

Device for Propulsion and Energy Conversion from Waves

FIELD OF THE INVENTION

- 5 [1] The present invention relates to the energy field, and more specifically the conversion of energy from waves into any other type of usable energy.
- [2] For this purpose, the invention targets a device or “wave-energy conversion system” with which to convert the energy from the wave movements generated by the swell into usable energy and while producing a propulsion counter to the direction of the swell.
- 10 [3] In fact, the swell forming on the surface of the water in seas and oceans is a wave phenomenon generated mainly by the wind, and capable of providing renewable energy. The energy generated by conversion of this renewable energy can be mechanical, hydraulic or even electrical energy. In the case of electric energy production, it is intended to power electrical equipment on the device or to be transported to an electrical distribution grid.
- 15 [4] The capture and conversion of this renewable energy can be done in various ways, but the majority of the current wave-energy conversion systems are based on a single principle. It consists in the displacement of a mobile element following the movement of the waves relative to a fixed element. This displacement of the first element relative to a second is then converted into usable energy by an energy conversion system.
- 20 [5] There are many wave-energy conversion systems in the world and they may be classified into three major categories:
- 25 - Heaving systems, called “point absorber,” made up of either a floating structure, partially or fully submerged, connected to a gravity base set on the bottom. Or two floating structures connected by a vertical-translation degree of freedom, with one of the floating structures following the swell and the other having a large inertia and hardly moving.
 - 30 - Reciprocating flaps, set on gravity bases in shallow water, near the shore. They are rotated by the horizontal movement of water particles.
 - Oscillating water columns can be floating or attached to the shore, and for which the pressure of the waves turns the compressed air turbine located in a tunnel.
- [6] In the case of conversion into electrical energy, the conversion system is based on the use of an electrical generator actuated by the rotation of another element under the action of the waves. This element may be a hydraulic motor or directly an electric generator itself.
- 35 [7] Currently the main dampers on commercial development of the wave-energy conversion systems are a lack of maturity, and also high production and

5 maintenance costs. In fact, the difficult environmental conditions to which they are subject coupled with moderate efficiency make the energy production cost uncompetitive compared to other renewable energies like solar or wind, whose technologies are now mature and have a production cost which keeps going down.

10 [8] In fact, the high expense items for a wave-energy conversion system installed at sea are located in the materials making up the wave-energy conversion system which must be capable of withstanding these environmental conditions and also in the installation thereof in a marine environment, for example involving anchoring.

[9] Consequently, there is still a need for proposing a low-cost solution capable of effectively converting the renewable energy generated by the movement of waves.

15 [10] Further, reducing the fuel consumption of powered ships is sought, and there is a need to propose a solution aiding propulsion which draws its energy from the energy of the swell.

BRIEF SUMMARY OF THE INVENTION

20 [11] For that purpose, a device is proposed here for propulsion and for conversion of the energy from the movement of waves comprising at least one floating structure (1), at least one keel (2) mounted mobile on the floating structure, according to at least one sliding movement (GT) relative to said floating structure along a heaving axis (Z),
characterized in that it comprises at least one flap (3) connected by a hinged system (A1, A2, A3) both to the keel and also to the floating structure (1), where
 25 said flap is configured for being positioned under the surface of the water, laid out so as to follow the oscillations of said keel by oscillating rotation under the action of wave movements, and generating a propulsion force directed substantially towards the center of gravity of said floating structure.

30 [12] Because of these dispositions, the horizontal propulsion produced by the reciprocating flap serves for countercurrent swimming to counter the effect of the local wind and/or the effect of the sea current and/or the effect of the swell itself. In fact, advantageously, the oscillating rotation of the flap produces a propulsion in a direction counter to the direction of the swell. This propulsion with a substantially horizontal resultant is used to move the floating structure forward
 35 against the swell (and also against the current and/or the wind).

[13] Advantageously, when the floating structure is connected to the rear part (i.e. the stern), of a boat (e.g. ship, barge, etc.), the propulsion generated by the floating structure can lead to a reduction of the demand on other propulsion systems of the boat. For example, when the boat is equipped with a propeller

motor as first propulsion means, the use of the floating structure the stern of the boat may, advantageously, reduce the fuel consumption. According to another connected advantage, the oscillating keel may be coupled to a generator (e.g. electrical) with which to provide the boat electrical energy.

5 [14] Note that in the presence of swell, the flap forces relative movement between the keel and the floating structure by oscillating rotation, thus allowing recovery of the energy from the movement of the waves. Further, in reaction, the movement of the flap is also forced by the relative heaving of the keel and the floating structure, leading to two relative movements which are coupled and
10 mutually amplifying one another.

[15] In the case where the floating structure is connected to an anchoring element, the generated propulsion may contribute to reducing the force exerted on the anchoring point. This reduction of the anchoring force has the advantage of allowing lighter and less costly anchoring solutions.

15 [16] In various embodiments of the invention, one and/or another of the following dispositions could further be used.

[17] According to an option, the hinged system may comprise a pivoting connection (A1) between the flap (3) and the keel. By these means, a robust and easy-to-implement connection results in order to allow the reciprocating of the
20 flap relative to the keel.

[18] According to an option, the hinged system may comprise a connecting rod connection (4) between the flap (3) and the floating structure (1). This forms a simple and basic and robust mechanical connection which does not require maintenance. According to an alternative option, in place of a connecting rod
25 system, there could be a guide using sliding of pins in openings or another auxiliary guiding system.

[19] According to an option, the hinge system may comprise a connecting element (4) connected to the floating structure (1) by a pivoting connection (A2) and connected to the flap (3) by a pivoting connection (A3). The connecting
30 element in question is comparable to a connecting rod which allows a pivoting movement of the flap relative to the keel without major parasitic movement compared to the floating structure. Further, this forms a simple and basic and robust mechanical connection.

