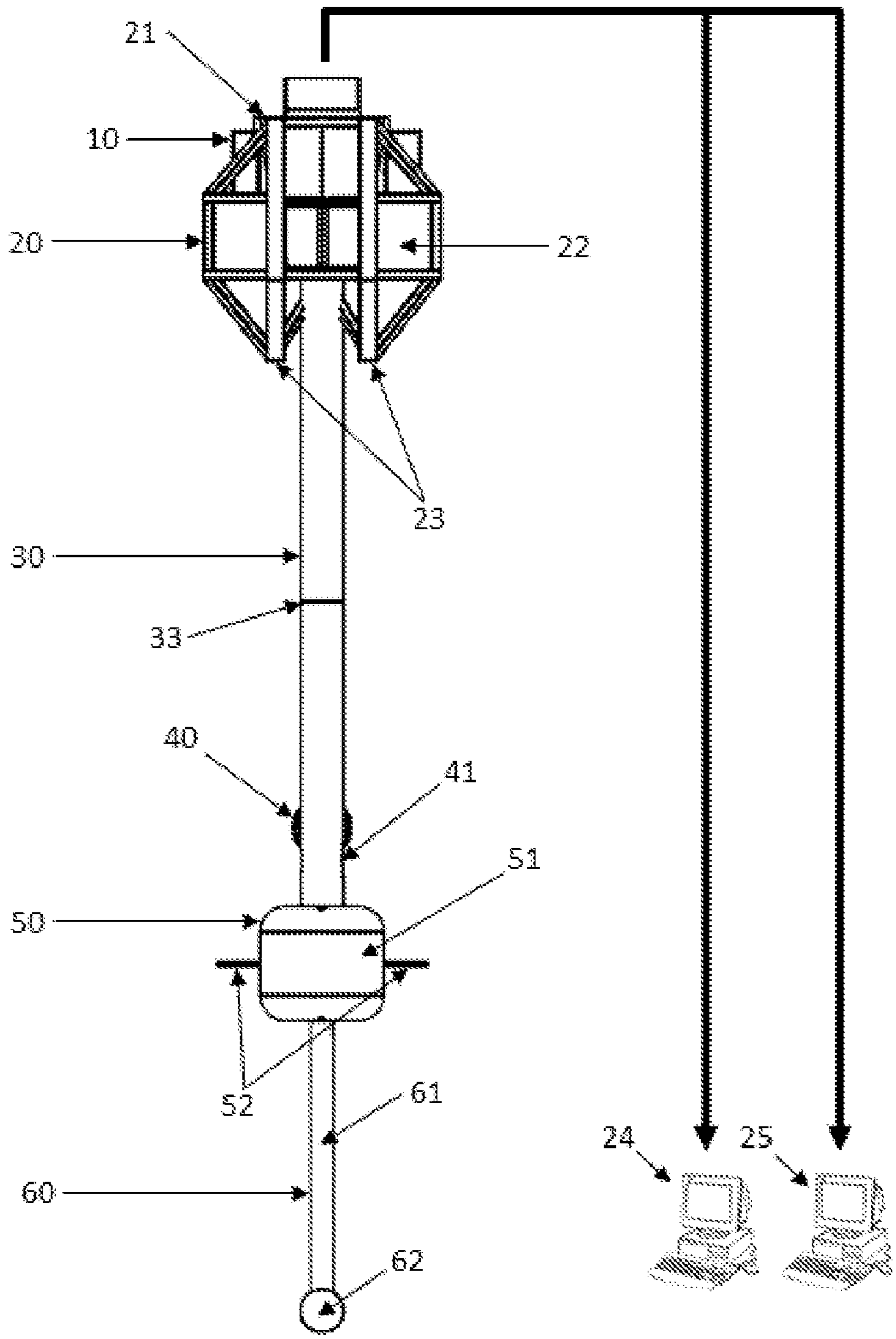

FIGURE 4

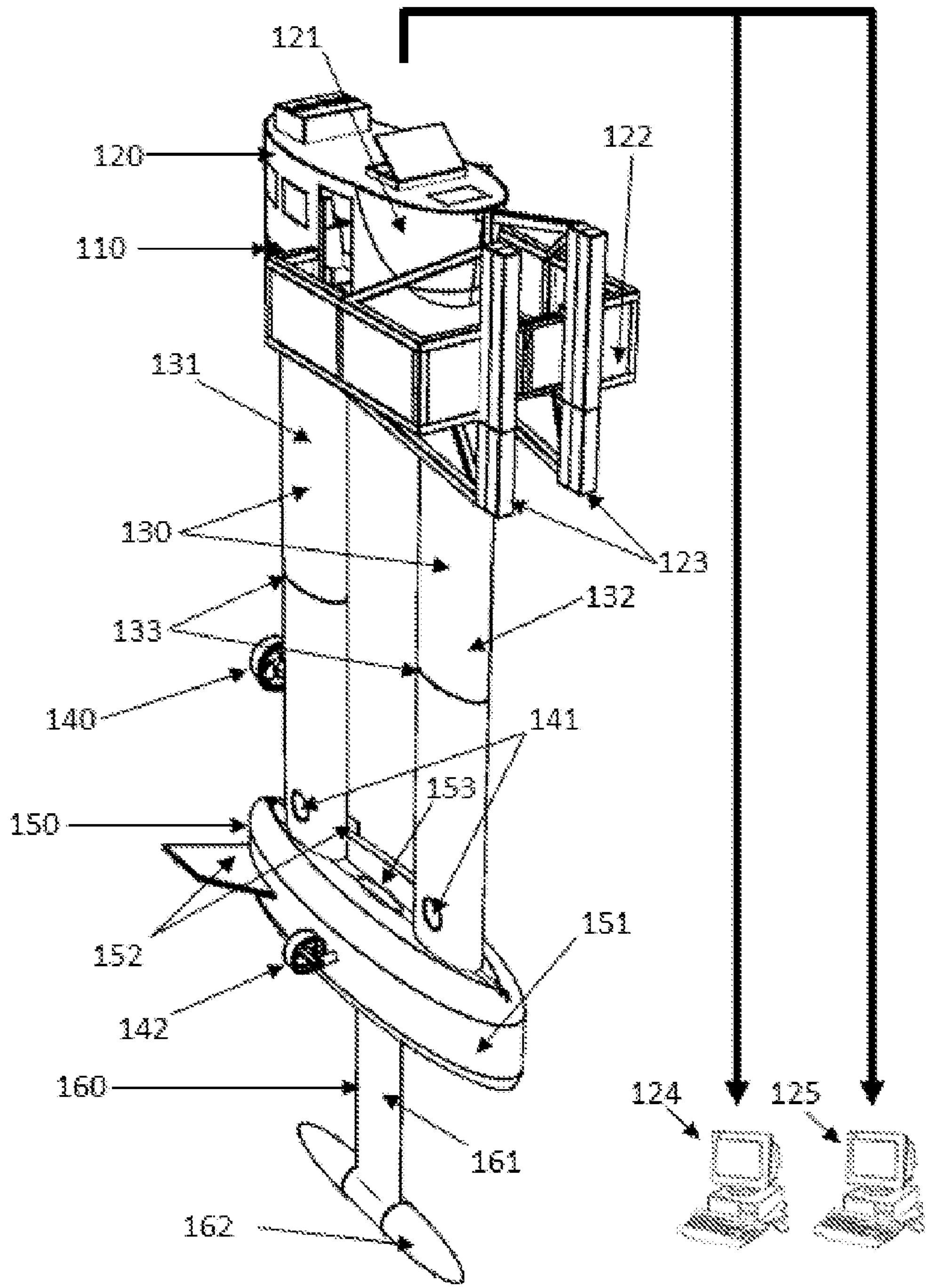
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FIGURE 5

