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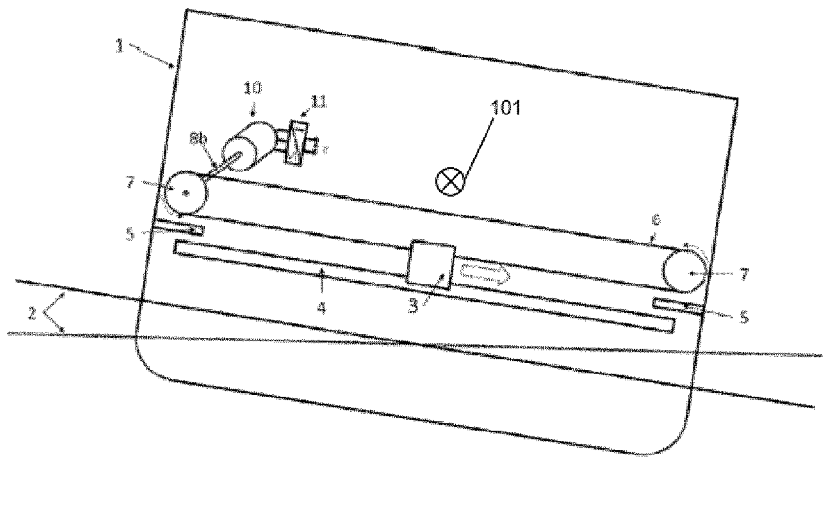

FIG. 3

(57) **Abstract:** The present invention relates to a wave energy to electrical energy converter, the wave energy converter comprising a hull (1), a movable mass (3), a guide (4) for displacement of the mass (3) and an electric power generator (10); the electric power generator (10) comprising a rotor, the mass (3) being coupled to the rotor by means of a mechanism configured to convert displacement of the mass (3) into rotation of the rotor; the mass (3), the guide (4), the generator (10) and the mechanism being in the hull (1); the guide having a port to starboard direction; the converter comprising a controller configured to adjust a rotor torque on the basis of the instantaneous position of the mass (3), instantaneous velocity of the mass (3) and the rolling of the hull (1).

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DESCRIPTION

WAVE ENERGY TO ELECTRICAL ENERGY CONVERTER

TECHNICAL SECTOR

The present invention relates to wave energy to electrical energy converters.

BACKGROUND

Wave energy converters (WECs) are already known in the state of the art, among which there are several differences in terms of the orientation with respect to the wave, the size of the wave energy converter, the location with respect to the shore, etc. However, there are also several differences in terms of the design of the wave energy converter, the way of transforming the captured wave movement or the way in which the captured wave movement is transformed into usable electrical energy.

In terms of design, many of the wave energy converters can be considered very innovative, as was the case with Pelamis (Henderson, R. (2006). Design, simulation, and testing of a novel hydraulic power take-off system for the pelamis wave energy converter. Renewable Energy, 31(2), 271-283.), others, on the other hand, are based on existing wave energy converters to provide them with another innovative aspect and/or improvement with respect to the previous ones.

There are some wave energy converters that can have most of their components outdoors without being protected from weather conditions, biofouling and/or marine salinity and others, as in the case of WO2008/040822A1, which have most of the Power Take-Off components inside the wave movement sensor itself or, as in the case of the Penguin (Beharie, R., & Side, J. (2012). Acoustic environmental Monitoring–Wello penguin cooling system noise study.), which are based on the design of a conventional vessel, having some precise shapes to maximize the extraction of electrical energy, inside which the power take-off is located.

Also, there are wave energy converters with a moving mass to generate energy from the movement of the mass through the inside of the sensor. In some cases, that mass can rotate, as in the Penguin (Beharie, R., & Side, J. (2012). Acoustic environmental Monitoring-Wello penguin cooling system noise study.), or move linearly.

In addition, there are some wave energy converters that have more than one electrical generator, as is the case of the Mutriku OWC (Oscillating Water Column) (Henriques, J., Portillo, J., Sheng, W., Gato, L., & Falcão, A. d. O. (2019). Dynamics and control of air turbines in oscillating-water-column wave energy converters: Analyses and case study. Renewable and Sustainable Energy Reviews, 112, 571-589.), protecting them from adverse environmental conditions. Even so, the vast majority of wave energy converters have far too limited functionality.

European patent EP3414451B1 relates to a PTO (Power Take-Off) device. In it, the kinetic energy of the sliding mass is transformed into electrical energy through a complex mechanical train composed of springs, inertia flywheels, planetary gear train, pulleys or transmissions and electrical machine. In this patent, the braking of the mass is entrusted to springs placed in the sliding shoe that are compressed and return the energy to inertia flywheels that store it to return it in the next movement. In EP3414451B1 it is necessary to maintain the same turning direction of the rotating machine.

It is desirable to maximize the conversion of wave energy into electrical energy, as well as to minimize the wear of the components of the wave energy to electrical energy converter.

DESCRIPTION OF THE INVENTION

In order to overcome the drawbacks of the prior art, a first aspect of the present invention relates to a wave energy to electrical energy converter, the wave energy converter comprising a hull, a movable mass, a guide for displacement of the mass and an electric power generator; the electric power generator comprising at least one rotor, the mass being coupled to the rotor by means of a mechanism configured to convert displacement of the mass into rotation of the rotor; the mass, the guide, the generator, and the mechanism being in the hull; the guide having a port to starboard guiding direction; the converter comprising a controller configured to adjust a rotor torque, the torque adjustment being based on an instantaneous position and instantaneous velocity adjustment of the mass to the rolling of the hull and on instantaneous position and instantaneous velocity estimates of the mass, the instantaneous position of the mass being a position relative to the position of the guide and the instantaneous velocity of the mass being a velocity relative to the velocity of the guide. Said another way, the controller is configured to adjust a rotor torque on the basis of an instantaneous position and instantaneous velocity adjustment of the mass to the rolling of the hull and on the basis of instantaneous position and instantaneous velocity estimates of the mass.

The rolling (also known as rocking) of the hull is caused by the impact of the waves on the hull, with the impact occurring while the hull is floating in water. This rolling causes a time-varying inclination angle of the hull (specifically, a heeling angle of the hull). The movable mass (e.g., sliding along the guide) is subjected to a time-varying inclination caused by the rolling of the hull. This time-varying inclination causes an acceleration of the mass, this acceleration being time-varying due to a variation over time of a gravitational force applied to the mass. Logically, the greater the heeling angle of the hull, the greater the gravitational force applied to the mass. The gravitational force applied to the mass causes a displacement of the mass from port to starboard and from starboard to port.

The mechanism allows converting a torque applied by the electric generator to the rotor into a force applied to the mass. The mechanism also allows converting a displacement of the mass along the guide into a rotation of the rotor. Thus, the electrical generator can operate by transforming kinetic energy of the mass into electrical energy and it can also operate by transforming electrical energy into kinetic energy of the mass. Thus, adjusting the torque applied to the rotor by the electric generator on the basis of the rolling of the hull and on the instantaneous position and velocity estimates of the mass allows maximizing the transformation of wave energy into electrical energy.

In some embodiments, the controller is configured to adjust the torque by means of a control objective, the control objective being defined to brake the mass before it reaches an end stroke of the guide. In this way, it is possible to minimize the energy lost in dissipation due to collisions of the mass with end strokes by reducing the displacement velocity of the mass on impact with an end stroke.

In some embodiments, a control objective of the controller is a sinusoidal evolution of the mass position, the mass position being relative to the guide. For example, the mass position may be defined by the equation:

$$x = A \cdot \sin(\omega \cdot t)$$

where:

x: is the position of the mass relative to the guide,

A: is the amplitude of the mass movement (i.e., half of the separation distance between ends of the mass movement in the displacement),

ω: is the frequency of the displacement of the mass, and

t: is the time.

The sinusoidal evolution of the position allows minimizing the mass velocity when the mass is at one end of the mass path, since the velocity is zero when the position x of the mass is maximum and when the position x of the mass is minimum. Furthermore, the velocity is maximum and minimum when the mass is equidistant from the ends. In this way, the control objective favors an energy dissipation minimization in eventual collisions between mass and end strokes, thus favoring a greater conversion of wave energy into electrical energy and a minimization of the wear of the converter.

In some embodiments, the controller is configured to adjust the constant torque, the constant power, or a combination of both on the basis of a control based on statistical techniques. This type of control has the ability to predict the effects of waves on the basis of a temporal model and, by anticipating the effect of the waves, maximizes the conversion of wave energy into electrical energy.

The port to starboard direction of the guides allows several guides with their respective movable masses to be positioned along the longitude of the hull. Since, in general, the longitude of the hull is greater than the width of the hull, this direction of the guides allows a relatively large number of guides to be placed with their respective movable masses, making it possible to convert the kinetic energy of these masses into electrical energy in a manner similar to that indicated above for a mass. In this way, it is possible to maximize the number of movable masses and thus the conversion of wave energy into electrical energy using a single hull.

In some embodiments, the direction of the guides is substantially perpendicular to the hull centerline (e.g., to the hull centerline plane). This direction allows maximizing the instantaneous inclination angles of the mass in the rolling of the hull, allowing maximizing the conversion efficiency of wave energy into electrical energy.

In some embodiments the guide is linear. This guide is simple and allows limiting the degrees of freedom of displacement of the mass thus allowing to reduce the required control processing time and thus allowing to base the control on more recent information (e.g., measurements), allowing in turn to improve the conversion efficiency of wave energy into electrical energy. In some embodiments, the guide is straight. The straight guide is even simpler and allows to base the control on an even simpler model so that the processing time required by the control is reduced.

In addition, obtaining electrical energy in the hull located in the water allows improving the electrical energy supply to other devices that are also located in the water such as, for example, an electric propulsion vessel and/or a sea farm. This improvement is due to the fact that the proximity between the device and the converter simplifies the load connection between the device and the converter and makes it possible to decrease the electrical energy losses due to the transport of electrical energy from the hull of the wave energy converter to the device. The electrical energy obtained by the wave energy converter can also be supplied to shore, for example, to the electricity grid.

In some embodiments, the angle of List of the wave energy converter is at most between 5 sexagesimal degrees and 2 sexagesimal degrees. It has been proven that with angles of List greater than 5 sexagesimal degrees the mass is blocked on the band where it remains at rest. A relatively small angle of List is advantageous to maximize the conversion efficiency of wave energy into electrical energy. This angle of List allows maximizing the uprighting of the wave energy converter when it begins to be subjected to waves. The smaller the angle of List the higher the uprighting torque. Maximizing this uprighting allows stabilizing the balance position of the mass (i.e., the position of the mass when the hull floats in water unaffected by any wave). This stabilization maximizes the conversion efficiency of wave energy into electrical energy, as it allows the mass to be held in the central position of the guide, without the need to provide energy to the mass, until the hull is subjected to waves, so that the longitude of displacement of the mass enabled by the guide is the same in opposite displacement directions of the mass. The fact of having a reduced angle of List results in energy savings as it is not necessary to position the mass by external means.