[20] According to an option, the flap (3) may further comprise a rear extension of the surface thereof (8), where said rear extension is connected to a front part of the flap (83) by a pivoting connection (A8).
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[21] This serves to amplify the propulsion effect, since the reciprocating of the rear extension is slightly later in phase than the reciprocating of the front part of the flap.

- [22] According to an option, the rear extension (8) may be returned to a neutral angular position relative to the front part of the flap (3) by a spring restoring system.
- 5 [23] It involves a simple and basic system, reliable and maintenance free. The restoring to the neutral position contributes to the effectiveness of the propulsion on meeting the swell.
- 10 [24] According to an option, the flap may further comprise a rear extension of the surface thereof (8), where said rear extension is flexible and fixed to the front part of the flap. Biomimetics is used in order to produce in that way a whale tail effect.
- [25] According to an option, the flap (3) may further comprise a rear extension of the surface thereof (8), connected to a front part of the flap (83) by a pivoting connection (A8), where said front part is then shaped like control arms (36, 37).
- 15 [26] According to an option, the keel may comprise several flaps (3, 3+) arranged one under the other, mounted so as to remain parallel with each other. By these means, the characteristics of the site where the device is positioned may be reflected in the number of flaps present on said keel. Each arrangement serves to get a device more compact on the surface if a sufficient draft is available, where each flap extends less individually but the effects of the flaps add up
- 20 power.
- [27] According to an option, it is intended that a resting position of the flap is defined by a reference angle, where said reference angle is defined by the surface of said flap and the longitudinal axis (X) perpendicular to the keel. In the case of a substantially flat flap, this serves to bring the main body of the flap
- 25 closer to the surface of the water.
- [28] According to an option, it is intended that said reference angle be included between 0 and 30°. By these means, the adjustment of the reference angle serves to position the end of the flap closest to the surface of the water where the efficiency of said flap is optimal.
- 30 [29] According to an option, the body of the flap extends mainly in a work plane and the transverse width of the flap increases going away from a zone where the hinged system connects the flap to the keel. The parts farthest from the hinge have the advantage of a larger lever arm and that way their force is optimized relative to a set surface area of the flap.
- 35 [30] If the reference resting condition is such that the flap is “flat,” then the working plane of the flap is perpendicular to the heaving axis (Z).
- [31] According to an option, the floating structure and the flap are made with at least one composite material. The use of this type of material has the advantage

of allowing the reduction of the total weight of the device and thus the total cost thereof.

- 5 [32] According to an option, it is intended that the composite material be a polyepoxide or polyester matrix comprising carbon fibers or fiberglass. By these means, this solution has good performance in mechanical and chemical robustness.
- 10 [33] According to an option, the device may further comprise at least one means for transmission of the relative movement of said keel to at least one electric converter in order to convert the mechanical energy of said movement into electrical energy, where the device then has a function of conversion of the energy of the movement of the waves. Note that the flap forces relative movement between the keel and the floating structure by oscillating rotation, thus allowing conversion of the energy from the movement of the waves into another form of energy.
- 15 [34] According to an option, the device further comprises a control unit (9) configured for driving the power collection rate in the electrical converter so as to thus balance between the propulsion produced by the countercurrent swimming and the transformed energy from the swell.
- 20 [35] The electrical converter (via the transmission means) constitutes a damper on the oscillatory movement of the flap. The control unit may modulate the energy collection taken by the electrical converter in order to keep enough energy for countercurrent swimming, according to the actual conditions of current, wind and swell.
- 25 [36] According to an option, the device may be usable and effective for a range of swell periods. By means of which, the device is profitably used even when the swell period does not correspond to the resonant period thereof and may convert energy from the movement of the waves over a very long range of swell periods.
- 30 [37] The energy conversion chain may act as a damper controlled in real time, simulating an artificial spring, which serves to change the resonant period of the system when the chain is not acting in purely resistive mode (in addition to acting as a damper, it can then act as a spring and as a mass).
- [38] According to an option, the range of swell periods can be included between 3 and 16 seconds, preferably included between 6 and 12 seconds.
- 35 [39] According to an option, the device may comprise a hydraulic cylinder (6) as transmission means.
- [40] According to an option, the electrical converter may be an electrical generator coupled to a hydraulic motor.

- [41] According to an option, the device may be connected to at least one anchoring element, for example to a buoy or any floating element with substantially fixed position. The effective anchoring force is reduced in this way; lighter weight and less costly anchoring solutions may thus be chosen. Further, reduced dimensions of the anchoring, and also of the lash onto the device lead to solutions that are easier to install and therefore less costly. They are more durable and experience less wear in comparison to passive anchorings.
- [42] According to an option, the device may be fixed to the stern of a boat or incorporated in the stern of a boat. The fuel consumption of powered ships is thus reduced with such a solution aiding propulsion by drawing its energy from the energy of the swell.
- [43] According to an option, the device may comprise a restoring spring between the floating structure (1) and the keel (2).
- [44] According to an option, the flap may have a rectangular or triangular or trapezoidal shape.
- [45] According to another aspect, a device is proposed for propulsion and for conversion of the energy from the movement of waves comprising at least one floating structure (1) connected to at least one anchoring element (16), at least one keel (2) mounted mobile on the floating structure, along at least one sliding movement relative to said floating structure along a heaving axis (Z), at least one means for transmission of the relative movement of said keel to at least one electrical converter for converting the mechanical energy of said movement into electrical energy,
characterized in that it comprises at least one flap (3) connected by a hinged system (A1, A2, A3) to the keel and to the floating structure (1), where said flap is configured for being positioned under the surface of the water, laid out so as to follow the oscillations of said keel by oscillating rotation under the action of wave movements, and generating a propulsion force directed substantially towards the center of gravity of said floating structure.
- [46] Most of the optional characteristics described above can be used in combination with the device disclosed in the preceding paragraph.
- [47] According to another aspect, a device for propulsion and for recovery of the energy of the movement of waves is proposed comprising:
- at least one floating structure (1; 100);
- at least one keel (2) mounted mobile on the floating structure, according to at least one sliding movement (GT) relative to said floating structure along a heaving axis (Z),
characterized in that it comprises at least one flap (8) connected by a hinged system (A1, A2, A3, A8) both to the keel and also to the floating structure (1), where said flap is configured for generating a propulsion force directed

substantially towards the center of gravity of said floating structure, and in that the hinged system comprises at least one control arm (3, 36, 37) mounted in rotation on the keel by a first pivoting connection (A1), and at least one linkage (4, 46, 47) connected to the floating structure by a second pivoting connection (A2) and connected to said control arm(s) by a third pivoting connection (A3), where the flap (8) is mounted in rotation on said control arm(s) by means of a hinge (A8) arranged in a rear position cantilevered relative to the third pivoting connection (A3).