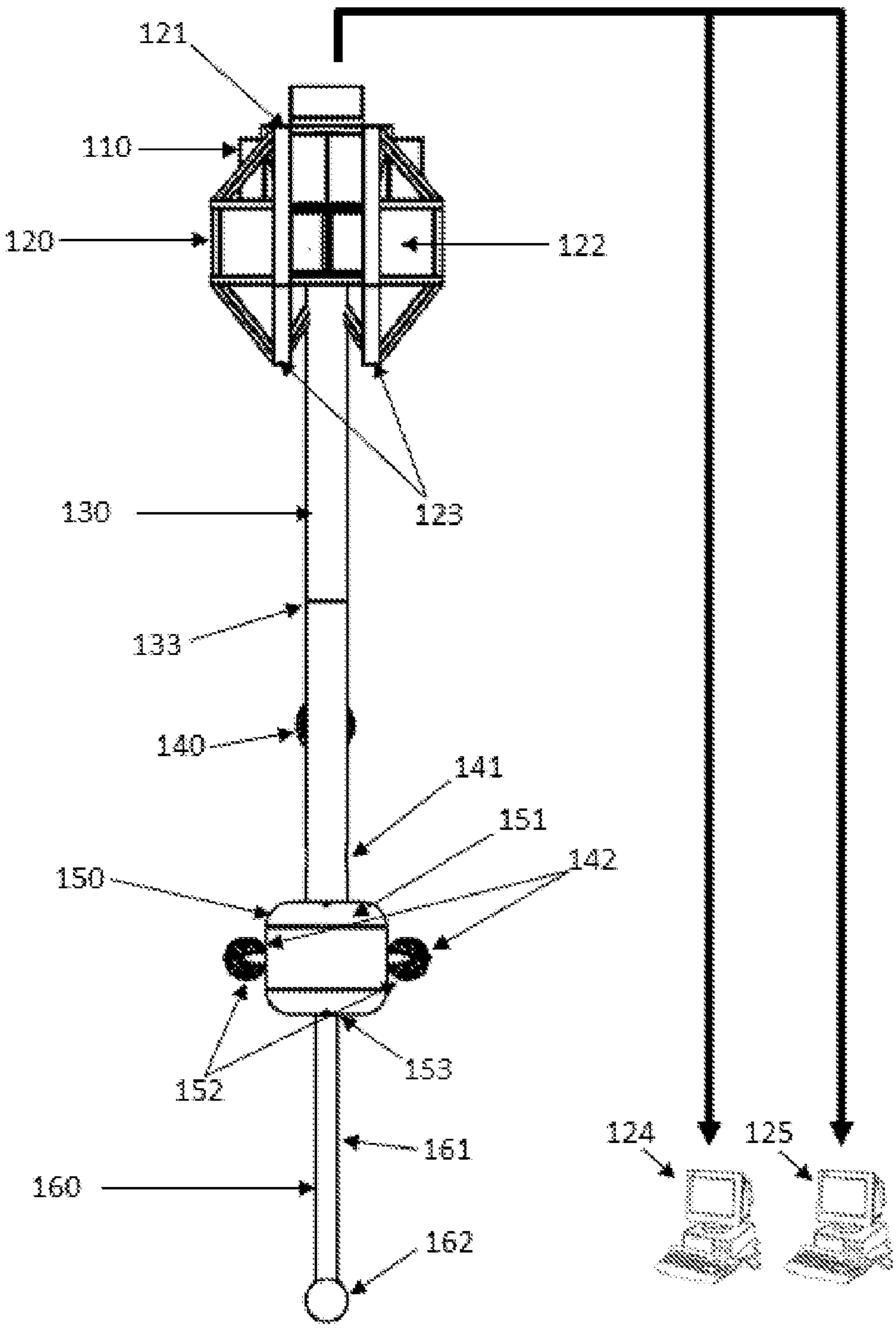
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FIGURE 6