In some embodiments, the hull has a block coefficient between 0.93 and 0.97 which allows maximizing the balance angle of the converter with respect to the incident wave. In addition, by having the converter with straight sides, the coefficient of viscous friction of the vessel with respect to the sea is reduced, thus increasing the balance of the converter with respect to the angle of the incident wave.

In some embodiments, the wave energy converter comprises a sensor for measuring instantaneous heeling angle of the hull and a sensor for measuring instantaneous position of the mass with respect to the guide, the controller being configured to receive the measurements taken by the sensors.

The sensor for measuring the instantaneous position of the mass can be for direct measurement of that position or for indirect measurement of that position. For example, the wave energy converter may comprise an accelerometer fixed with respect to the mass and an accelerometer fixed with respect to the guide. Thus, from the measurements of these two accelerometers, the instantaneous position of the mass with respect to the guide and instantaneous velocity of the mass with respect to the guide can be measured or calculated.

For example, a rotary encoder can directly or indirectly measure the instantaneous position of the mass by taking angular position and/or angular velocity measurements of the rotor.

In some embodiments, the controller is configured to estimate height and peak period of the waves, on the basis of measurements taken by a sensor configured to measure heeling angle of the hull.

In some embodiments, the instantaneous position and velocity estimates of the mass are obtained by a state observer. The state observer allows estimating future positions and future instantaneous velocities of the mass. In some embodiments, the state observer estimates are based on measurements taken by the sensors to measure instantaneous inclination angle of the hull and to measure instantaneous position of the mass with respect to the guide. In some embodiments, the state observer estimates are based on measurements taken by the sensor of instantaneous height of waves.

In some embodiments, the hull delimits an inner volume, the mass, the guide, the generator, and the mechanism being in the inner volume. The location of the mass, the guide, the generator, and the mechanism in the inner volume allows to protect, at least partially, the mass, the guide, the generator, and the mechanism from environmental adversities.

In some embodiments, the hull comprises a deck, the deck delimiting the inner volume. The deck allows to increase the protection of the mass, the guide, the generator, and the mechanism against environmental adversities.

In some embodiments, the deck is a flush deck. The flush deck allows to increase the protection, as it extends from the stern to the bow of the hull.

In some embodiments, the converter comprises stops at end strokes of the guide, the stops being for blocking the displacement of the mass. While it is desirable to convert the kinetic energy of the mass into electrical energy before the mass reaches an end stroke, the hull may be subjected to disturbances that exceed the controller's ability to prevent the mass from reaching the end stroke. The stop minimizes the wear of the hull caused by impacts of the mass when the mass reaches an end stroke of the guide. For example, the stops are shock absorbing stoppers and are at the end strokes of the guide.

In some embodiments, each stop comprises an elastic device (e.g., a spring) such that the stop returns to the mass some of the kinetic energy lost by the mass on the impact with the spring.

In some embodiments, each stop comprises a hydraulic device, allowing the hydraulic device to absorb the kinetic energy lost by the mass on the impact with the hydraulic device.

In some embodiments, the wave energy converter comprises bearings, each bearing comprising an inner ring and an outer ring, an outer surface of the outer ring of each of the bearings being in contact with the guide and the inner ring being attached to the mass; the guide having a shape complementary to an assembly formed by the mass and the bearings. These bearings allow a displacement of the mass along the guide with relatively low friction.

In some embodiments, the mechanism comprises pulleys, a belt and a shaft attached to one of the pulleys, the belt being mechanically coupled to the mass and the pulleys such that a displacement of the mass causes rotation of the pulleys; and the rotor being mechanically coupled to the shaft. The rotor is coupled to the shaft so that the shaft rotation causes rotation of the rotor, and the rotation of the rotor causes rotation of the shaft. The rotor can be mechanically coupled directly to the shaft. Thus, the instantaneous rotation of the shaft is equal to the instantaneous rotation of the rotor at any instant. The rotor can be mechanically coupled to the shaft by means of a multiplier. Thus, the instantaneous angular velocity of rotation of the rotor is higher than the instantaneous angular velocity of rotation of the shaft.

In some embodiments, the mechanism is configured so that the rotor rotates in a first direction when the mass moves in the port to starboard direction, and so that the rotor rotates in a direction opposite to the first direction when the mass moves from starboard to port.

In some embodiments, the mechanism is configured so that the rotor rotates in a first direction when the mass moves in the port to starboard direction, and continues turning in the same direction when the mass moves from starboard to port.

In some embodiments, an AC/DC converter (alternating current to direct current converter) is electrically connected to an output of the wave energy generator. The AC/DC converter converts alternating voltage generated by the generator (e.g., an alternating voltage of time-varying root mean square (RMS) value and time-varying frequency) to direct voltage (e.g., direct voltage of varying average value). This conversion allows maximizing the DC electrical energy generated by the wave energy converter.

The generator output AC voltage has a time-varying RMS value and a time-varying frequency. This variation in RMS value and frequency is caused by the changes in the linear velocity of the mass, converted into changes in the rotational velocity driving the generator rotor. Thus, the converter allows maximizing the conversion efficiency of kinetic energy of the mass into electrical energy for different displacements and/or total masses (e.g., it allows maximizing the conversion efficiency of wave energy with different maximum heights and/or with different frequencies).

In some embodiments, the AC/DC converter is in the inner volume of the hull. This makes it possible to improve the protection of the AC/DC converter with respect to the environment (e.g., with respect to a saline environment), thus slowing down the wear of the AC/DC converter.

In some embodiments, an AC/DC/DC converter (alternating current to direct current and direct current to direct current converter) is electrically connected to an output of the electric power generator. The AC/DC/DC converter, in a first conversion, converts alternating voltage generated by the generator (e.g., an alternating voltage of time-varying RMS value and time-varying frequency) into direct voltage (e.g., a direct voltage of time-varying average value). The AC/DC/DC converter, in a second conversion, converts direct voltage of time-varying average value into direct voltage of time-constant average value. The AC/DC/DC converter allows maximizing, under different wave conditions, the conversion efficiency of wave energy into electrical energy supplied to a direct voltage electrical energy consuming device.

In some embodiments, an electrical energy accumulator (e.g., a battery or a super capacitor) is electrically connected to an output of the AC/DC/DC converter such that the accumulator is charged with electrical energy supplied by the AC/DC/DC converter.

In some embodiments, the electrical energy accumulator is in the hull. In this way, the mass of the accumulator can be used to achieve a proper hull balance.

In some embodiments, an AC/DC/DC/DC/AC converter (alternating current to direct current, direct current to direct current, and direct current to alternating current converter) is electrically connected to an output of the electric power generator. The AC/DC/DC/AC converter, in a first conversion, converts alternating voltage generated by the generator (e.g., an alternating voltage of time-varying RMS value and time-varying frequency) into direct voltage (e.g., a direct voltage of time-varying average value). The AC/DC/DC/AC converter, in a second conversion, converts direct voltage of time-varying average value into direct voltage of time-constant average value. The AC/DC/DC/AC converter, in a third conversion, converts direct voltage of time-constant average value into alternating voltage of time-constant RMS value and time-constant frequency. The AC/DC/DC/AC converter allows maximizing, under different wave conditions, the conversion efficiency of wave energy into electrical energy supplied to an alternating voltage electrical energy consuming device of time-constant RMS value and time-constant frequency.

In some embodiments, the mass is a first mass, the guide is a first guide, the mechanism is a first mechanism, the electric power generator is a first electric power generator, and the rotor is a first rotor; the converter comprises a second movable mass, a second guide for displacement of the second mass, and a second electric power generator; the second electric power generator comprises a second rotor, the second mass being coupled to the second rotor by means of a second mechanism configured to convert displacement of the second mass into rotation of the second rotor; the second mass, the second guide, the second generator, and the second mechanism are in the hull; the second guide has a port to starboard direction; the controller is configured to adjust a torque of the second rotor, the torque adjustment of the second rotor being based on an instantaneous position and instantaneous velocity adjustment of the second mass to the rolling of the hull and on instantaneous position and instantaneous velocity estimates of the second mass, the instantaneous position of the second mass being a position relative to the position of the second guide and the instantaneous velocity of the second mass being a velocity relative to the velocity of the second guide.

The wave energy to electrical energy converter comprising several masses can convert the kinetic energy of several masses into electrical energy, making it possible to increase the energy conversion performed by the wave energy converter.

In some embodiments, the wave energy converter comprises activatable and deactivatable blockers of the displacement of at least one of the masses. In this way, the wave energy converter can selectively block, depending on the available wave energy, the displacement of at least one of the masses of the wave energy converter into electrical energy.

In some embodiments, the wave energy converter is configured to activate and deactivate one or more blockers of the activatable and deactivatable blockers on the basis of measurements of instantaneous heeling angles of the hull. In this way, the wave energy converter adjusts the movable mass (and the mass that remains static) on the basis of the waves to which the hull is subjected. This allows the wave energy converter to adjust the rolling of the ship and adjust that rolling to maximize the conversion of kinetic energy of the movable mass into electrical energy.

In some embodiments, the wave energy converter is configured to activate and deactivate one or more blockers of the activatable and deactivatable blockers on the basis of measurements of instantaneous height of the waves. In this way, the wave energy converter adjusts the movable mass, and also adjusts the mass that remains static, on the basis of the waves to which the hull will be subjected in the future. This allows the wave energy converter to anticipate the rolling of the ship that will be caused by the wave to maximize the energy conversion of a wave that will impact the hull in the future.

In some embodiments, the first mass has a total mass different from a total mass of the second mass. Two masses with different total mass allow to increase the possibilities of adaptation of distribution of the mass (both movable and blocked), compared to two masses with the same total mass, allowing to increase the conversion efficiency of wave energy into electrical energy under different wave conditions. For example, if two 10 kg masses are available, the only movable mass combinations will be 10 kg and 20 kg. However, if a 10 kg mass and a 15 kg mass are available, the possible movable mass combinations are 10 kg, 15 kg and 25 kg.

In some embodiments, the wave energy converter is configured so that the generator or generators thereof can operate at lower loads than the rated load (can operate at different masses), adjusting to sea conditions at any given time.

In some embodiments, the control strategy under consideration, using time series-based methods, seeks to maximize the energy extraction of the floating device, without compromising its stability. For this purpose, they all keep the moving mass, or moving masses, oscillating with respect to the center point of the displacement guide. The electrical energy generation control techniques contemplated are: at constant power, at constant torque, a combination of constant power and torque, quadratic torque, cubic torque, etc., with respect to the velocity of the oscillating mass in the same stroke. The input parameters to the control system are: effective incident wave height, period of the incident wave, position of the mass on the displacement guide, rated torque, and power of the electrical machine. With this, the control algorithm estimates, in real time, the resistant torque, and consequently the power, that the electrical machine will demand at all times. To do so, it modifies the settings of the power electronics present between the electrical machine and the electrical energy sink.