[48] Most of the optional characteristics described above can be used in combination with the device disclosed in the preceding paragraph, in particular the elastic restoring applied to the hinge (A8) of the flap.

BRIEF DESCRIPTION OF THE DRAWINGS

[49] Other aspects, goals and advantages of the invention will appear upon reading the following description of several embodiments thereof, given as nonlimiting examples. The invention will also be better understood in light of the attached drawings on which:

[50] Figure 1 is a schematic view of the propulsion device positioned in open sea.

[51] Figure 2 is a sectional schematic view of the propulsion device.

[52] Figure 3 is a top view of the propulsion device.

[53] Figure 4 is an operating diagram of a hydraulic cylinder coupled to a hydraulic motor.

[54] Figure 5 shows an output power curve as a function of the period of the swell, and also the available horizontal propulsion because of the countercurrent swimming.

[55] Figure 6 shows a curve of possible operating points according to the energy collection balancing control.

[56] Figure 7 shows a variant relating to the means of transmission of the relative movement of the keel.

[57] Figure 8 shows, in one or more embodiments, a section view of an alternative of the propulsion device.

[58] Figure 9 shows, in one or more embodiments, a top view of an alternative of the propulsion device.

[59] Figure 10 shows, according to an embodiment, the integration of the propulsion and/or conversion device into a boat type floating structure.

[60] Figure 11 shows, according to another embodiment, an alternative to the integration of the propulsion and/or conversion device into a boat type floating structure.

[61] Figure 12 shows in more detail an elastic restoring, pivoting connection for a flap made in two articulated parts.

[62] Figure 13 shows an example of yield curves for the propulsion device according to the period of the swells.

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DETAILED DESCRIPTION OF THE INVENTION

[63] In the various figures, the same references designate identical or similar items. For reasons of clarity of exposition, some parts may not be shown to scale.

10 [64] In Figure 1, a wave-energy conversion system **10** is positioned near a buoy **16** in a marine environment.

[65] According to a first example, the wave-energy conversion system **10** is attached to a buoy serving as an anchoring point **16** by a lash **13**. The buoy **16** is itself anchored to the sea bottom, for example by a chain **15** connected to a ballast **17** resting on the bottom.

15 [66] In the remainder, the terms “wave-energy conversion system,” “wave-energy conversion device” or “wave-energy conversion machine” may be used to designate the entity with reference **10**.

20 [67] Under the action of the swell, along the direction thereof **18**, the wave-energy conversion system naturally turns itself to face the direction of the swell by rotation around the buoy **16**. More generally, several phenomena may compete to make the wave-energy conversion device drift; it involves in particular the local wind and/or the local sea current and/or the swell itself (induced by the wind).

25 [68] According to another example, the buoy can be free of an anchoring on the sea bottom via the connection **15** directly attached to a submerged mobile structure with greater inertia than that of the wave-energy conversion system **10**.

30 [69] According to another example, the wave-energy conversion system may not have any physical anchoring point. For example, the wave-energy system may be provided with GPS location means and a controller; in this case, a target GPS position is assigned to the wave-energy conversion system and a feedback control with which to maintain the wave-energy conversion system in a position near the target position by countercurrent swimming of the flap.

35 [70] As shown in **Figures 2 and 3**, the wave-energy conversion system comprises a floating structure **1** and a keel **2** capable of sliding relative to the floating structure **1** along a heaving axis **Z**. The wave-energy conversion system also comprises a reciprocating flap or simply called flap labeled **3** which will be seen later.

[71] Floating Structure

- [72] In the example shown in Figures 2 and 3, the floating structure **1** may have a form similar to that of a boat so as to have a minimum stress from the swell and so that the front part where the anchoring point **13** is located serves to slice through the waves. A longitudinal axis labeled **X** and also a transverse axis labeled **Y** are defined for the floating structure.
- [73] Further, the floating structure **1** comprises a cross passage located opposite the anchoring point **13**, and which comprises the translational slider GT receiving the keel **2**.
- [74] The floating structure is made up of a hull providing the floatability and tightness of the structure, where the waterplane area is somewhere between 5 and 40 m² for a height included between 2 m and 6 m, and where the length **L_b** along the axis **X** is generally larger than the width **L_c** along the axis **Y**. The dimensions must be adapted in order to assure flotation during difficult environmental conditions, and also to the constraints related to the site receiving the device **10**, like, for example, the depth of the water. More precisely, the dimensions of the floating structure may be a 40 m² waterplane area and a 6 m height.
- [75] Additionally, the hull of the floating structure is made of composite material on a metal framework. The composite materials may be any composite material resisting the maritime environmental conditions. As an example, the composite materials are carbon fibers or fiberglass incorporated in a matrix of a heat cured polymer, like for example polyepoxide or polyester. The metal framework is made from a metal or a metal alloy like steel also capable of withstanding maritime environmental conditions, like for example the force of the waves or even the corrosion resulting from the liquid environment.
- [76] The floating structure may be solid or hollow. In a typical configuration, it comprises cavities, where these cavities are used in order to house the energy conversion device which will be detailed later and which is thus protected from environmental climatic conditions.
- [77] Some cavities can also be filled with cellular foam blocks with density much less than 1 (for example expanded polyurethane), in order to give the floating structure a good unsinkability.
- [78] Advantageously, the floating structure and in particular the energy conversion device are protected from bad weather and climatic conditions with, for example, a hatch cover shown symbolically in Figure 2.
- [79] Keel
- [80] As shown in Figures 2 and 3, the keel **2**, generally positioned opposite the anchoring point **13** of the floating structure **1**, is capable of sliding through the floating structure by means of the slider GT.