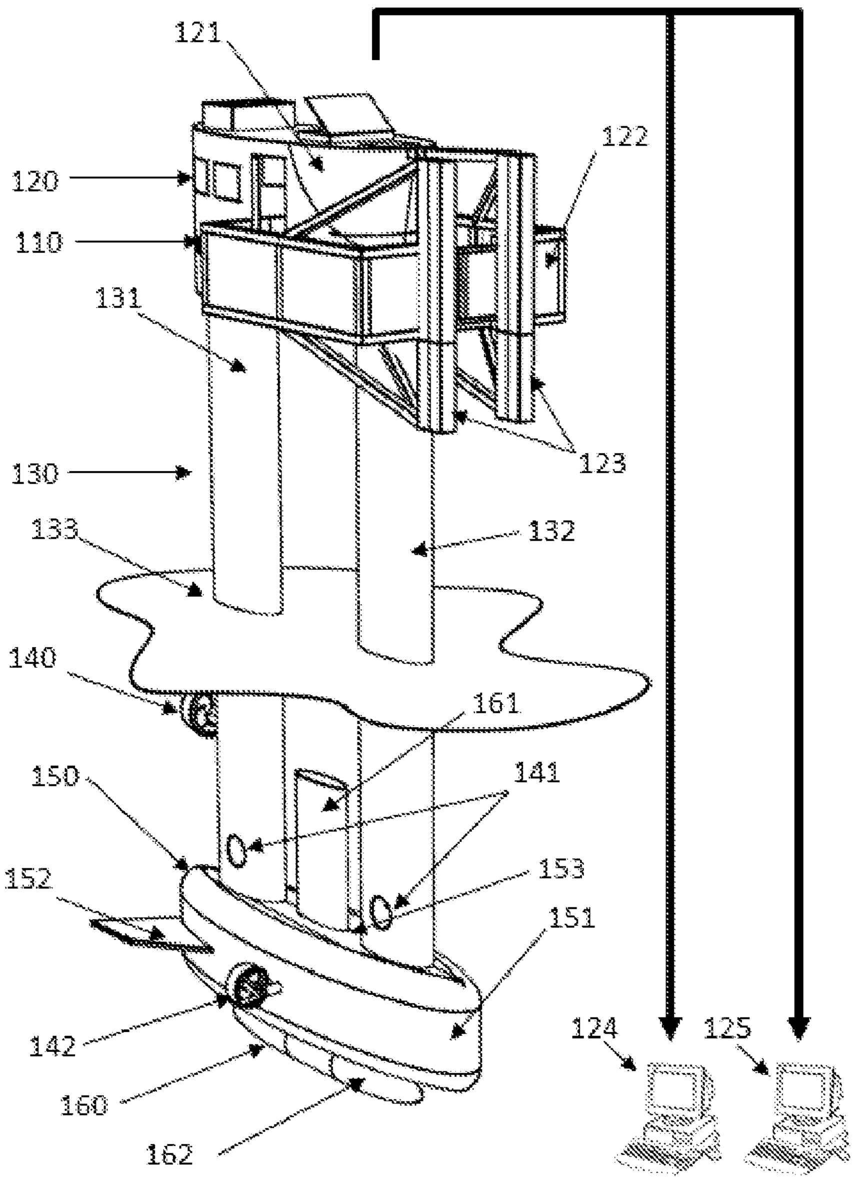
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FIGURE 7