In some embodiments, the wave energy converter comprises a trailer and/or hitching means for a trailer; the trailer and/or the hitching means for a trailer being mechanically coupled to the hull. The trailer and/or the hitching means for a trailer allow the hull to be displaced in a controlled manner, for example, to a port. In this way, the maintenance of the wave energy converter is facilitated.

In some embodiments, the hull comprises a portion for mechanical coupling of the hull to a propeller. The propeller allows the hull to be displaced without the need for an additional vehicle. That is, by attaching the outboard propeller to the hull, the hull becomes part of a first vehicle, so that a second vehicle is not needed to displace the hull in a controlled manner.

In some embodiments, the hull comprises at least two ballast tanks and at least two other ballast tanks, being:

- a first tank of the at least two ballast tanks on the starboard side of the hull;

- a second tank of the at least two ballast tanks on the port side of the hull;
- a first tank of the at least two other ballast tanks on the starboard side of the hull;
- a second tank of the at least two other ballast tanks on the port side of the hull;

the at least two tanks being below the at least two other tanks;

the converter comprising filling and emptying regulation means for the ballast tanks; the converter being configured to actuate the regulation means to adjust a hull rolling period to a period of incident waves on the hull.

By regulating the filling and emptying of the ballast tanks, it is possible to adjust the location of the center of gravity of the hull to adapt said center of gravity to the variable behavior of the waves (for example, by adjusting the distance between the metacenter and the center of gravity of the hull). Adjusting the location of the center of gravity of the hull so that the rolling period of the hull coincides with, or is close to, the period of the waves allows maximizing the electrical energy obtained with the converter and also varying the angle of List as desired.

The ballast in the ballast tanks can be water, liquids of different densities than water, or solid materials such as sand.

In some embodiments, the hull comprises at least one orifice for inlet and/or outlet of water (e.g., seawater) to/from the tanks, the at least one orifice connecting the inside of the ballast tanks with the outside of the hull (e.g., with seawater) and the regulation means being configured to regulate water inlet to the tanks and/or water outlet from the tanks through the at least one orifice.

In some embodiments, the at least two tanks are connected to each other by connecting orifices (e.g., limber holes) that allow movement of ballast from one tank to another, the at least two other tanks are connected to each other by connecting orifices (e.g., limber holes) that allow movement of ballast from one tank to another. These embodiments make it possible to minimize the number of ducts connecting tanks to others so as to minimize the number of pumps to transfer ballast from any of the ballast tanks, to any of the ballast tanks and/or between any of the ballast tanks. Preferably, the at least two tanks are not connected to the at least two other tanks by connecting orifices (e.g., limber holes) that allow movement of ballast from one tank to another.

In some embodiments, the regulation means comprise at least two pumps for transferring the ballast through the connection orifices.

The regulation means may comprise valves in the connecting orifices to control the passage of the ballast through the connecting orifices.

In some embodiments, the at least two tanks are below the movable mass, the guide for displacement of the mass and the electric power generator.

In some embodiments, the at least two tanks are below the hull hold plan.

In some embodiments, the at least two other tanks are above the movable mass, preferably over the displacement guide of the mass and the electric power generator.

In some embodiments, the at least two other tanks are inside the hull, in the upper part of the hull.

In some embodiments, the at least two tanks comprise a third tank and a fourth tank, the third tank of the at least two tanks being closer to the bow of the hull than to the stern of the hull, and the fourth tank of the at least two tanks being closer to the stern of the hull than to the bow of the hull; comprising the at least two other tanks a third tank and a fourth tank, the third tank of the at least two other tanks being closer to the bow of the hull than to the stern of the hull, and the fourth tank of the at least two other tanks being closer to the stern of the hull than to the bow of the hull.

In some embodiments, each of the following tanks has a longitude in the hull length direction of at least the one-half of the hull length, preferably at least two-thirds of the hull length: first tank and second tank of the at least two tanks, and first tank and second tank of the at least two other tanks.

In some embodiments, the tanks have an amount of ballast such that the angle of List of the energy converter is non-zero. Thus, the inclination of the ship causes an initial displacement of the movable mass (i.e., it is not necessary to convert electrical energy into mechanical energy of the mass in order to initially displace it).

The period of the waves is estimated, for example, from measurements from an accelerometer arranged in the converter (e.g., in the hull) configured to measure accelerations of the hull in the vertical direction, i.e., upwards and/or downwards. The period of the waves can be estimated, for example, by detecting wave peaks and valleys on the basis of accelerometer measurements.

The period of the waves can be measured before the waves impinge the hull. For example, it can be measured with a buoy provided with an accelerometer arranged so that the wave impinges on the buoy before impinging on the hull. It can also be estimated through a time series algorithm.

The wave height is measured, for example, by measurements taken by an accelerometer arranged in the hull.

The wave height can be measured before the wave impinges on the hull. For example, it can be measured with a buoy provided with an accelerometer arranged so that the wave impinges on the buoy before impinging on the hull. It can also be estimated through a time series algorithm.

In some embodiments, the converter comprises an additional electric power generator, the additional generator being in the hull, the additional electric power generator comprising an additional rotor, the mass being couplable to the additional rotor by means of a mechanism configured to convert displacement of the mass into rotation of the additional rotor; the controller being configured to couple and uncouple the additional rotor to the mass by means of the mechanism on the basis of height of a wave incident on the hull.

Thus, the same mass is couplable to the rotor of the electric power generator (i.e., the first rotor) and to the additional rotor of the additional electric power generator.

In this way, the number of electric power generators to which the mass is coupled is adjusted according to the energy of a single wave or several waves. If a wave is relatively high (i.e., has relatively high energy), the additional rotor is coupled to the mass to convert the wave energy into electrical energy with the two generators and thus increase the electrical energy generated, as the torque applied by the two generators on the mass is greater than the torque applied by only one of the generators.

If a subsequent wave is lower (i.e., has less energy), the additional rotor can be decoupled with respect to the mass as a single generator allows converting sufficient wave energy into electrical energy.

These embodiments also make it possible to avoid having to adjust the mass to the expected conditions of incident waves on the hull. For example, it avoids having to use a different mass in converters floating in locations with very different wave conditions.

The additional rotor can be coupled to the mass through the rotor of the electric power generator. In other words, the mechanism through which the mass is coupled to the additional rotor may include the first electric power generator.

A second aspect of the present invention relates to a use of the wave energy converter of the first aspect of the invention, the direction of the guide(s) being substantially perpendicular to a water wave front on which the hull floats. This orientation of the guide allows maximizing the wave energy converted into electrical energy as the direction of the guide is substantially perpendicular to the direction of the wave front impacting the hull. This energy maximization is particularly high if the direction of the guide(s) is substantially perpendicular to the hull centerline (e.g., perpendicular to the hull centerline plane).

The different aspects and embodiments of the invention defined hereinbefore can be combined with one another, provided that they are mutually compatible.

Additional advantages and features of the invention will become apparent from the following detailed description and will be particularly noted in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

As a complement to the description, and for the purpose of helping to make the features of the invention more readily understandable, in accordance with practical exemplary embodiments of the invention, said description is accompanied by a set of figures which, by way of illustration and not limitation, represent the following:

Figure 1 shows a perspective view of a hull of a wave energy converter according to the invention.

Figure 2 shows a schematic view of a hull of a wave energy converter according to the invention in different positions depending on the phase of the wave in contact with the hull.

Figures 3 and 4 show schematically components of a wave energy converter according to the invention, the hull of Figure 3 having a heeling angle different from the heeling angle of the hull of Figure 4.

Figure 5 shows a side view of a mechanical coupling between a mass and a guide of a wave energy converter according to the invention.

Figure 6 shows a schematic front view of components of a wave energy converter according to the invention.

Figure 7 shows a schematic front view of components of a wave energy converter according to the invention.

Figure 8 shows a schematic perspective view of a mechanical coupling between a pulley and an electric power generator of a wave energy converter according to the invention.

Figure 9 shows a schematic plan view of a mechanical coupling between a pulley and an electric power generator of a wave energy converter according to the invention.

Figures 10 and 11 show schematically components of a wave energy converter according to the invention, the hull of Figure 10 having a heeling angle different from the heeling angle of the hull of Figure 11.

Figure 12 shows a schematic perspective view of a mechanical coupling between a pulley and an electric power generator of a wave energy converter according to the invention.

Figure 13 shows a schematic plan view of a mechanical coupling between a pulley and an electric power generator of a wave energy converter according to the invention.

Figures 14, 15, 16 and 17 show graphs representing the extracted electrical power, divided by the rated power of the electrical generator (power per unit), versus the distance traveled of the moving mass divided by the beam of the floating object (distance per beam unit relative to the center of the displacement guide) for different control strategies, for a port to starboard stroke. Figure 14 shows the control strategy for braking the moving mass and extracting electrical energy at constant torque. Figure 15 shows the control strategy for braking the moving mass and extracting electrical energy at constant power. Figure 16 shows a control strategy for braking the moving mass and extracting electrical energy at constant power and torque. Figure 17 shows a control strategy for braking the moving mass and extracting electrical energy at quadratic torque.

DESCRIPTION OF PREFERRED EMBODIMENTS OF THE INVENTION

In the description of the possible preferred embodiments of the invention it is necessary to give numerous details to favor a better understanding of the invention. Even so, it will be apparent to the person skilled in the art that the invention can be implemented without these specific details. On the other hand, well-known features have not been described in detail to avoid unnecessarily complicating the description.

Figure 1 illustrates a portion of a hull 1 of a wave energy to electrical energy converter. Hull 1 defines an inner volume 100 and a hull centerline 101. Hull 1 can define a centerline plane where the center of gravity of the hull is located.

Figure 2 schematically illustrates various positions of the hull 1 relative to a wave 200. Specifically, Figure 2 shows various positions of a stern area of the hull 1. As illustrated in Figure 2, wave 200 causes a variation in the heeling angle of the hull 1, the heeling angle at each instant being dependent on the phase of wave 200 at the instant. In Figure 2, the wave front 200 is parallel to the centerline 101 of the hull 1 (e.g., parallel to the centerline plane where center of gravity 101 of the hull 1 is located). As illustrated in Figure 2, the centerline 101 is perpendicular to the paper plane in Figure 2. The centerline is, for example, a line in the centerline plane of the hull 1 on which the center of gravity of the hull 1 is located.

Figure 3 is a schematic view in the direction of the centerline 101 of the hull 1. Figure 3 schematically illustrates components of a wave energy to electrical energy converter. Hull 1 has a heeling angle defined by the imaginary straight lines 2. The non-zero heeling angle is due to the action of a wave on hull 1.