- [81] The keel **2** has a long main body labeled **20** with one high-end and one low-end, and the dimensions for the keel are in a range of 3 to 15 m long and 20 to 100 cm circumference. The dimensions of the keel **2** are determined based on the dimensions of the floating structure **1** and the flap **3**, or even as a function of the depth of the water, for example.
- [82] The keel **2** is made of a material having a larger density than water, and whose physical and chemical properties allow it to resist maritime environmental conditions. As an example, the keel may be made from a metal or metal alloy like steel. The lower end of the keel, making up the submerged part of the keel, is preferably curved and ballasted in order to reposition the center of gravity of the device in the vertical of the center of thrust and thus guarantee the equilibrium of the wave-energy conversion system on the surface of the water.
- [83] For this purpose, a ballast **28** is provided arranged in the area of the lower end of the keel as shown in Figure 2. This ballast **28** represents a significant mass and confers the keel a mass and an inertia to movement greater than that of the floating structure.
- [84] The upper end making up the non-submerged part of the keel is overhung by a plate **21** which extends transversely relative to the heaving axis.
- [85] A restoring spring **22** which interacts between the keel and the floating structure is optionally present.
- [86] This aforementioned plate **21** is connected both to the restoring spring **22** and also to the hydraulic cylinder **6**. The hydraulic cylinder may be a double-acting linear cylinder. The barrel of the hydraulic cylinder is attached onto the floating structure, and the rod of the hydraulic cylinder **6** serving to transmit force and displacement to the piston is connected to the plate **21** by a hinged connection. This hinged connection may be a pin or pivot connection. In that way, during translational movement of the keel relative to the floating structure generated by the movement of the waves, the force of the movement of the keel is transmitted to the hydraulic cylinder via the rod of the cylinder driving a pressure variation of the fluid of the hydraulic cylinder. Under the action of the movement of the waves and the restoring spring **22**, the keel returns to a low position transmitting a new force to the cylinder, and thus generating a new pressure variation which can be converted into another type of energy. Since the stiffness K of the restoring spring influences the oscillatory resonant frequency of the pair (i.e., keel, floating structure), the stiffness of the spring may be determined based on the swell periods the most commonly encountered on the target installation site.
- [87] It needs to be noted that the spring may be a real mechanical spring, but the role of the spring may also be performed by the energy conversion chain as

will be seen later. It is also possible to combine the two solutions, in order to vary the stiffness dynamically.

[88] According to another embodiment, shown in Figure 7, the keel does not have a coupling to the hydraulic cylinder, but comprises a toothed part **64** called rack gear which is coupled to a pinion **66**. During the translational movement of the keel under the action of the wave movement, the main body **20**, keel **2** transmit the translational movement thereof via the rack **64** to the piston **66** and it thus becomes a rotational movement. This rotational movement may then be used to drive an alternator of an electric generator in order to convert the mechanical energy into electrical energy, for example.

[89] Reciprocating Flap

[90] According to an embodiment, a flap **3** is provided in addition to the keel and the floating structure. The flap **3** in question can be described as “oscillating” or “reciprocating” or “beating.” As will be seen in the following, the flap **3** may have a single part or else two parts hinged to each other, without just the same excluding other configurations.

[91] The flap **3** looks like a thin structure extending mainly in two directions (plane of the flap, working plane with the flap) with a small thickness along the third direction. The thickness of the flap can vary between the leading edge **31** and the trailing edge **32** in the way an aerodynamic aileron does.

[92] According to a variant, the flap does not necessarily extend in a single plane but can have a broken effect to it as illustrated in Figure 1.

[93] The flap **3** is connected by a hinged system to the keel and to the floating structure. The flap **3** is positioned under the surface of the water. The shape of the flap may be rectangular, triangular or trapezoidal. As an example, the shape of the flat may be similar to the tales of marine mammals, like dolphins or whales, for example. The flap **3** has dimensions where the length along the **Y**-axis is larger than the width along the **X** axis. The thickness of the flap is defined so as to be consistent with the other sizes, in particular from the perspective of the strength against the forces imparted by the waves.

[94] The dimensions of the flap **3** must be suited to the dimensions of the floating structure **1** and the keel **2**, themselves suited to the environmental conditions and the constraints of the site. The dimensions of the flap are located in a range from 4 to 20 m long, 2 to 9 m wide, and a thickness that can go up to 65 cm. More precisely, the dimensions are 20 m for the length located at the end of the flap, 8 m wide and 65 cm high.

[95] According to an embodiment, the flap may be made of steel or composite materials (plastic with fiberglass or carbon fibers type) or a combination of the two. With the implementation in composite materials, the flap can be configured

with some flexibility, by controlling in particular the layout of the fibers the length of the string. This flexibility optimizes the propulsive aspect, just like a palm.

[96] According to an embodiment, the flap may have an aircraft wing profile.

5 [97] As in the illustration from Figures 2 and 3, the flap **3** is connected to the keel **2** by a pivoting connection **A1**. For this purpose, the flap comprises two arms **36**, **37** arranged generally symmetrically relative to the longitudinal axis **X** and which extend away from the main part of the flap towards the keel under and on the sides of the floating structure. An axle shaft **51** is provided which passes through both sides of the keel and each of the arms **36**, **37** of the flap. It needs to be
10 remarked that the arms could be brought closer than in the example shown in the figures and could be adjacent to the main body **20** of the keel.