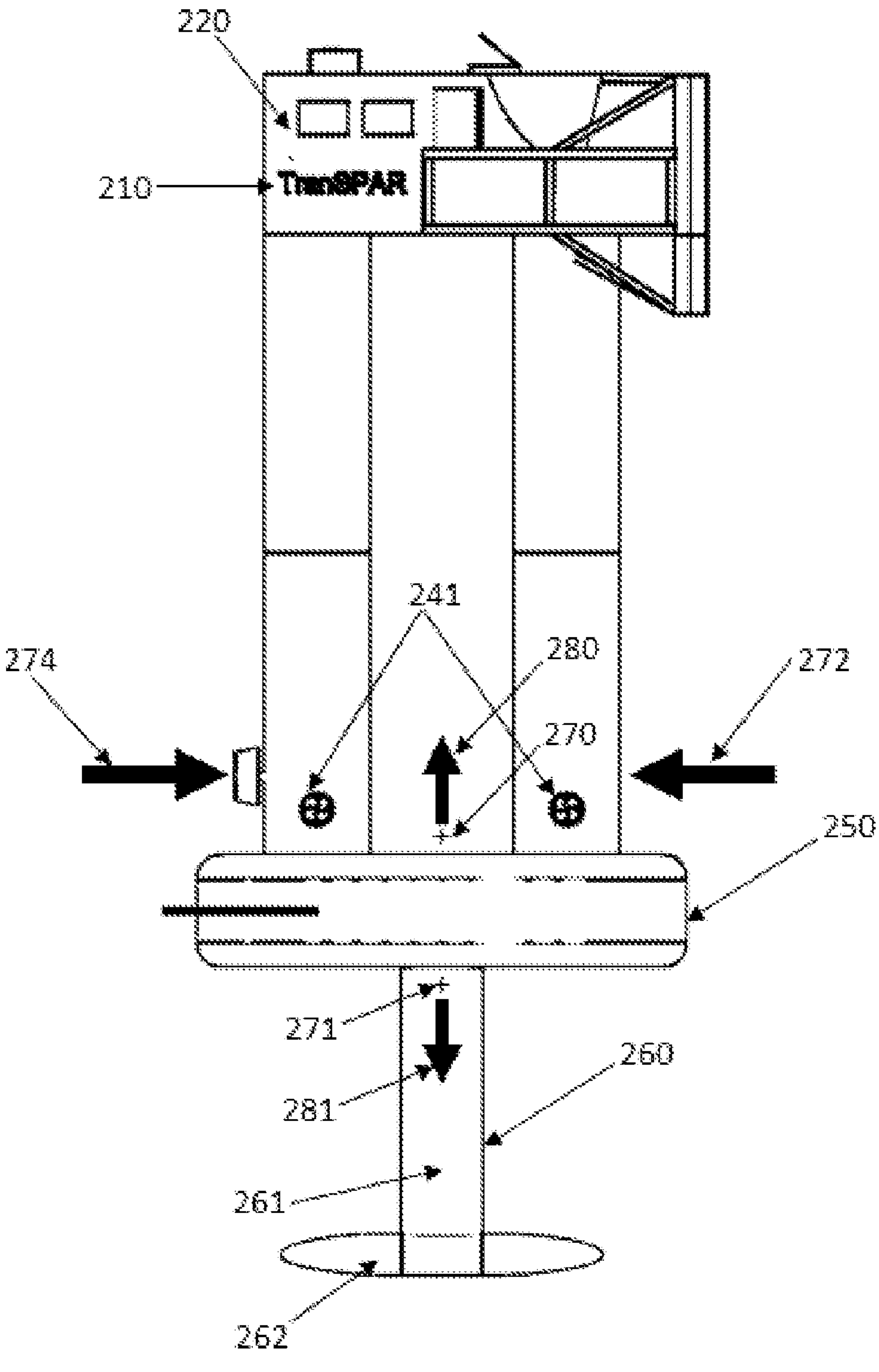
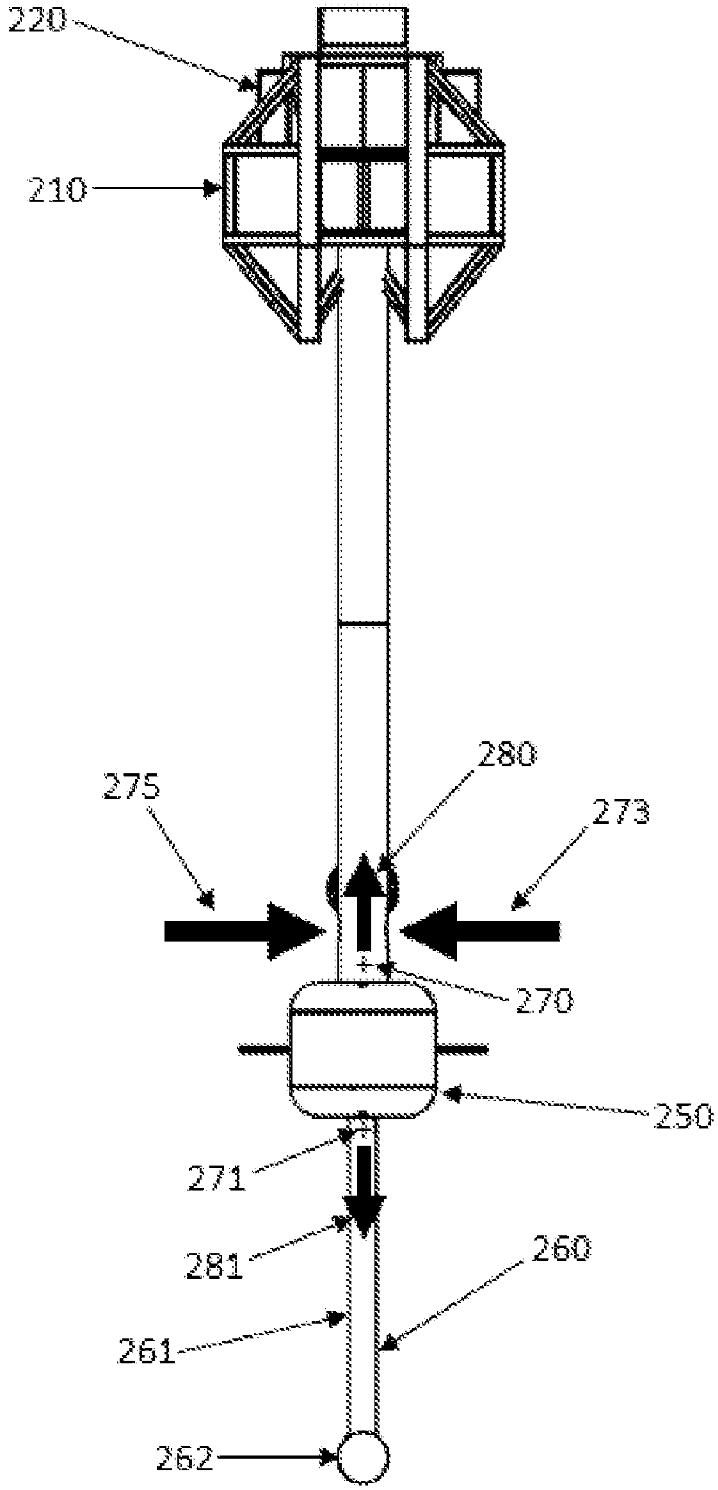


FIGURE 8



SPAR BASED MARITIME ACCESS VEHICLE

UTILITY PATENT APPLICATION
(NON-PROVISIONAL)

[0001] This application claims priority from application 61/417,250, filed Nov. 25, 2010.

FIELD

[0002] The present disclosure relates to a machine for the safe loading and unloading of passengers while at sea.

BACKGROUND

[0003] The safe transfer of technicians between a ship and either other ships or maritime installations is a problem in offshore wind farm maintenance, where technician may travel long distances to reach an installation by ship and then require a smaller secondary vessel to access the numerous turbines in the wind farm. Typically, the second stage transport is performed using catamaran, small waterplane area twin hull (SWATH), or other light vessel. While fast, the primary downside of the catamaran is that it is unable to safely access the turbines in waves over 1.4 meters, and in the case of the SWATH it is more expensive to build. A secondary problem in the current best practice is that technicians boarding and disembarking from the secondary vessel are exposed to the elements.

[0004] There is a need for a vessel which would permit safer transport of technicians between a mother ship and individual wind farm turbines; and which is capable of operating in a wider variety of wave and weather conditions.