Continuing with Figure 3, the wave energy converter comprises a movable mass 3, a guide 4 for displacement of the mass 3 and an electric power generator 10, the generator 10 comprising a rotor. Guide 4 is a guide perpendicular to the centerline 101 of the hull 1. The wave energy converter comprises a mechanical coupling mechanism from the rotor to the mass 3, the coupling mechanism being configured to convert displacement of the mass 3 into rotation of the rotor. This mechanism allows converting a torque applied to the rotor into a force applied to the mass 3 and also allows converting a force applied to the mass 3 into a torque applied to the rotor. The wave energy converter comprises a controller not illustrated in the figures, the controller being configured to adjust a rotor torque. By adjusting the rotor torque, the kinetic energy of the mass 3 converted into electrical energy is adjusted, as well as the displacement of the mass 3. The torque adjustment is based on an instantaneous position and instantaneous velocity adjustment of the mass to the rolling of the hull 1 and on instantaneous position and instantaneous velocity estimates of the mass 3, being the instantaneous position of the mass 3 with respect to the guide 4 and being the instantaneous velocity of the mass 3 with respect to the guide 4.

Thus, it is possible to maximize the conversion of kinetic energy of the mass 3 into electrical energy, taking into account the instantaneous position and instantaneous velocity of the mass 3 in the rolling of the hull 1.

The coupling mechanism comprises a belt 6, pulleys 7 and a first shaft 8b. The belt 6 is attached to the mass 3, for example, the belt 6 is tied to the mass 3. The belt 6 converts a displacement of the mass 3 into rotations of the pulleys 7.

The pulleys 7 may be attached to the hull 1 such that each of the pulleys 7 may rotate about its central shaft, each central shaft being at a fixed location with respect to the hull 1. For example, the center of each of the pulleys 7 may be coupled to a bar, for example, by means of a bearing, the bar being fixed with respect to the hull 1. Thus, if the belt 6 has sufficient tension, a displacement of the mass 3 towards one of the pulleys displaces the belt 6 such that the belt 6 causes rotation of each of the pulleys 7 with respect to the central shaft of the pulley.

The first shaft 8b and one of the pulleys 7 are integral. Therefore, one of the pulleys 7 and the first shaft 8b rotate at the same angular velocity.

Continuing with Figure 3, the port area of the hull 1 is more elevated than the starboard area of the hull 1. Gravity exerts a force on the mass 3. If this force is high enough, it causes a linear acceleration of the mass 3 towards the starboard area of the hull 1, the linear acceleration having a direction parallel to the guide 4. In order for gravity to cause linear acceleration of the mass 3 and electrical energy generation, the gravitational force must overcome a frictional force between the mass 3 and the guide 4 as well as a force derived from the braking torque caused by the generator 10 on the rotor of the generator 10.

As illustrated in Figure 5, the guide 4 has a shape complementary to a shape of the mass 3 such that the mass 3 can be displaced along the guide 4. To reduce a frictional force between the mass 3 and the guide 4, the wave energy converter may comprise bearings 300 interposed between the mass 3 and the guide 4. The bearings 300 may be bearings known to the person skilled in the art, each bearing comprising an inner ring, an outer ring, and solids of revolution between the outer ring and the inner ring and in contact with the outer ring and the inner ring. The outer surface, visible in Figure 5, of the outer ring of each of the bearings 300 is in contact with the guide 4.

As illustrated in Figures 3, 4 and 7, the wave energy converter comprises stops 5. The stops 5 protect the hull 1 against impacts from the mass 3. In particular, the stops 5 limit the displacement of the mass 3 by blocking the advance of the mass 3, that is, by limiting the stroke of the mass 3 in the vicinity of side walls of the hull 1.

As illustrated in Figure 6, the wave energy converter may not comprise stops 5, the hull 1 being able to act, for example, as a stop of the displacement of the mass 3 along the guide 4 if the controller has failed to brake the mass 3, by properly adjusting the braking torque caused by the generator 10 in the rotor, before the mass 3 collides with the hull 1.

Figure 4 schematically illustrates components of the wave energy to electrical energy converter, the hull 1 having a heeling angle defined by the imaginary straight lines 2. The heeling angle in Figure 4 has a sign opposite to the sign of the heeling angle illustrated in Figure 3. Figure 4 is a schematic view in the direction of the centerline 101 of the hull 1. The non-zero heeling angle is due to the action of a wave on hull 1.

Continuing with Figure 4, the starboard area of the hull 1 is higher than the port area of the hull 1. Gravity applies a force to mass 3. If this force is high enough, it causes a linear acceleration of the mass 3 towards the port area of the hull 1, the linear acceleration having a direction parallel to the guide 4. In order for gravity to cause linear acceleration of the mass 3 and electrical energy generation, the gravitational force must overcome a frictional force between the mass 3 and the guide 4 as well as a force derived from a braking torque caused by the generator 10 on the rotor of the generator 10.

Figures 3, 4 and 8 illustrate a first shaft 8b integral with the rotor of the generator 10. The rotor of the generator 10 is not illustrated in the figures.

As illustrated in Figures 3, 4 and 8, the turning direction of the first shaft 8b depends on the displacement direction of the mass 3. For example, if the mass 3 is displaced in a first direction, for example, to starboard, the first shaft 8b rotates in a second direction; and if the mass 3 is displaced in a direction opposite to the first direction, for example, to port, the first shaft 8b rotates in the opposite direction to the second direction.

The generator 10 can generate electrical power as known in the prior art, for example, by varying a magnetic flux passing through a loop by means of a rotation of the rotor, the loop being an electrical conductor. The generator 10 can cause an opposing torque to a rotation. This torque, opposed to a rotation of the first shaft 8b and of the pulley attached to the first shaft 8b, makes it possible to convert kinetic energy of the mass 3 into electrical energy. The opposing torque is adjustable by the controller by means of signals generated by the controller to adjust electrical and/or magnetic parameters of the generator 10 (e.g., signals to adjust a magnetic field between stator and rotor of the generator 10). It is also possible that, at certain instants of time, the generator 10 acts as an electrical machine, applying a torque on the rotor that causes acceleration of the mass 3. This acceleration of the mass 3 allows the position and velocity of the mass 3 to be adjusted to maximize the wave energy conversion, as well as to minimize the risk of mass 3 reaching the end strokes of the guide 4.

The torque applied to the rotor can be adjusted from the controller in ways known in the prior art. For example, given the same rotor angular velocity, an increase in the modulus of a magnetic flux between rotor and stator of the generator 10 would cause an increase in the opposing torque to the rotation of the rotor, i.e., increasing moduli of the magnetic induction vectors of the magnetic flux. Another way of adjusting the opposing torque compatible with the above manner comprises adjusting an electrical resistance of the generator 10. Thus, the controller can adjust the torque applied to the rotor by adjusting a magnetic parameter of the generator 10 such as, for example, the magnetic flux, and/or an electrical parameter of the generator 10 such as, for example, an electrical resistance.

The adjustment of the opposing torque to the rotation of the rotor causes an adjustment of the acceleration of the mass 3. Thus, the wave energy converter can adjust an acceleration of the mass 3 by adjusting the opposing torque to the rotation of the rotor of the generator 10 rotor.

The wave energy converter may comprise a sensor for measuring instantaneous heeling angle of the hull 1 and a sensor for measuring instantaneous position of the mass

3 with respect to the guide 4, the controller being configured to receive the measurements taken by the sensors. The sensor for measuring instantaneous position of the mass 3 is, for example, a rotary encoder coupled to the generator 10 for measuring instantaneous rotational velocity of the rotor and instantaneous angular position of the rotor, allowing measurements of the instantaneous position and instantaneous velocity of the mass 3 with respect to the guide 4 to be obtained from the instantaneous rotational velocity of the rotor and instantaneous angular position of the rotor.

The sensor for measuring instantaneous heeling angle of the hull 1 is, for example, a gyroscope fixed with respect to hull 1.

The control configuration can be performed on the basis of the following equations that model the behavior of the hull 1 and the mass 3 under the influence of waves.

$$I_{x\prime x} \cdot \frac{d^2\phi}{dt^2} + b \cdot \frac{d\phi}{dx} + g \cdot \Delta \cdot GZ(\phi) = M$$

where:

ϕ: is the heeling angle of the hull 1,

$I_{x\prime x}$: is the longitudinal moment of inertia of the hull with all components supported by the hull,

M: is the moment generated by a wave on the hull,

b: is the damping coefficient of the hull balance,

g: is an acceleration caused by gravity and approximated as 9.8 (m/s^2),

Δ: is a displacement of the floating device (i.e., the mass of the hull 1 with all components supported by the hull 1), and

$GZ(\phi)$: is the uprighting arm acting on the hull 1.

$$\frac{dv}{dt} = g \cdot (\sin(\phi) - \mu \cdot \cos(\phi)) - \frac{B}{m} \cdot v$$

where:

v: is a displacement velocity of the mass 3 with respect to the guide 4,

$\frac{dv}{dt}$: is a derivative with respect to the time of v,

g: is an acceleration caused by gravity and approximated as 9.8 (m/s^2),

ϕ: is a heeling angle of the hull 1,

μ: is a dynamic friction coefficient between the mass 3 and the guide 4,

B: is a coefficient of viscous friction to which the mass 3 is subjected (e.g., viscous friction between air and the mass 3 and viscous friction between the bearings 300 and the guide 4 due to a lubricating oil between the bearings 300 and the guide 4), and

m: is the total mass of the mass 3.

The hull 1 and the mass 3 (or, in case the wave energy converter comprises several masses, the masses) and, optionally, the guide 4, the mechanism for converting displacement of the mass 3 into rotation of the rotor and the generator 10 (or, in case the wave energy converter comprises several masses, the displacement guides of the masses, the mechanisms for converting displacements of the mass into rotations of the rotor and the generators), can be designed on the basis of the following equations:

$$\tan(\phi) = \frac{m \cdot B}{2 \cdot \Delta \cdot GM_t}$$

where:

ϕ: is an angle of List of the hull 1,

m: is the total mass of the mass 3 (or the masses, in case the wave energy converter comprises several masses),

B: is the dimension of the beam of the hull 1,

Δ: is a displacement of the floating device, and

GM_t: is the metacentric height of the hull 1 with all components supported by the hull 1.

$$A = \frac{1}{\sqrt{(1-\Lambda^2)^2 + 4 \cdot \kappa^2 \cdot \Lambda^2}}$$

where:

A: is the amplification of the heeling angle of the hull 1 with respect to the slope of the incident wave, comprising values between 1 and 10,

κ: is a dimensionless damping coefficient, and

Λ: is a result of dividing a frequency of the incident waves in the hull 1 by a frequency of the hull 1, where the hull frequency is based on:

$$\omega_0{}^2 = \frac{g \cdot \Delta \cdot GM_t}{I_{xx'}}$$

where:

ω_0: is a natural frequency of the hull 1,

g: is an acceleration caused by gravity and approximated as 9.8 (m/s^2),

Δ: is a displacement of the floating device,

GM_t: is the metacentric height of the hull 1 with all components supported by the hull 1, and

$I_{xx'}$: is the longitudinal moment of inertia of the hull 1 with all components supported by the hull.