[98] Further the flap **3** is connected to the floating structure by a connecting rod connection. In the example shown, it involves a conventional connecting rod **4**. At one of the ends thereof, said connecting rod **4** is connected to the floating
15 structure **1** by a pivoting connection (axis **A2**) to the middle of an axle shaft **52** and at the other of the ends thereof, the connecting rod is connected to the flap **3** by another pivoting connection (axis **A3**). According to another example, the connecting rod **4** may be broken down into two connecting rods **46** and **47**. Such a disposition can allow maintaining the stability of the flap and allow taking up
20 the torsional forces which may be exerted on the flap by the water.

[99] The example described above forms a hinged system which connects the flap **3** both to the keel and of the floating structure. Of course, other hinged-system solutions allow connecting the flap to the keel and to the floating structure while allowing a rotation of horizontal axis parallel to **Y** (therefore a horizontal
25 axis reciprocating).

[100] The axis of rotation of the connection **A3** is located at a distance **Le** from the axis of rotation of the pivot point **A1**. The axis of rotation of the connection **A3** is located at a distance **Lf** from the leading edge **32** of the flap. The distance **Le** may be about the length of the connecting rod **4** (distance **A2 – A3**) or a little
30 longer.

[101] Further, according to an option, the reference position of the flap at rest, meaning without swells, is defined according to a reference angle between one of the surfaces having the greatest surface area and an axis **X** perpendicular to the keel. This reference angle is included between 0 and 30°.

35 [102] Because of these arrangements, under the influence of the swell, the flap **3** oscillates by oscillating rotation around the pivot connection **A1** following the movement of the waves. This rotary movement has the consequence of forcing the relative heaving of the keel **2** compared to the floating structure **1** along the **Z** axis.

- [103] Locally in the area of the position of the wave-energy conversion machine, the movement of the swell consists of successive rising and falling of the surface of the water. This movement may be considered, with respect to time, as quasi-sinusoidal.
- 5 [104] Advantageously, the wave-energy conversion machine is intended to react to this oscillatory movement of the surface of the water. To do that, a range of swell periods is considered, typically ranging from 4 seconds to 12 seconds, specifically a frequency of 0.08 to 0.25 (in cycles per second), in which one or more resonant modes of excitation of the relative movement of the keel compared to the floating structure are located.
- 10 [105] More precisely, for an excitation frequency that is not too far from one of the resonant modes, when the surface of the water rises, the flap along with the floating structure rises compared to the keel (which has a significant inertia to displacement), and therefore the keel also rises, but with some delay. In the second part of the cycle, specifically when the surface drops again, the floating structure and the flap descend relative to the keel which has an inertia to displacement, and therefore the keel also lowers with some delay.
- 15 [106] The delay observed in the movement of the keel relative to the flap and the floating structure therefore induces a relative oscillatory movement of the keel relative to the floating structure. This movement is also roughly sinusoidal.
- 20 [107] Optimal yields result when the delay of the oscillatory movement to the keel relative to the floating structure is sufficient.
- [108] According to the configurations, a delay greater than 45° will already give a very good oscillatory movement and according to the configurations, an optimum may be observed with a delay which may go from 90° to 180° .
- 25 [109] Referring to Figure 2, when the flap and the floating structure rise relative to the keel, the spring **22** compresses and the rod of the piston descends. Conversely, when the flap and the floating structure descend relative to the keel, the spring **22** extends and the rod of the piston rises. The alternating movement of the piston is converted into hydraulic energy by a system typically shown in Figure 4 (see later).
- 30 [110] For very long swell periods, therefore with a significantly lower excitation frequency, the delay of the keel is smaller and consequently so is the relative movement between the keel and the floating structure which leads to a reduced efficiency.
- 35 [111] At the other end of the scale, for very short swell periods, therefore with a significantly higher excitation frequency, the delay of the keel is greater, and can reach up to 180° or more (phase opposition), but the amplitude of the movements is then further reduced which also leads to a reduced efficiency.

- [112] An analogy can be made between the system described above and the excitation of a mass-spring system which forms a second-order damped oscillatory system. The physical stiffness of the spring (or the apparent stiffness when the spring is made up of a damper controlled in real time) participates in the definition of the main resonant frequency if there can be several of them.
- [113] The periodic oscillation of the flap **3** causes a hydraulic pumping due to the double-acting hydraulic cylinder **6** which supplies a hydraulic accumulator. The accumulated pressure is next used to activate a hydraulic motor **MH** coupled to an electric generator **G**, shown in Figure 4.
- [114] The periodic oscillation of the flap **3** serves to generate a propulsion by oscillating rotation at countercurrent from the swell **18**, comparable to the propulsion generated by tales of marine mammals. This propulsion at countercurrent from the swell serves to reduce the force exerted on the anchoring by the device **10** which drifts going away from the anchoring point **16**.
- [115] Figure 4 shows the system for conversion of the hydraulic/electrical energy generated by the movement of the waves. During the movement of the double-acting linear cylinder **6** under the force of the displacement of the keel **2**, a pressure increase is generated in the hydraulic circuit **40**. The double-acting linear cylinder serves to generate a pressure both during the rise of the keel and the descent thereof. The maintenance of this pressure during the rising and also the descending is provided by the antibackflow valves **41**; **42**; **43**; **44**. The pressure generated is directed via the hydraulic circuit to a hydraulic accumulator **7** used as a buffer. Energy production is performed by the alternator **G** driven by the hydraulic motor **MH** under the effect of the pressure in the hydraulic circuit **40**, and maintained continuously by the hydraulic accumulator **7**.
- [116] The alternator **G** is driven by a control unit **9**. This control unit **9** is configured for driving the power collection rate by the electric converter associated with the control unit.
- [117] An electric converter may be provided downstream from the alternator **G** in order to deliver electric power **Q** in the desired form (e.g. direct, alternating, local consumption, remote delivery, etc.).
- [118] The electrical power produced corresponds to mechanical work done by the oscillatory movement of the keel. As the collected power increases, the amplitude of the oscillatory movement of the keel is reduced. Consequently as more power is collected to produce electricity, the resultant for propulsion for countercurrent swimming is lower. Therefore a compromise must be reached between the electrical power collected and the need for countercurrent swimming in order to relieve the anchoring device.