[0005] Existing spar buoys, due to small water plane area and large mass, provide stable platforms in a variety of wave conditions. For the most part, these SPAR are towed and moored in a given location and cannot be used for transport. U.S. Pat. No. 3,413,946, issued Dec. 3, 1968 to H. U. von Schultz, describes a spar buoy vessel which travels in a horizontal configuration before being cantilevered to a vertical position upon reaching its destination.

[0006] In U.S. Pat. No. 3,842,774, issued Oct. 22, 1974 to Kinder, a spar buoy vessel is capable of motion while in a horizontal configuration, and again rotates into a stable vertical position by changing its center of gravity; but is then no longer capable of motion.

[0007] In U.S. Pat. No. 3,953,905, issued May 4, 1976 to Paitson, a spar buoy is equipped with a v-shaped wing just above its centre of gravity, to lift and stabilize the spar during towing, but which is not capable of independent motion.

[0008] There is a need for a vessel having the stability of a spar buoy platform which is capable of transport in this orientation, to permit stable access to and exit from offshore installations, including wind farms, or for use in other turbulent or high wave environments.

SUMMARY

[0009] The present disclosure is for a novel vessel or craft designed to provide an integrated offshore transfer system capable of operating in volatile ocean conditions, ideally suited to wind farm maintenance. The geometry of the spar based vessel of the present disclosure, with the incorporation of a small water plane area, significantly reduces the vessel's response to wave excitation forces. This allows such a vessel (the TranSPAR™ craft) to approach and connect to marine installations safely, even in high waves, and to permit safe passenger transfer between the TranSPAR™ craft and its destination.

[0010] A topside structure, which in normal operation is balanced above the waterline (and which may include a deck and cabin), is connected to a hull comprised of one or more low waterline profile vertical struts connected to a buoyancy chamber portion of the hull, and an extended high density keel. The topside structure connects to the hull at the vertical struts, and the extended keel, comprised of a keel strut and keel bulb, hangs from the buoyancy chamber portion of the hull. The vertical struts are chosen of sufficient length to maintain the topside structure substantially out of the water in permitted operating conditions, but ensuring that the thrusters (which may be affixed to the vertical struts or hull) remain under water. The keel strut and keel bulb ensure that the centre of gravity of the vessel is below the centre of buoyancy, which is what gives this vessel an inherently stable righting moment, akin to that of a spar buoy. The buoyancy chamber, may extend into the vertical struts and/or keel strut, without departing from this disclosure. Unlike traditional spar buoys; the hull, keel and vertical struts of the vessel disclosed herein are designed for low hydrodynamic drag when travelling through the water, and are equipped with one or more propulsive elements (propellers, impellers, jets, rotors, thrusters, etc.) to supply thrust substantially along the center of drag of the vessel (the centre of drag being determined at normal operating speeds in calm water). Further stability or dampening for roll or pitch caused by rough waves is provided first by fins on the hull. Although the distance between the centre of buoyancy above the centre of mass might be traditionally maximized in spar buoys for greater stability, in the vessel of the present disclosure the design may also take into account dampening undesirable harmonic motion of the vessel during acceleration and also by addressing drag by the extended keel.

[0011] Variable ballast and thrust may be employed for further efficiency and stability.

[0012] Optionally, control systems for the buoyancy chamber adjust ballast following loading or unloading of the topside structure. As people and equipment are loaded onto the vessel, water is pumped out of the buoyancy chamber to maintain a desired average water plane/waterline associated with vessel geometry and weather conditions. Water is pumped in when the load is removed to maintain the optimal water plane/waterline for travel. While the vessel is docked, the variable ballast can be used to raise or lower the vessel to one or more preferred docking heights at different installations and locations (i.e. the turbine and the primary supply ship).

[0013] Optionally, variable thrust at one or more heights on the vessel adjust for shifting of the centre of drag at changing speeds and wave height, which can be dynamically estimated by the control system using feedback from gyroscopes on the vessel, and an overall thrust vector dynamically aligned with the position of that centre of drag.

[0014] Due to the low water plane area, the oscillations in the forces on the vessel of the present disclosure caused by high waves have a less pronounced effect than on traditional light craft. As such, the vessel of the present disclosure may be safely used on more operating days at offshore wind turbines than existing craft. The water plane area (the cross sectional area of the vertical struts at the waterline during operation) should be less than of the average cross-sectional area of the hull, and can be made as low as possible while still providing necessary displacement and structural support to the topside structure.

[0015] The TranSPAR™ craft of the preferred embodiment disclosed herein, is capable of an increase in access in wave conditions over 1.4 meters. The design criteria of the TranSPAR™ craft permit that in a preferred embodiment, the geometry may be optimized to produce limited motion of the TranSPAR™ craft due to expected wave amplitudes in the operating environment specified for offshore wind farm maintenance.

[0016] Safety is improved as motion of the vessel during transfer is reduced by a decreased response to the wave excitation forces as a result of its small waterplane area.

[0017] Other design criteria used to minimize operational and capital costs preferably include: minimizing the vessel's weight, optimizing the vessel's geometry, and using the most efficient means of propelling the vessel.

[0018] As such, the keel struts and vertical struts may be hollow or filled with light material, and shaped with a lean profile for smooth forward motion.

[0019] The vessel can be hydro-dynamically shaped in ways atypical of spar buoys, but more typical of catamaran, submarines and other ocean vessels. Some desirable hydrodynamic shapes may include, a tube shaped buoyancy chamber, tube shaped keel bulb, fully flat keel without a bulb and high density within the keel strut, foil/blade shaped struts, fins to dampened or affect pitch and roll caused by acceleration or waves. A large weight in the keel is dominant in determining the centre of gravity/mass of the vessel, and the hull shape helps defines a longitudinal direction of travel for the vessel; or in other words. The cross sectional area of the vertical struts over the range of waterlines for the vessel should be low, and, in a preferred embodiment, also streamlined for motion in the longitudinal direction.

[0020] Turning and lateral motion can also be achieved using traverse thrusters embedded in the vertical struts. In this manner, the vessel may more safely approach and dock with offshore platforms in high seas.