The controller is not illustrated in any of the figures. The controller may comprise components in the hull 1 and/or remote from the hull 1. The controller may comprise a memory with instructions that, when executed by a processor of the controller, cause the controller to adjust a rotor torque, the instructions comprising adjusting instantaneous position and instantaneous velocity of the mass 3 to the rolling of the hull 1 on the basis of instantaneous position and instantaneous velocity estimates of the mass 3, the instantaneous position of the mass 3 being a position relative to the position of the guide 4 and the instantaneous velocity of the mass 3 being a velocity relative to the velocity of the guide 4.

Figure 10 schematically illustrates components of a wave energy converter equal to the wave energy converter illustrated in Figure 3 except for the addition of a multiplier 9. As known in the prior art, the multiplier 9 is configured to provide at an output of the multiplier 9 an angular velocity of rotation greater than an angular velocity of rotation at an input of the multiplier 9. An input of the multiplier 9 and the second shaft 8a are integral, so that the input of the multiplier 9 rotates at the same angular velocity as the second shaft 8a. An output of the multiplier 9 and the third shaft 8a' are integral, so that the output of the multiplier 9 and the third shaft 8a' rotate at the same angular velocity. Hull 1 illustrated in Figure 10 has the same heeling angle as the hull 1 illustrated in Figure 3. Figure 10 is a schematic view in the direction of the centerline 101 of the hull 1 (as indicated above, the centerline may be a line of the centerline plane, the center of gravity of the hull 1 being on said line).

Figure 11 schematically illustrates components of a wave energy converter equal to the wave energy converter illustrated in Figure 4 except for the addition of the multiplier 9. Hull 1 illustrated in Figure 11 has the same heeling angle as the hull 1 illustrated in Figure 4. Figure 11 is a schematic view in the direction of the centerline 101 of the hull 1.

Continuing with Figures 3, 4, 8 and 9, the wave energy converter comprises a rectifier electrically connected to an output of the generator 10. The rectifier is configured to convert alternating current generated by the generator 10 into direct current. Specifically, Figures 8 and 9 illustrate an AC/DC converter 11 that converts an output voltage of the generator 10, the output voltage of the generator 10 having a time-varying RMS value and a time-varying frequency, into a continuous voltage v of time-varying average value. Logically, the output voltage of the generator 10 is of electrical energy generated by the generator 10 from the kinetic energy of the mass 3.

Figure 12 schematically illustrates one of the pulleys 7, a second shaft 8a that mechanically couples the pulley to the multiplier 9, a third shaft 8a’ that mechanically couples the multiplier 9 to the generator 10, and an AC/DC converter 11 electrically connected to an output of the generator 10. The scheme of Figure 12 is similar to that of Figure 8 except that, instead of the first shaft 8b, Figure 12 includes the second and third shafts 8a, 8a’ and the multiplier 9.

Figure 13 schematically illustrates one of the pulleys 7, a second shaft 8a that mechanically couples the pulley to the multiplier 9, a third shaft 8a’ that couples the multiplier 9 to the generator 10, and an AC/DC converter 11 electrically connected to an output of the generator 10. The scheme of Figure 13 is similar to that of Figure 9 except that, instead of the first shaft 8b, Figure 13 includes the second and third shafts 8a, 8a’ and the multiplier 9.

An example test was performed on a scale model to obtain initial results. The model has a hull 1 with a beam of 1020 millimeters and a length of 3230 millimeters. The effect of wave models was tested, with the waves having the following characteristics:

1. 2 meters of significant height and a period of 8 seconds.
2. 1.25 meters of significant height and a period of 6 seconds.
3. 1 meter of significant height and a period of 4.5 seconds.
4. 2.25 meters of significant height and a period of 5 seconds.

Being the significant height the arithmetic mean of the height of the highest third of waves recorded in a period of 20 to 30 minutes, from the valley of the wave to the peak. The period of the wave group with the highest energy is called the peak period and is denoted Tp.

In the experiment with a 1:10 scale model, three masses of respective total masses of 4, 6 and 8 kilograms were used, in order to see the variation of the power obtained as a function of masses of different total masses. Thus obtaining effective powers that meet the expected results on the basis of the scale of the model depending on the different configurations, thanks to a generator located in the model. For example, the lowest effective power was achieved with the first wave example and with the mass of 6 kilograms, while the maximum power was achieved with the example 4 and the mass of 6 kilograms. Extrapolating these results to the dimensions of the prototype, the ideal mass of the mass or mass summation is 500 kg.

Figures 14, 15, 16 and 17 show graphs representing examples of the extracted electrical power, divided by the rated power of the electrical generator (hereafter referred to as power per unit generated), versus the distance traveled by the moving mass, divided by the beam of the floating object (distance per beam unit of the floating object, taking the center of the sliding guide as a reference for a distance per unit equal to zero). It is expressed how the power per unit generated is affected, for different control strategies, for a port to starboard stroke and a starboard to port stroke.

Figure 14 shows a control strategy in which a braking torque of the rotor is constant at two extreme portions of the displacement of the mass 3 along the guide 4. The two extreme portions of the displacement of the mass may not necessarily comprise the ends of the guide 4 and, in fact, in Figures 14 to 17 they do not comprise them as illustrated on the respective abscissa axes.

Figure 15 shows a control strategy in which the electrical power generated from the kinetic energy of the mass 3 is constant at two extreme portions of the displacement of the mass 3 along the guide 4.

Figure 16 shows a control strategy in which a braking torque of the rotor is constant at two extreme portions of the displacement of the mass 3 along the guide 4. In addition, the electrical power generated from the kinetic energy of the mass 3 is constant in two portions of the displacement of the mass 3 along the guide 4, the portions being one portion adjacent to one of the portions in which the braking torque of the rotor is constant and one portion adjacent to the other of the portions in which the braking torque of the rotor is constant.

Figure 17 shows a control strategy in which a braking torque of the rotor is quadratic at two extreme portions of the displacement of the mass 3 along the guide 4. The braking torque of the rotor is quadratic with respect to the distance between the position of the mass 3 and the end of the displacement of the mass 3 closest to the mass 3.

The hull may comprise ballast tanks along the length and the beam of the hull and at different heights. Specifically, the hull may comprise at least four ballast tanks and at least four other ballast tanks, being:

- a first tank of the at least four ballast tanks closer to the bow of the hull than to the stern of the hull;
- a second tank of the at least four ballast tanks closer to the stern of the hull than to the bow of the hull;
- a third tank of the at least four ballast tanks on the starboard side of the hull;
- a fourth tank of the at least four ballast tanks on the port side of the hull;
- a first tank of the at least four other ballast tanks closer to the bow of the hull than to the stern of the hull;

- a second tank of the at least four other ballast tanks closer to the stern of the hull than to the bow of the hull;

- a third tank of the at least four other ballast tanks on the starboard side of the hull;

- a fourth tank of the at least four other ballast tanks on the port side of the hull;

at least four tanks being below the at least four other tanks;

the converter comprising filling and emptying regulation means for the ballast tanks; the converter being configured to actuate the regulation means to adjust a hull rolling period to a period of incident waves on the hull.

The regulation means may be actuated, for example, with a processor configured to actuate the regulation means so as to allow the ballast tanks to be filled and emptied (e.g., the pump(s) that drive the ballast is(are) actuated and/or the valve(s) that control the passage of the ballast are opened) to adjust the weight of the ballast tanks so that the hull rolling period coincides with, or is close to, a period of incident waves on the hull.

When an ordinal number (such as "first", "second", "third", etc.) is used as an adjective preceding a term or expression, that ordinal number is used (unless expressly specified otherwise) simply to indicate a particular characteristic, such as to distinguish that particular characteristic from another characteristic described by the same or a similar term or expression. For example, a "first device" may be so named simply to distinguish it from, for example, a "second device". Thus, the mere use of the ordinal numbers "first" and "second" preceding the term "device" does not indicate any other relationship between the two devices, nor does it indicate any other characteristic of one or both devices. For example, the mere use of the ordinal numbers "first" and "second" before the term "device" (1) does not indicate that either device is sequentially before or after any other in order or location; (2) does not indicate that either device occurs or acts before or after any other in time; and (3) does not indicate that either device is above or below any other in importance or quality. Furthermore, the mere use of ordinal numbers does not define a numerical limit for the characteristics identified with the ordinal numbers. For example, the mere use of the ordinal numbers "first" and "second" preceding the term "device" does not indicate that there should be no more than two devices and the mere use of the ordinal number "second" preceding the term "device" does not indicate that there should be a "first device".

In view of this description and figures, the person skilled in the art may understand that the invention has been described according to some preferred embodiments thereof, but that multiple variations may be introduced in said preferred embodiments, without leaving the object of the invention as claimed.

In this text, the term "comprise(s)" and its derivations (such as "comprising", etc.) should not be understood in an exclusive sense. That is to say, these terms should not be interpreted as excluding the possibility that what is described and defined may include more elements, stages, etc.

CLAIMS

1. Wave energy to electrical energy converter, the wave energy converter comprising a hull (1), a movable mass (3), a guide (4) for displacement of the mass (3) and an electric power generator (10); the electric power generator (10) comprising a rotor, the mass (3) being coupled to the rotor by means of a mechanism configured to convert displacement of the mass (3) into rotation of the rotor; the mass (3), the guide (4), the generator (10) and the mechanism being in the hull (1); the guide having a port to starboard guiding direction; the converter comprising a controller configured to adjust a rotor torque, the torque adjustment being based on an instantaneous position and instantaneous velocity adjustment of the mass to the rolling of the hull (1) and on instantaneous position and instantaneous velocity estimates of the mass (3), the instantaneous position of the mass being a position relative to the position of the guide and the instantaneous velocity of the mass being a velocity relative to the velocity of the guide.

2. The wave energy converter of claim 1, the wave energy converter comprising a sensor for measuring instantaneous heeling angle of the hull (1) and a sensor for measuring instantaneous position of the mass (3) with respect to the guide (4), the controller being configured to receive the measurements taken by the sensors.

3. The wave energy converter of any one of the preceding claims and a time series-based control system, which seek as an objective to maximize the energy extraction of the floating device, without compromising its stability.

4. The wave energy converter of any one of the preceding claims, the hull (1) delimiting an inner volume, the mass (3), the guide (4), the generator (10) and the mechanism being in the inner volume.

5. The wave energy converter of claim 4, the hull comprising a deck, the deck delimiting the inner volume.

6. The wave energy converter of claim 5, the deck being a flush deck.

7. The wave energy converter of any one of the preceding claims, the wave energy converter comprising stops (5) at end strokes of the guide (4), the stops being for blocking the displacement of the mass (3).

8. The wave energy converter of any one of the preceding claims, the wave energy converter comprising bearings (300), each bearing comprising an inner ring and an outer ring, an outer surface of the outer ring of each of the bearings (300) being in contact with the guide (4) and the inner ring being attached to the mass (3); the guide (4) having a shape complementary to an assembly formed by the mass (3) and the bearings (300).

9. The wave energy converter of any one of the preceding claims, the mechanism comprising pulleys (7), a belt (6) and a shaft (8b, 8a) attached to one of the pulleys (7), the belt (6) being mechanically coupled to the mass (3) and to the pulleys (7) such that a displacement of the mass (3) causes rotation of the pulleys (7); and the rotor being mechanically coupled to the shaft.