- [119] Note that in some configurations, the electrical energy is used to operate a reverse osmosis water desalination facility.
- [120] As shown in Figure 4, the system may comprise a range sensor labeled **CC**, capable of measuring in real time the position of the keel relative to the floating structure. The control unit **9** may in that way know the amplitude and frequency of the oscillatory movement of the keel relative to the floating structure. With this information, the control unit 9 may adjust in real time the power collection of the electricity production chain in order to adjust the parameters of the conversion chain, specifically adjust the apparent stiffness and the damping coefficient.
- [121] In the version shown in Figure 4, which uses a hydraulic system, a proportional bypass solenoid valve **94** is provided which serves to adjust in real-time the oscillatory work collection from the flap and the keel.
- [122] The control unit drives the solenoid valve **94** proportionally. When the solenoid valve is open, the hydraulic fluid passes freely from one chamber of the cylinder to the other without collecting work. Conversely, when the solenoid valve 94 is closed, all the hydraulic fluid is pumped by the piston of the double-action hydraulic cylinder. Of course, for partial and controlled openings of the solenoid valve, there is a corresponding partial collection of work.
- [123] In the all-electric embodiment shown in Figure 7, there is no valve, but it is the direct control of the alternator **G** by the control unit **9** which produces a resisting torque tending to dampen the oscillatory movement of the keel. Of course the resisting torque is adjusted in real time depending on the aforementioned criteria as needed for collection in order to produce electricity, as needed for countercurrent swimming propulsion, and for maintaining an apparent stiffness in an acceptable window.
- [124] With these software functions, the control unit may adjust the electrical power collected and also balance between propulsion produced by countercurrent swimming and the energy from the swell transformed into electricity.
- [125] Figure 5 shows an example of both an available electric power curve **C1** as a function of the period of the swell on the converter and also a power curve **C2** representative of the substantially horizontal propulsion contributing to the countercurrent swimming.
- [126] On the curve **C1**, the effectively converted electrical power depends on the swell period; it is a maximum for a period near 6 seconds. This curve reflects the behavior of a purely resistive conversion chain such as described in Figure 4.
- [127] The curve **C2** results from the same system as the curve **C1**, but with no energy production. Two propulsion production peaks can be seen at 6 seconds and at 9.5 seconds; they correspond to two resonant modes of the system. The

first (at 6 seconds) may be described as the resonant mode in pitching of the floating structure **1**. This resonant mode excites the oscillation of the flap **3** which is at the origin of the resulting propulsion. The second, at 9.5 seconds, may be described as the resonant mode in heaving of the floating structure **1**. It excites the oscillation of the flap **3** in even greater proportions. The value of the resulting propulsion is however fairly close for these two modes, for the system described by **C1** and **C2**.

[128] Further, as with the curve **C2**, with a reactive conversion chain, the placement of these propulsion peaks can be positioned depending on the incident swell period.

[129] According to a target embodiment, the wave-energy conversion machine may be sized to generate 400 kW nominal power; 150 to 200 tons displacement; 14 m draft. Oscillating flap dimensions: 8 m × 20 m, no apparent weight in water (equivalent density about 1). The float dimensions can be: 40 m² waterplane area and a 6 m height.

[130] The electrical energy produced may be used for powering onboard electrical devices (e.g. control unit 9 and accessories). The electric energy produced may be used remotely by means of a transmission cable connecting the wave-energy conversion machine to a remote site or towards an electric distribution grid.

[131] According to a specific variant, the electric energy produced on board may be used for seawater desalination needs.

[132] According to another variant, the energy produced by the relative oscillation of the keel and the floater may be used directly for desalination needs without necessarily being converted into electric energy. For example, by pumping seawater through a reverse osmosis membrane.

[133] Figure 6 shows a sample curve of the operating points in the case of a 6 second incident wave, and corresponding to the first peak of the curves **C1** and **C2** shown in Figure 5. In fact, as mentioned above, the control unit may control in real time the power collection, by controlling the quantity of converted electrical energy. The energy which is not converted shows up in the form of horizontal propulsion of the oscillating flap. In that way, the points farthest to the left on the curve from Figure 6 represent a low collection level and a maximization of the countercurrent swimming, whereas conversely the points located to the right on the curve correspond to two large collections (high damping level) with an amplitude of the oscillating flap much smaller and consequently a much weaker countercurrent swimming power.

[134] The driving and balancing can be done locally or else remotely operated from, for example, a control center in the case of a marine farm of wave-energy conversion machines.

- [135] It needs be remarked that the movement of the keel relative to the floating body may be strictly translational as shown in the figures, but according to a variant not shown the movement of the keel could comprise another component in the case where, for example, it is mounted rotatably relative to a hinge point of the floating body located well away with a fairly sizable radius of curvature.
- [136] As for the reference position for the flap, forming the rest position and defining the aforementioned preset angle, it needs to be remarked that this reference position may be adjustable by means of an adjustment device, for example a screw-nut device which moves the position of the axis **A2** vertically, where this device may be adjusted once and for all for the target site or else be controlled by the control unit **9**. To move the position of the axis **A2**, an eccentric cam whose angular position is controlled may also be used.
- [137] The Figures 8 and 9 show, in one or more embodiments, an alternative to the wave-energy conversion system shown in Figures 2 and 3.
- [138] The structural elements (e.g. keel, flap, etc.), the physical and chemical properties thereof, and also the layout configurations thereof shown in Figures 2 and 3 may be partially or wholly transposable to this embodiment.
- [139] In this embodiment, the flap **3** is made in two parts and comprises a rear extension **8**, which supplements a portion marked **83** here which is hinged from a part of the keel (by **A1**) and also the floating structure (by **A2**, **A3**). In other words, in this configuration, the flap **3** is formed by a front portion **83** and a rear extension **8**.
- [140] For example, the leading edge of the rear extension **8** is connected to the front portion **83** by a connection pivoting along an axis of rotation **A8**. An axle shaft or a hinge **58** may be used in order to make this rotatable mounting.
- [141] In a variant shown in Figure 11, the front portion **83** may be formed as one or two control arms **36**, **37**, where the flap function is greatly reduced for said arms, since the control arms are then intended to transmit the main forces exerted on the rear extension **8** via the keel and the connecting rod(s).
- [142] In the example shown, this rear extension **8** may be considered as an additional flap attached to the front portion **83** of the flap **3**, and which supplements the aerodynamic profile of the front portion **83**. According to the respective surface areas of the front portion **83** and the rear extension **8**, the contributions of each to the hydraulic force may be smaller or larger.
- [143] In this embodiment, the axis of rotation of the connection **A3** is located at a distance **Le** from the axis of rotation of the pivot point **A1**. The axis of rotation of the connection **A3** is located at a distance **Lf1** from the axis of rotation of the connection **A8**. The axis of rotation of the connection **A8** is located at a distance