[0021] Other design criteria used to enhance vessel stability at rest and in motion, optionally include: Control systems for vessel thrusters and ballast to cause thrust to be applied opposite to the centre of vessel drag, which may oscillate with weather conditions; fins on the ballast tank or other submerged portions of the vessel; and lateral thrusters.

[0022] At its most basic, the vessel disclosed herein is for transporting people in water, comprising one or more forward propulsive elements for propelling the vessel in a longitudinal direction defined by the shape of either the keel or the hull; the keel connected below a hull having a buoyancy chamber, which is connected to a topside structure by one or more vertical struts, and together with a permitted range of loads, defines a range of centers of gravity for the vessel; in which, for a range of operational waterline positions of the vessel along the one or more vertical struts, the range of centers of gravity is located below a range of centers of buoyancy for the vessel determined by the range of operational waterline positions. In a basic design, the range of centers of gravity are determined for loaded and unloaded configurations using a vessel buoyancy control system, the preferred transit waterline of the vessel is determined at the design stage and a net effective center of drag calculated or determined experimentally for the vessel travelling at that net effective waterline for a variety of wave conditions, and the net effective center of buoyancy adjusted by an active ballast system to return the vessel to the preferred waterline. Active ballast systems, known in the art, can be used to balance volumes and positions of water and gas buoyancy chamber within the hull (and possibly extending into the struts), in order to assist in maintaining stability during operation, achieve desired waterline during transit, and possibly adjust height during docking and undocking to safer boarding and loading.

[0023] In order to safely operate, the TranSPAR™ craft of the present disclosure addresses the following operational states, and has an appropriate response to forces on the vessel during such states.

[0024] Stationary not Using a Dynamic Positioning System:

[0025] Weight removed from vessel: Example: Crew disembarks from the vessel to a turbine or mother ship. Method: Active ballast system floods ballast tanks to compensate for the removed weight and maintain vessel draft.

[0026] Weight shifted inside the vessel: Example: Crew movement aboard vessel. Method: Vessels righting moment, derived from the fixed ballast, can overcome weight shifts due to crew movement or payload movement. This can be further compensated for by adjusting the variable ballast of the vessel with the active ballast system.

[0027] Wave Loading: Method: Because of the low waterplane area, the vessel has a limited response to wave excitation forces. Motions that are induced by waves can be damped out efficiently because of the geometry of the vessel which has high added mass and damping characteristics, the design of which is readily apparent to the person skilled in the art of naval architecture.

[0028] Wind Loading: Method: Topside dimensions will be minimized to reduce wind loading. Wind loading that is experienced will be managed through the righting moment derived from the fixed ballast. This can be further compensated for by adjusting the variable ballast of the vessel using the active ballast system.

[0029] Stationary Using a Dynamic Positioning System

[0030] Station keeping: Method: Vessel may preferably be kept on station using a dynamic positioning system. Such a system controls and allocates thrust dynamically to maintain position globally, or with reference to another vessel.

[0031] Weight removed from vessel: Example: Crew disembarks from the vessel to a turbine or mother ship. Method: An active ballast system may flood ballast tanks to compensate for the removed weight, if necessary.

[0032] Weight shifted inside the vessel: Example: Crew movement aboard vessel.

[0033] Method: Vessels righting moment, derived from the fixed ballast, can overcome weight shifts due to crew movement or payload movement. This can be further compensated for by adjusting a variable ballast of the vessel with an active ballast system.

[0034] Wave Loading: Method: Because of the low waterplane area, the vessel has a limited response to wave excitation forces. Motions that are induced by waves are dampened efficiently by the geometry of the vessel.

[0035] Wind Loading: Method: In a preferred design, topside dimensions are minimized to reduce wind loading. Wind loading that is experienced is counteracted by the righting moment derived from the fixed ballast. This can be further compensated for by adjusting a variable ballast of the vessel using an active ballast system.

[0036] In Motion Propulsion and Stability Control

[0037] In motion, the vessel of the present disclosure has a stable response to each of the following forces within its operating range.

[0038] Drag Force: Method: Drag force associated with motion is overcome, one or more propulsion units located at substantially the same elevation as the transverse center of drag. For motion in the longitudinal direction, that is forward and aft, overall thrust from the propulsion unit should preferably be applied at substantially the same vertical position as the transverse drag force, at the preferred waterline. For motion in the transverse direction, that is port and starboard, thrust from a secondary transverse propulsion units may also be applied substantially at the effective longitudinal center of drag. The ability to apply thrust force both longitudinally and transversely is a desired feature to allow the vessel a high degree of manoeuvrability.

[0039] Manoeuvring Force: Example: Steering the vessel. Method: Manoeuvrability at speed may be provided by a rudder located behind one propulsion unit, or through the use of an array of propulsive units on either side of the vessel, or use of a steerable propeller or some combination thereof. The rudder could be a foil to direct thrust through a range of directions. At low speed and while docked, secondary transverse propulsion units may be provided to control the position and heading of the vessel.

[0040] Weight shifted inside the vessel: Example: Crew movement aboard vessel. Method: Vessel's righting moment, derived from the fixed ballast, can overcome weight shifts due to crew movement or payload movement. This can be further compensated for by adjusting a preferred variable ballast of the vessel with a preferred active ballast system.

[0041] Wave Loading: Method: Because of the low waterplane area, the vessel has a limited response to wave excitation forces. Motions that are induced by waves can be damped out efficiently because of the geometry of the vessel.

[0042] Wind Loading: Method: Topside dimensions should be minimized to reduce wind loading. Wind loading that is experienced is counteracted by the righting moment derived from the fixed ballast. This can be further compensated for by adjusting a variable ballast of the vessel using an active ballast system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0043] Certain embodiments will be described in relation to the drawings in which:

[0044] FIG. **1** is a perspective view of a preferred embodiment of the vessel of the present disclosure.

[0045] FIG. **2** is a side view of the preferred embodiment of the vessel of FIG. **1**.