10. The wave energy converter of any one of the preceding claims and an AC/DC/DC converter, the AC/DC/DC converter being electrically connected to an output of the electric power generator (10).

11. The wave energy converter of any one of the preceding claims, the mass (3) being a first mass, the guide (4) being a first guide, the mechanism being a first mechanism, the electric power generator (10) being a first electric power generator, and the rotor being a first rotor; the wave energy converter comprising a second movable mass, a second guide for displacement of the second mass and a second electric power generator, the second electric power generator comprising a second rotor, the second mass being coupled to the second rotor by means of a second mechanism configured to convert displacement of the second mass into rotation of the second rotor; the second mass, the second guide, the second generator, and the second mechanism being in the hull (1); the second guide having a port to starboard direction; the controller being configured to adjust a torque of the second rotor, the torque adjustment of the second rotor being based on an instantaneous position and instantaneous velocity adjustment of the second mass to the rolling of the hull (1) and on instantaneous position and instantaneous velocity estimates of the second mass, the instantaneous position of the second mass being a position relative to the position of the second guide and the instantaneous velocity of the second mass being a velocity relative to the velocity of the second guide.

12. The wave energy converter of claim 11, the first mass having a total mass different from a total mass of the second mass.

13. The wave energy converter of any one of the preceding claims, the wave energy converter comprising a trailer and/or hitching means for a trailer; the trailer and/or the hitching means for a trailer being mechanically coupled to the hull (1).

14. The wave energy converter of any one of the preceding claims, the hull (1) comprising a portion for mechanical coupling of the hull to an outboard propeller.

15. The wave energy converter of any one of the preceding claims, the hull comprising at least two ballast tanks and at least two other ballast tanks, being:

- a first tank of the at least two ballast tanks on the starboard side of the hull;
- a second tank of the at least two ballast tanks on the port side of the hull;
- a first tank of the at least two other ballast tanks on the starboard side of the hull;
- a second tank of the at least two other ballast tanks on the port side of the hull;

the at least two tanks being below the at least two other tanks;

the converter comprising filling and emptying regulation means for the ballast tanks; the converter being configured to actuate the regulation means to adjust a hull rolling period to a period of incident waves on the hull.

16. The wave energy converter of any one of the preceding claims, the converter comprising an additional electric power generator, the additional generator being in the hull (1), the additional electric power generator comprising an additional rotor, the mass (3) being couplable to the additional rotor by means of a mechanism configured to convert displacement of the mass (3) into rotation of the additional rotor; the controller being configured to couple and uncouple the additional rotor to the mass (3) by means of the mechanism on the basis of height of a wave incident on the hull (1).

17. Use of the converter of any one of the preceding claims, the direction of the guide(s) being substantially perpendicular to a water wave front in which the hull (1) floats.