Lf2 from the leading edge **32** of the extension **8**. The distance **Le** may be about the length of the connecting rod **4** or a little longer.

- [144] Because of these arrangements, under the influence of the swell, the rear extension **8** oscillates by oscillating rotation around the pivot **A8** following the movement of the waves. This oscillating rotation combined with the oscillating rotation of the front portion **83** of the flap 3 around the axis **A1** serves to reinforce the propulsion and the relative heaving of the keel 2 compared to the floating structure 1 along the axis Z.
- [145] Note that the flap generally has two degrees of freedom in rotation. A first degree of freedom relates to the pivoting of the front portion **83** compared to the keel (around A1). A second degree of freedom relates to the pivoting of the rear portion **8** compared to the front portion 83 (around A8). The oscillation of the second degree of freedom around (A8) is sinusoidal type and is delayed in phase relative to the oscillation of the first degree of freedom (around A1) also a sinusoidal type.
- [146] Mounting on Vessel
- [147] Figure 10 shows, according to an embodiment, the integration of the propulsion and/or conversion device to a boat/ship/vessel type floating structure.
- [148] The structural elements (e.g. keel, flap, etc.), the physical and chemical properties thereof, and also the layout configurations thereof shown in Figures 2 and 3 or Figures 8 and 9 may be partially or wholly transposable to this embodiment.
- [149] In this embodiment, the wave-energy conversion system **10** is attached, directly or indirectly to the stern **104** of a boat **100** by attachment means.
- [150] Directly is understood to mean that at least one of the walls of the floating structure is in contact with at least one of the walls of the boat **100**.
- [151] Conversely, indirectly is understood to mean that the walls of the floating structure **1** and the boat **100** are not directly in contact, and the contact is through an intermediate element.
- [152] In an example, the floating structure **1** may be fixed to a rear plate or to a rear gunwale of the boat **100**. In that way, the boat can be equipped later, or the wave-energy conversion system **10** even installed or removed based on the need.
- [153] In the example shown, the ship **100** has significant dimensions compared to the dimensions of the keel and the flap. However, smaller vessel dimensions can also be suitable.
- [154] Remark that advantageously, the keel 2, even in the lowest position thereof, does not extend downward past the hull of the boat. In other words, the addition

of the wave-energy conversion system **10** to the boat does not increase the draft of the combination.

5 [155] Figure 11 shows, according to another embodiment, an alternative to the integration of the propulsion and/or conversion device into a boat type floating structure.

[156] The structural elements (e.g. keel, flap, etc.), the physical and chemical properties thereof, and also the layout configurations thereof shown in Figures 2 and 3 or Figures 8 and 9 may be partially or wholly transposable to this embodiment.

10 [157] In this embodiment, keel **2** of the wave-energy conversion system is directly incorporated in the stern of the boat **100** (i.e. the back of the boat) by passing through it from one side to the other. In that way the floating structure **1** is combined with the structural hull of the ship **100**.

15 [158] In that way, as previously described, the upper end of the keel forming the non-submerged part of the keel, can be connected via a plate to a restoring spring **22**. According to an alternative, the plate may be connected to a hydraulic cylinder as was previously described.

20 [159] In this embodiment, the flap **3**, positioned under the surface of the water, is connected according to a hinged system previously described in Figures 2 and 3 or in Figures 8 and 9.

[160] According to an example, the flap **3** is defined by a rear extension **8** connected to a front part **83** of the flap **3** which here ends at a connecting arm.

25 [161] The rear extension is connected to the connecting arm **83** by the pivoting connection **A8**. The connecting arm **83** is connected to the keel **2** by the pivoting connection **A1**.

30 [162] Additionally, the flap **3** may be connected to the end of the stern of the boat by one or more connecting rods **46, 47**, for example, on each of the arms of the flap (**36, 37**). In the example shown, it involves conventional connecting rods. At one of the ends thereof, each of the connecting rods may be connected to the end of the stern of the boat by a pivoting connection **A2** by means of an axle shaft. At the other end thereof, each of the connecting rods may be connected to the arm **83** of the flap **3** by the pivoting connection **A3**.

35 [163] According to another perspective, it may be considered that said rear extension **8** itself fully forms the propelling reciprocating flap. Then, the hinged system which connects the flap to the keel and to the floating structure comprises:

- two control arms **36, 37** rotatably mounted on the keel by a hinge called first pivoting connection **A1** preferably attached on both sides of the keel.
- two connecting rods **46, 47** connected to the floating structure by a hinge called

the second pivoting connection **A2** and connected to said control arms by a hinge called third pivoting connection **A3**.

5 [164] The flap **8** is mounted rotatably on said control arms with a rotary hinge with axis **A8** laid out in a rear cantilevered position relative to the third pivoting connection **A3**.

[165] Note that there could be a single control arm instead of two, and a single connecting rod instead of two connecting rods.

10 [166] However, preferably there are a left control arm and a right control arm arranged symmetrically relative to a longitudinal axis **X** of the ship **100**. Similarly, a left connecting rod and a right connecting rod are arranged symmetrically relative to the longitudinal axis **X**. In this way, in case of imbalance of the right/left pressure on the flap, the torsional forces around the longitudinal axis **X** can be taken up.