[0046] FIG. **3** is a front view of the preferred embodiment of the vessel of FIG. **1**.

[0047] FIG. **4** is a perspective view of a second preferred embodiment of the vessel of the present disclosure further comprised of additional inventive features.

[0048] FIG. **5** is a front view of the preferred embodiment of the vessel of FIG. **4**.

[0049] FIG. **6** is a perspective view of a second preferred embodiment of the vessel of FIG. **4** in which the keel has been retracted for storage.

[0050] FIG. **7** is a side view of a generalized vessel of the present disclosure having similar dimensions to the embodiments shown in FIG. **1** and FIG. **4**.

[0051] FIG. **8** is a front view of the generalized vessel of FIG. **7**.

DETAILED DESCRIPTION

[0052] One or more preferred embodiments of the vessel will now be described in greater detail with reference to the accompanying drawings.

[0053] FIG. **1** shows a vessel **10** designed to meet certain wave condition specifications—safe operation in 3 meter waves. A topside structure **20**, which in normal operation is balanced above the waterline **33** (and which may include a cabin **21** and a deck **22**), is connected by one or more low waterline profile vertical struts **30** to an enclosed hull **50** which houses a buoyancy chamber **51**. An extended keel **60**, comprised of a keel strut **61** and keel bulb **62**, hangs from the hull **50**. In the embodiment show, there is a single aft vertical strut **31** and a single forward vertical strut **32**. Thrust is provided by one or more propulsive elements of known types, as may be varied in individual designs according to the prior art. In the embodiment shown in FIG. **1**, a propeller **40** is provided, along with transverse thrusters **41** through the aft vertical strut **31** and the forward vertical strut **32**. The transverse thrusters **41** permit the vessel **10** to turn on the spot without the need for a rudder and/or operation of the propeller **40**. Preferably, the volume of water in the buoyancy chamber **51** is controlled by a buoyancy control system **24**, located in the cabin **21**, to operate known valves and/or pumps to control the net effective waterline **33** of the vessel **10**. Preferably, the thrust provided by the propeller **40** and transverse thrusters **41** is controlled by a propulsion control system **25**, also preferably located in the cabin **21**. Docking fenders **23** for docking at, inter alia, offshore wind turbines are also shown.

[0054] As shown in FIG. **2** and FIG. **3**, for the specifications noted above, the vessel **10** has a length of 6.1 meters, a beam of 3.5 meters, a draft of 9.1 meters, and a total height of 15.1 meters. The displacement of the vessel is approximately 13 tonnes. The large mass of a preferably lead keel bulb **62**, and the length of the keel strut **61** are designed to cause the centre of mass/gravity of the vessel to lie below or near the bottom of the enclosed hull **50** having buoyancy chamber **151**. The volume and lower density of the vertical struts **30** and hull **50** counteract the mass of the keel **60** to cause the center of buoyancy (at the desired waterline **33**) to be positioned clearly above the center of gravity/mass. In the embodiment shown, (as depicted in FIG. **7**, the center of buoyancy is above or near the top of the hull.

[0055] FIG. **4** and FIG. **5** show different views of another preferred embodiment of the vessel **110**. In this embodiment of the vessel **110**, a new option is provided for propulsion. Similar to vessel **10**, vessel **110** comprises some similar elements. A topside structure **120**, which in normal operation is balanced above the waterline **133** (and which may include a cabin **121** and a deck **122**), is connected by one or more low waterline profile vertical struts **130** to an enclosed hull **150** which houses a buoyancy chamber **151** and features optional stability fins **152**. An extended keel **160**, comprised of a keel strut **161** and keel bulb **162**, hangs from the hull **150**. In the embodiment show, there is a single aft vertical strut **131** and a single forward vertical strut **132**. Docking fenders **123** for docking at, inter alia, offshore wind turbines are also shown.

[0056] However, in this embodiment of the vessel **110**, forward propulsion is provided by an array of propulsive elements **140** comprising the rear propeller **141** on the aft strut **131**, side propellers **143** on either side of the hull **150** and transverse thrusters **142** through the aft strut **131** and the forward strut **132**. Through the use of the propulsion control system **125**, the array of propulsive elements **140** can provide (on the basis of dynamic estimation and instrumentation feed-back) a thrust vector (of the type more fully described in relation to FIG. **7** and FIG. **8** below) forward thrust substantially opposite the drag force vector and in the horizontal plane of the net effective waterline **133**. However, such a control system may be considered optional, given the very stable righting moment against pitch or roll provided by the shape of the buoyancy chamber and the position of the center of gravity/mass below the centre of buoyancy.

[0057] Also, the embodiment of the vessel **110** of FIG. **4**, a keel shaft **153** disposed through the hull **150** permits retraction of the keel **160** for operation in shallower waters, or for storage. Although the present design does not include the feature, one can envision the vertical struts slideable mounted within shafts of the topside structure to permit a vessel within the scope of this disclosure to collapse further, for storage or for use in calmer seas—without departing from the scope of the present invention.

[0058] FIG. **7** is a side view of a generalized vessel **210** of the present disclosure having similar dimensions to the embodiments shown in FIG. **1** and FIG. **4**, showing forces acting on the vessel. By design, the centre of gravity **271** of the vessel **210** is kept below the center of buoyancy **270** in operation; such that the gravitational force **281** and buoyancy force **280** always act to right the vessel regardless of orientation. One or more propulsive elements (rotors, propellers, thrusters, etc) **240** is used to propel the vessel **210** under thrust force vector **274**. In order to minimize undesirable pitching of the vessel, at least one propulsive element is preferably positioned substantially at the same vertical heights as the net effective center of drag substantially at drag force vector **272** (as shown in FIG. **3**); or if the propulsive elements **240** are an array the thrust force vector **274** is dynamically positioned to maintain predominantly horizontal motion, and turning can be accomplished without a rudder. In other words, where more than 1 propulsive element is used, control systems can cause the net effective propulsive force to adjust to the same vertical position as an estimate of the net effective center of drag. In a simplified design, a single propulsive element can be placed at the same elevation as the center of transverse drag, with thrust being directed by a rudder.