FIGURES

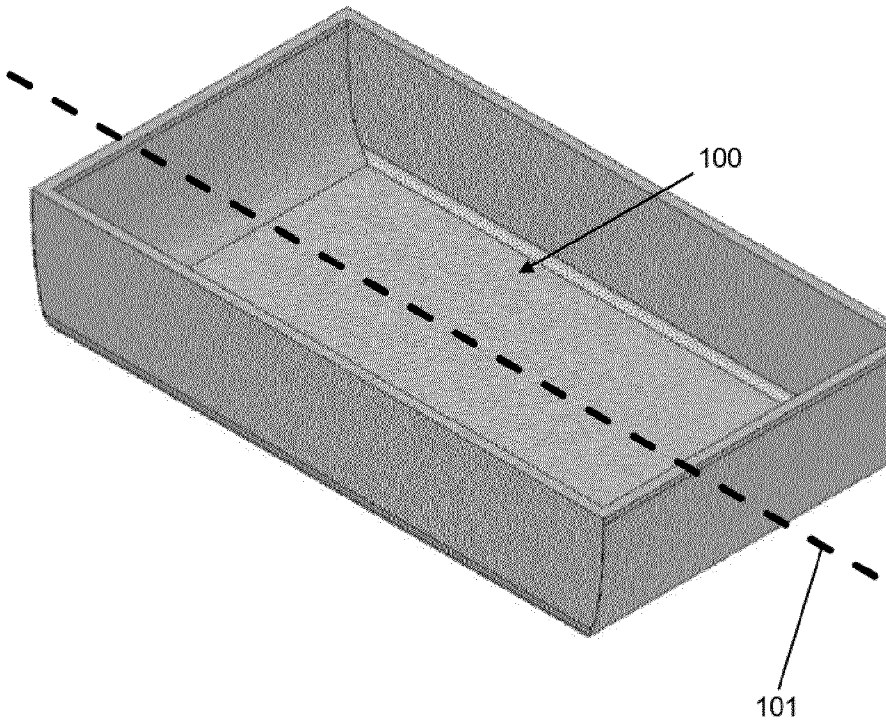

FIG. 1

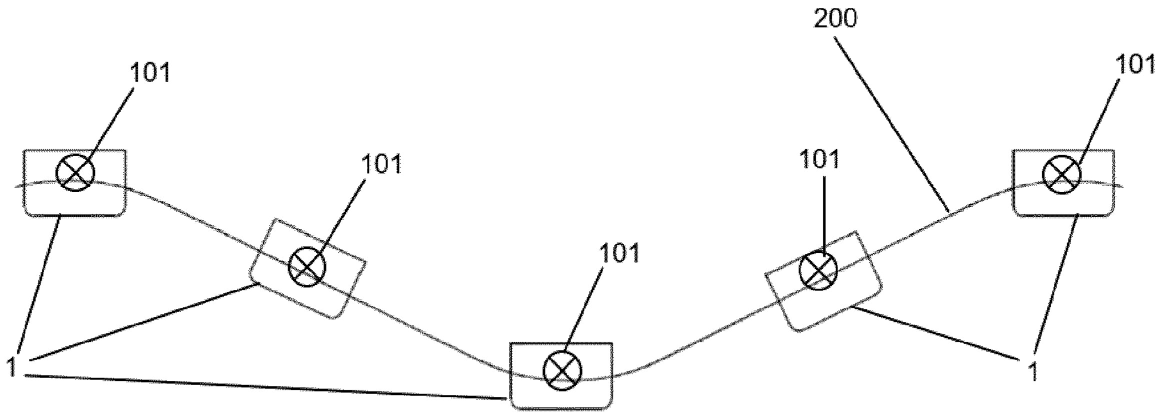

FIG. 2

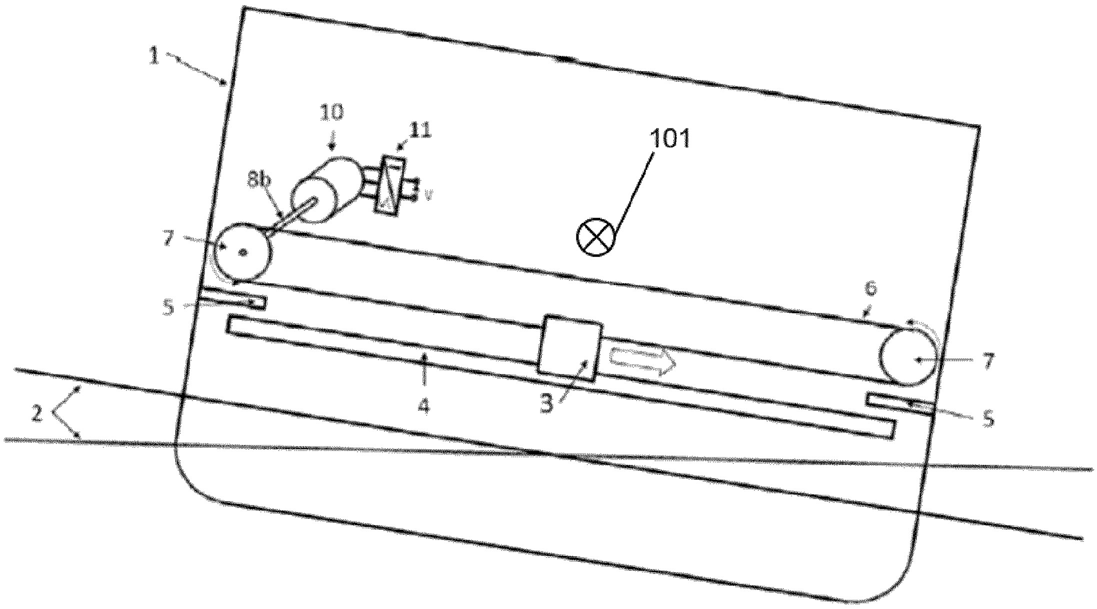

FIG. 3

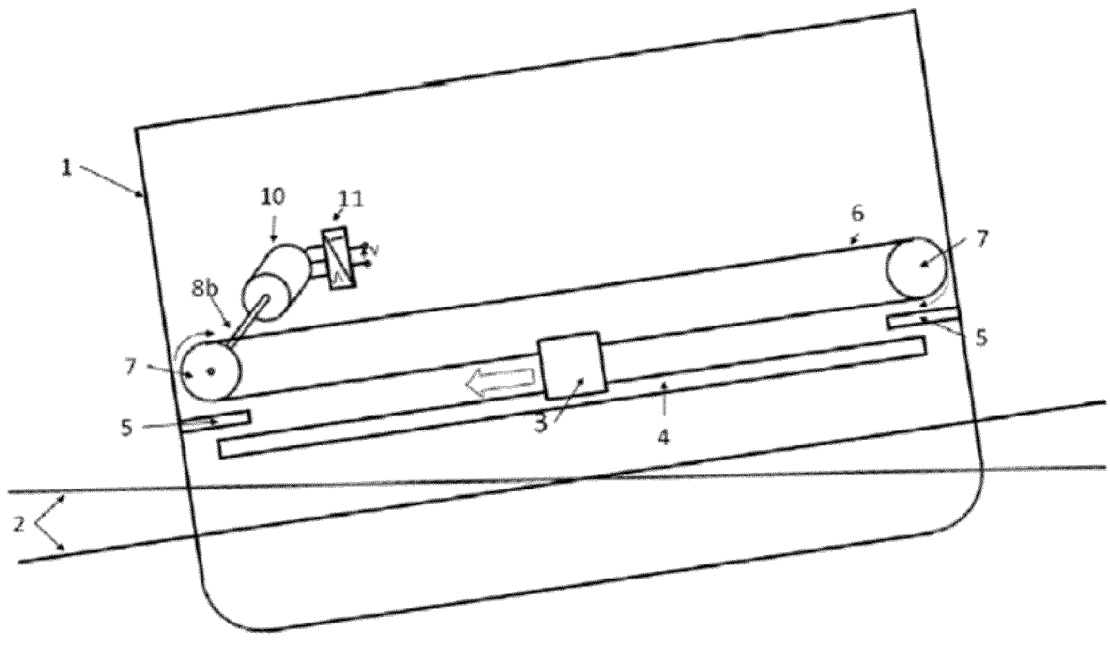

FIG. 4

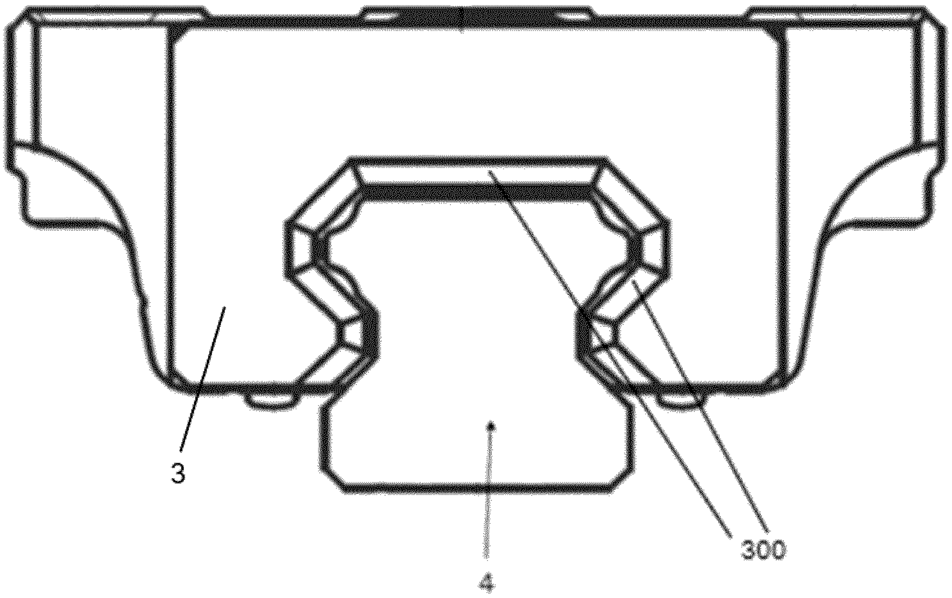

FIG. 5

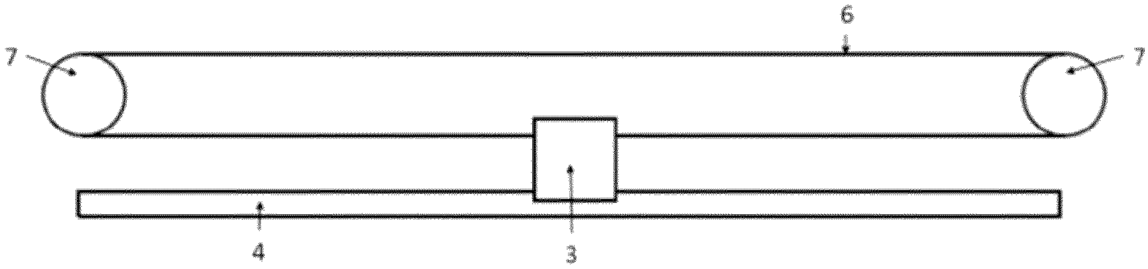

FIG. 6

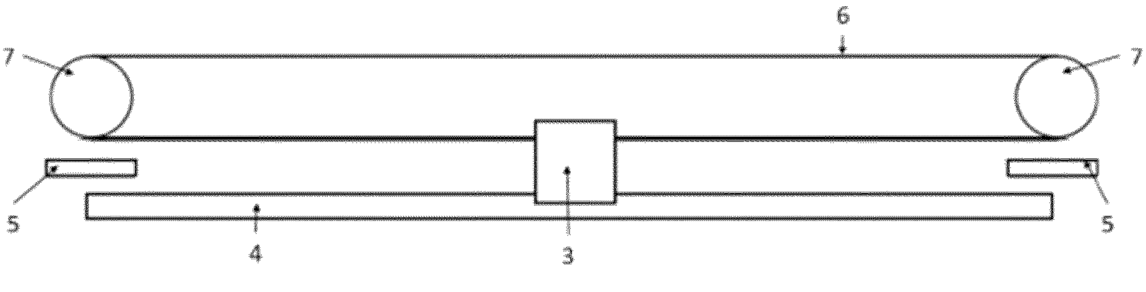

FIG. 7

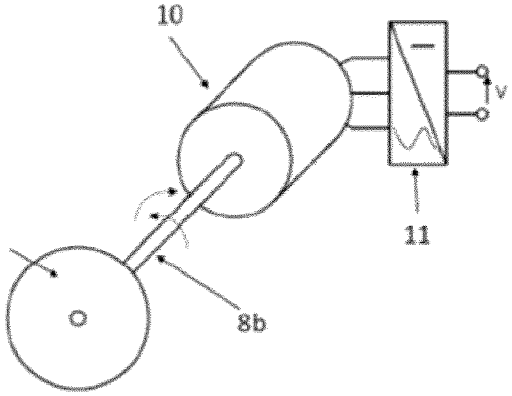

FIG. 8

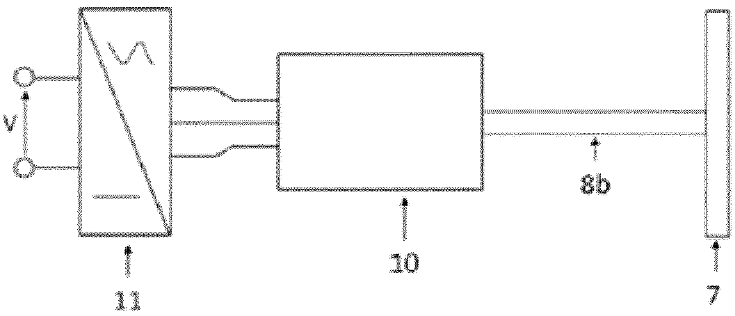

FIG. 9

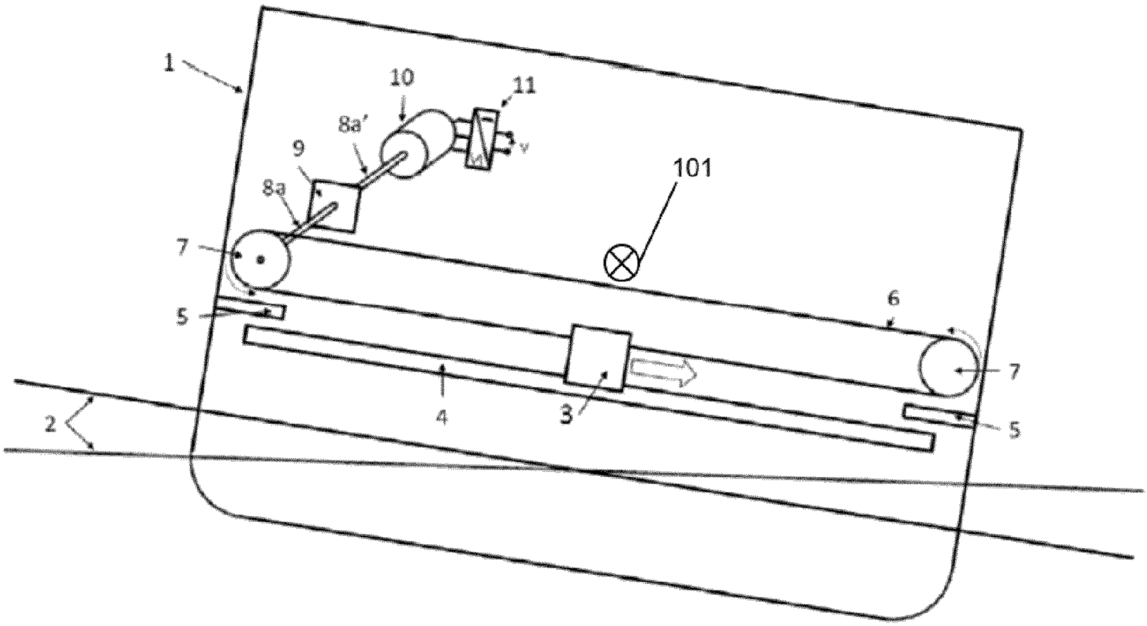

FIG. 10

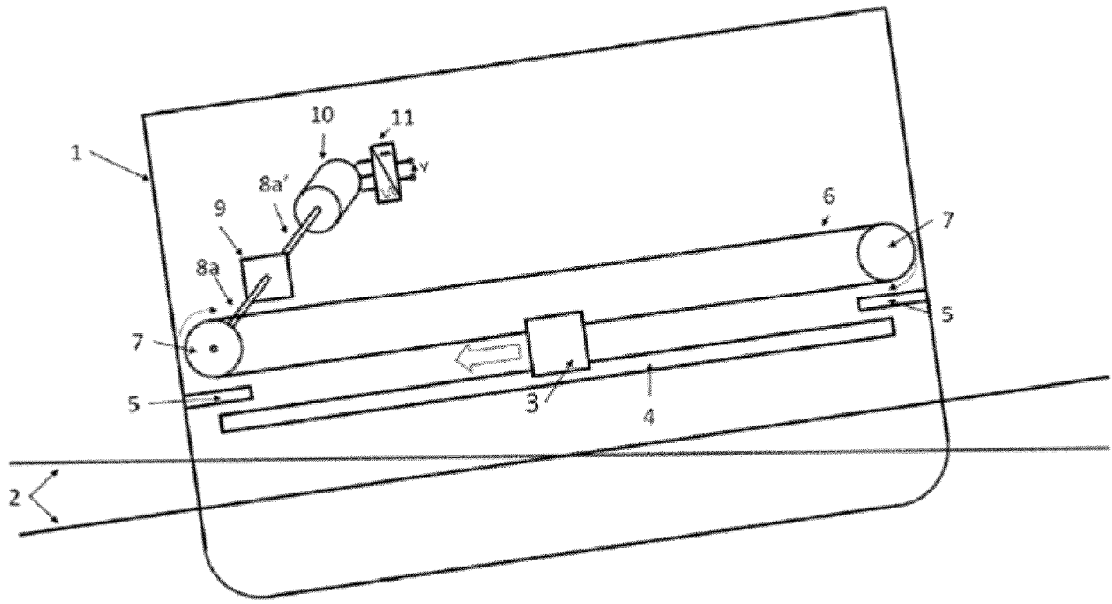

FIG. 11

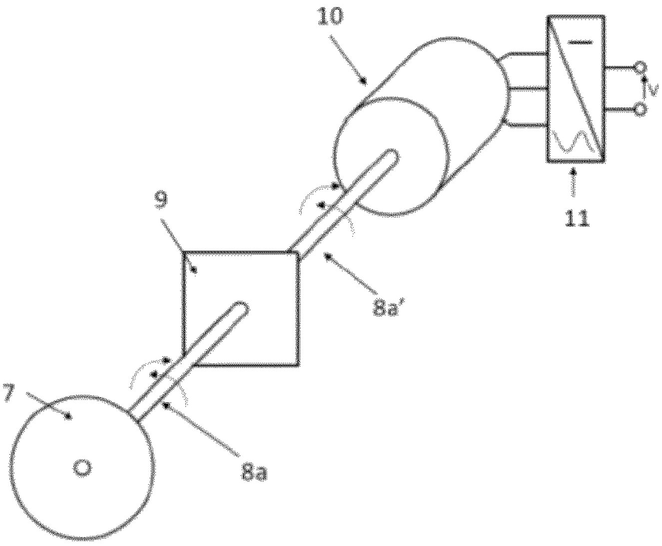

FIG. 12

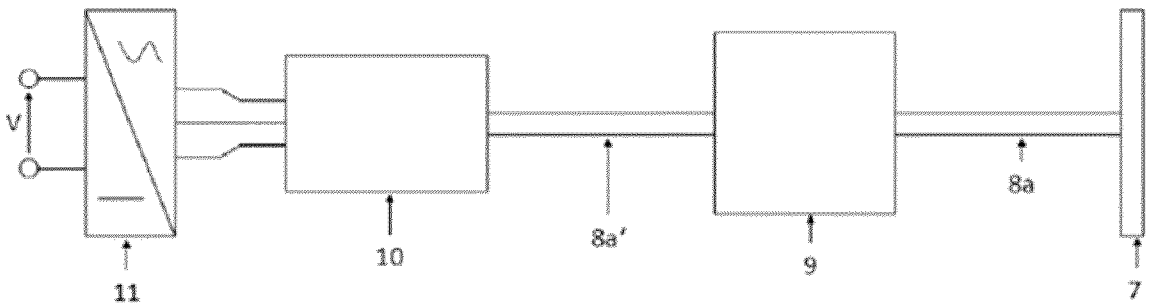

FIG. 13

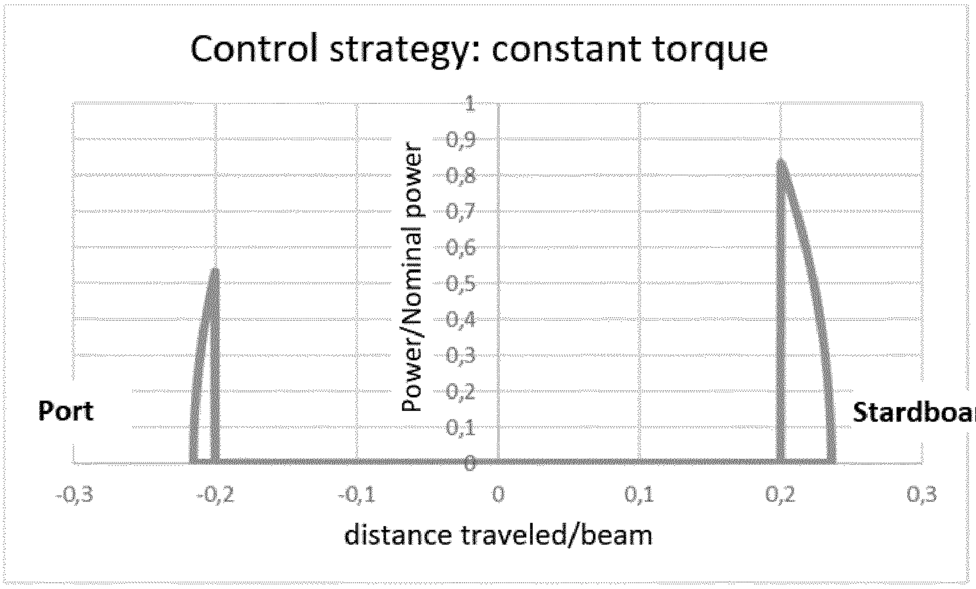
Control strategy: constant torque
Power/Nominal power
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
Port
Stardboard
-0,3
-0,2
-0,1
0
0,1
0,2
0,3
distance traveled/beam

FIG. 14

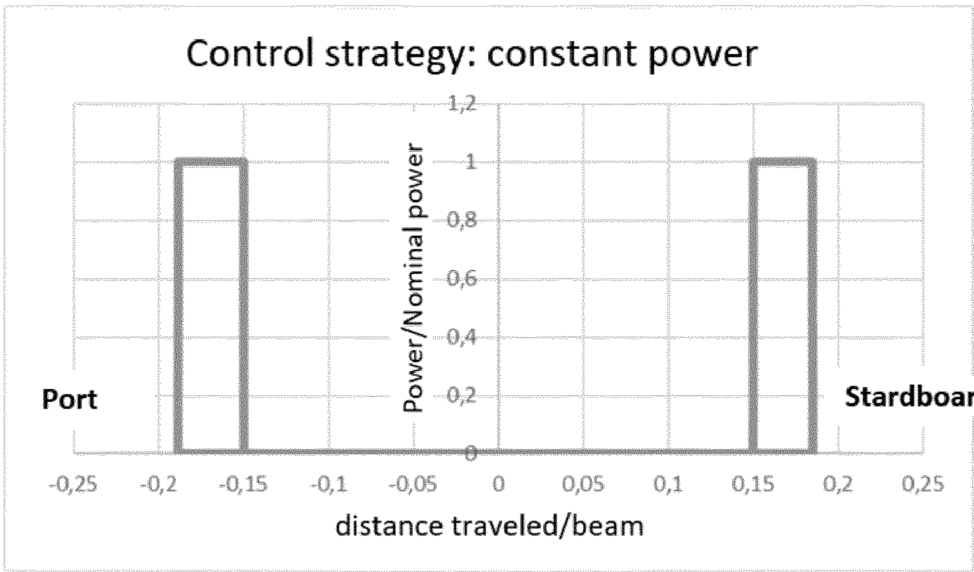
Control strategy: constant power
Power/Nominal power
1,2
1
0,8
0,6
0,4
0,2
0
Port
Stardboard
-0,25
-0,2
-0,15
-0,1
-0,05
0
0,05
0,1
0,15
0,2
0,25
distance traveled/beam

FIG. 15

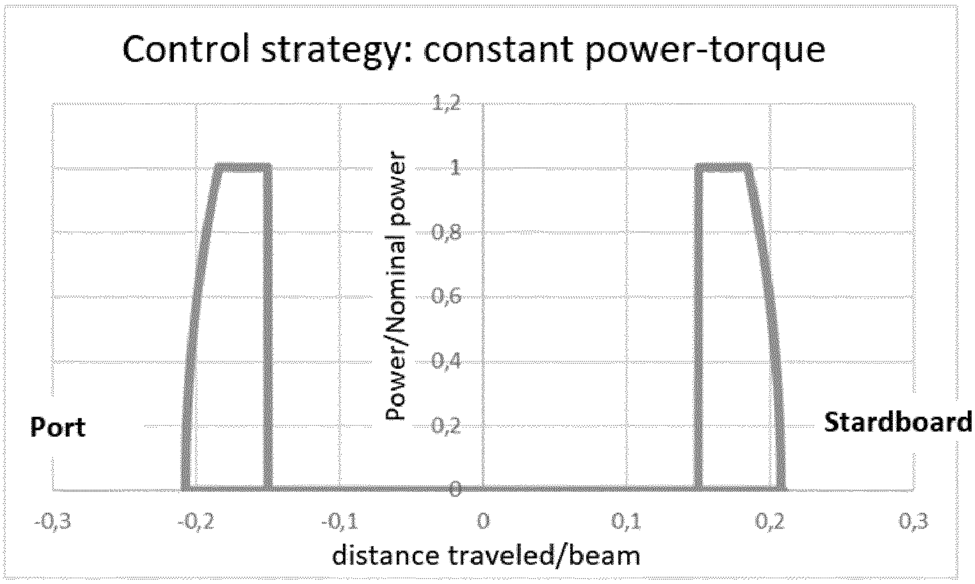
Control strategy: constant power-torque
Power/Nominal power
1,2
1
0,8
0,6
0,4
0,2
0
Port
Stardboard
-0,3
-0,2
-0,1
0
0,1
0,2
0,3
distance traveled/beam

FIG. 16

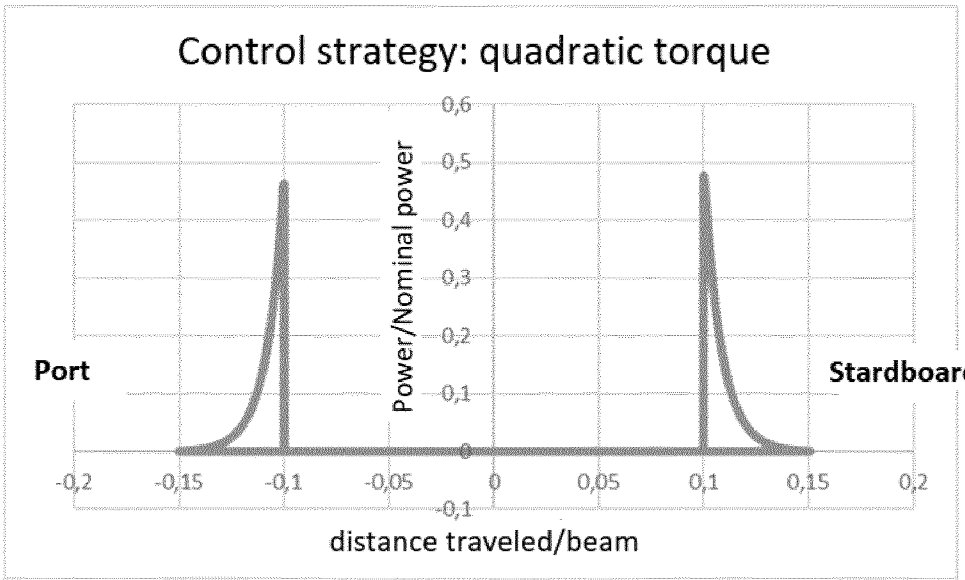
Control strategy: quadratic torque
Power/Nominal power
0,6
0,5
0,4
0,3
0,2
0,1
0
-0,1
Port
Stardboard
-0,2
-0,15
-0,1
-0,05
0
0,05
0,1
0,15
0,2
distance traveled/beam

FIG. 17

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/059353

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03B13/20 F03B15/00 F03G7/08
ADD.

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)
F03B F03G

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 2012/248775 A1 (STEWART DAVID B [US] ET AL) 4 October 2012 (2012-10-04) paragraphs [0002], [0059] - [0062]; figure 7A -----	1-11,13, 14,16,17 12,15
A	US 2015/096292 A1 (SKAF ROBERT GEORGES [CA]) 9 April 2015 (2015-04-09) paragraphs [0002], [0044] - [0046]; figures 1-19 -----	1-17
A	US 2011/185719 A1 (BEANE GLENN L [US]) 4 August 2011 (2011-08-04) paragraphs [0007] - [0027], [0148] - [0150]; figures 14-28 -----	1-17
A	US 2018/258905 A1 (ELEFANT FELIX [FR] ET AL) 13 September 2018 (2018-09-13) paragraphs [0014], [0015], [0067] - [0073]; figures 8a-8d -----	1-17

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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"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

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2024	26/08/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Lux, Ralph

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/059353

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