[0059] As shown in FIG. **8**, to enhance the station keeping performance of the vessel, additional transverse thrusters **241** applying a net transverse thrust force **275** may be preferably included at substantially the same elevation as the net effective transverse drag force **273**.

[0060] In the preferred embodiment of FIG. **7**, one 400 horse power diesel engine (not shown) can propel the vessel by driving a single propulsion unit **240** located at substantially the same elevation as the expected longitudinal center of drag **272** for the preferred net effective water plane/waterline. The vessel may have a normal operating speed of 12 knots, with power available to transit at 15 knots. Velocity lost to light vessels typically used in offshore wind farm maintenance and repair (travelling at above 20 knots) is made up by increasing the environmental operability window (significant wave heights up to 3 m), which allows the vessel to dock effectively, complete safe transport and transfers in more variable wave conditions. By including additional secondary transverse propulsion units **241**, shown in FIG. **8**, the vessel **210** achieves a high level of maneuverability both at high speeds, during transit, and low speeds, while approaching and connecting to, inter alia, a turbine. Overall thrust may be controlled conventionally by a trained mariner, using an engine throttle control and secondary thruster power allocation control. Control from the operator may be a combination of a wheel and throttle control for the propulsion system and a joystick type arrangement for the secondary transverse propulsion units allowing the operator a high degree of control, while maintaining simplicity—or some other design which permits the operator to take fullest advantage of the propulsion options available.

[0061] The foregoing embodiments and advantages are merely exemplary and are not to be construed as limiting the present invention. The present teaching can be readily applied to other types of apparatuses. Also, the description of the embodiments of the present invention is intended to be illustrative, and not to limit the scope of the claims, and many alternatives, modifications, and variations will be apparent to those skilled in the art.

1. A vessel for transporting loads over water, comprising:

a. One or more forward propulsive elements for propelling the vessel in a longitudinal direction;

b. A hull having an underwater buoyancy chamber, a keel connected below the buoyancy chamber, and one or more vertical struts extending above the buoyancy chamber to connect the hull to a topside structure;

c. The hull and the topside structure, together with a permitted range of loads on the topside structure and ballast in the buoyancy chamber, defining a range of centers of gravity for the vessel;

d. in which, for a range of operational waterline positions of the vessel along the one or more vertical struts, the range of centers of gravity is located below a range of centers of buoyancy for the vessel determined by the range of operational waterline positions.

2. The vessel of claim **1** in which the one or more vertical struts have a maximum water plane area which is less than the average cross sectional area of the buoyancy chamber.

3. The vessel of claim **1** in which the one or more vertical struts have a maximum water plane area which is less than 25% of the average cross sectional area of the buoyancy chamber.

4. The vessel of claim **1** in which each of the one or more vertical strut has a maximum water plane area less than 15% of the average cross sectional area of the buoyancy chamber.

5. The vessel of claim **1** in which the keel comprises a keel strut hydro-dynamically shaped as a foil for movement in the longitudinal direction and a keel bulb hydro-dynamically shaped as a tube for movement in the longitudinal direction.

6. The vessel of claim **1** in which the buoyancy chamber is hydro-dynamically shaped as a tube for movement in the longitudinal direction for movement in the longitudinal direction.

7. The vessel of claim **1** in which the vertical struts are hydro-dynamically shaped as foils for movement in the longitudinal direction.

8. The vessel of claim **1** in which the hull is hydro-dynamically shaped for movement in the longitudinal direction.

9. The vessel of claim **1** in which for a range of expected heights for drag force vectors on the vessel defined by the range of operational waterline positions, a net forward propulsive force generated by the one or more forward propulsive elements is applied at substantially such range of expected heights.

10. The vessel of claim **9** in which there is one forward propulsive element positioned at an expected value for the height of a net effective drag force vector on the vessel for a predetermined operational waterline.

11. The vessel of claim **9** in which there is at least one forward propulsive element positioned above the range of expected heights for drag force vectors and at least one propulsive element positioned below the range of expected heights for drag force vectors, and a computer implemented dynamic thrust controller causes the net forward propulsive force to be positioned at a height equal to an estimated value for a current drag force vector determined by the computer implemented dynamic thrust controller.

12. The vessel of claim **1** further comprising an active ballast control system for controlling the volume or location or both volume and location of water and air in the buoyancy chamber.

13. A vessel for transporting loads over water, comprising:

a. One or more forward propulsive elements for propelling the vessel in a longitudinal direction;

b. A hull, hydro-dynamically shaped for movement in the longitudinal direction, having an underwater buoyancy chamber, a keel connected below the buoyancy chamber, and vertical struts extending above the buoyancy chamber to connect the hull to a topside structure;

c. the vertical struts having a maximum water plane area which is less than 25% of the average cross sectional area of the buoyancy chamber;

d. The hull and the topside structure, together with a permitted range of loads on the topside structure and ballast in the buoyancy chamber, defining a range of centers of gravity for the vessel;

e. in which, for a range of operational waterline positions of the vessel along the one or more vertical struts, the range of centers of gravity is located below a range of centers of buoyancy for the vessel determined by the range of operational waterline positions; and a net forward propulsive force generated by the one or more forward propulsive elements is applied at substantially such range of expected heights; and

f. an active ballast control system for controlling the volume or location or both volume and location of water and air in the buoyancy chamber.

14. The vessel of claim **13** in which there is one forward propulsive element positioned at an expected value for the height of a net effective drag force vector on the vessel for a predetermined operational waterline.

15. The vessel of claim **13** in which there is at least one forward propulsive element positioned above the range of expected heights for drag force vectors and at least one propulsive element positioned below the range of expected heights for drag force vectors, and a computer implemented dynamic thrust controller causes the net forward propulsive force to be positioned at a height equal to an estimated value for a current drag force vector determined by the computer implemented dynamic thrust controller.

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