15 [167] The control arms **36**, **37** are elongated parts capable of supporting significant flexion forces, in particular in the cantilevered part (segment **A3 – A8**). These arms may be made of metal or of high mechanical performance composite. The profile thereof and section thereof are optimized to contain the flexion, torsion and traction forces.

20 [168] The connecting rods **4**, in substantially vertical middle position, especially work under traction and compression. The control rods **4**, **46**, **47** are made of metal or of high mechanical performance composite.

[169] For the flap **8**, both for the shapes thereof and for the structure and material thereof, the characteristics stated for the reciprocating flap throughout the preceding apply here.

25 [170] The gap between the extreme low position of the keel **2** and the average level of the surface of the water is noted **TE2**; it indicates the draft of the wave-energy conversion propulsion system.

30 [171] The gap between the lowest point of the hull and the average level of the surface of the water is noted **TE1**; it indicates the draft of the boat itself, for a given useful load.

[172] According to an example, **TE2–TE1** is less than 1 m, preferably less than 50 cm.

35 [173] Preferably, **TE2** may be less than **TE1**, meaning that the presence of the wave-energy conversion system does not increase the draft of the ship **100**, as shown in Figure 10.

[174] Thus advantageously, the incorporation of the keel with the stern of the boat does not impact or only moderately impacts the draft which is still mainly governed by the load of the boat.

- [175] In an example shown in Figure 11, the distance separating the hinges A1 and A3 is greater than 6 m; it may be included between 8 m and 10 m. The rear part of the flap is then submerged in water 2 to 3 m deep.
- [176] As already indicated and explained, there may be an energy conversion system operationally positioned in parallel with the spring 22.
- [177] Figure 12 shows, in one or more embodiments shown in particular in Figures 8 to 11, a pivoting connection between the front part **83** of the flap **3** (respectively the arms **36**, **37**) and the rear extension **8**, with an elastic restoring function.
- [178] According to this function, the front part of the flap **83** is connected by the pivoting connection **A8** to the rear extension **8** and comprises one or more restoring springs **86**.
- [179] The springs are arranged such that for each spring, one end of the spring is fixed to the front part **83** of the flap, and the other end is fixed onto the rear extension **8**. In the example shown, compression springs are used.
- [180] In rest position, meaning without wave movement, the springs are compressed serving to keep the arm **83** aligned with the rear extension **8**.
- [181] During the wave movement, the rear extension **8** oscillates by oscillating rotation around the pivoting connection **A8**, and the restoring force of the springs then serves to return the rear extension **8** to a neutral angular position relative to the front part **83** of the flap.
- [182] Further, it is possible to mount an angular stop on the flap **3** so as to keep the angle **θ8** in a certain angular range. Preferably, the angle **θ8** is comprised between $+30^\circ$ and -30° .
- [183] Instead and in place of the compression spring, the elastic restoring function could result from one or more traction springs or a torsion spring (e.g. torsion bar).
- [184] Figure 13 shows a sample result for a large size flap, in particular in the configuration from Figure 11. All the recovered wave-energy conversion energy is transformed into propulsion (there is little or no electrical conversion). The curve **C8** shows the propulsion resultant with the flap in two parts (i.e. with the hinge **A8** operating). The curve **C7** shows the propulsion resultant with the same layout of the flap but with the hinge **A8** blocked. For the curve **C8**, the best yield is obtained around a swell period of 10 seconds. For this curve **C7**, the best yield is obtained in the area of a swell period of 9 seconds, but it is substantially lower than that of the curve C8, which emphasizes the contributing effect of the hinge **A8**.

CLAIMS

Claim 1. A device (10) for propulsion and for recovery of the energy of the movement of waves comprising:

- at least one floating structure (1; 100);

5 - at least one keel (2) mounted mobile on the floating structure, according to at least one sliding movement (GT) relative to said floating structure along a heaving axis (Z),

characterized in that it comprises at least one flap (3; 83, 8) connected by a hinged system (A1, A2, A3) both to the keel and also to the floating structure (1), where

10 said flap is configured for being positioned under the surface of the water, arranged so as to follow the oscillations of said keel by oscillating rotation under the action of wave movements, and generating a propulsion force directed substantially towards the center of gravity of said floating structure.

Claim 2. The device according to claim 1, characterized in that the hinged
15 system comprises a pivoting connection (A1) between the flap (3) and the keel.

Claim 3. The device according to any one of claims 1 to 2 characterized in that the hinged system comprises a connecting rod connection between the flap (3) and the floating structure (1).

Claim 4. The device according to any one of claims 1 to 2 characterized in
20 that the hinge system comprises a connecting element (4) connected to the floating structure (1) by a pivoting connection (A2) and connected to the flap (3) by a pivoting connection (A3).

Claim 5. The device according to any one of the preceding claims, characterized in that the flap (3) further comprises a rear extension where said rear
25 extension is connected to a front part (83) of the flap by a pivoting connection (A8).

Claim 6. The device according to claim 5, characterized in that said rear extension (8) is returned to a neutral angular position relative to the front part of the flap by a spring restoring system (86).

Claim 7. The device according to any one of claims 1 to 4 characterized in
30 that the keel comprises several flaps (3, 3+) arranged one under the other, mounted so as to remain parallel with each other.

Claim 8. The device according to any one of claims 1 to 5 characterized in that a resting position of the flap is defined by a fixed angle, where said fixed angle is defined by the surface of said flap and the longitudinal axis (X) perpendicular to
35 the keel.

Claim 9. The device according to any one of claims 1 to 6 characterized in that the body of the flap extends mainly in a work plane and the width of the flap increases going away from a zone where the hinged system connects the flap to the keel.

5 **Claim 10.** The device according to any one of claims 1 to 9 further comprising at least one means for transmission of the relative movement of said keel to at least one electric converter in order to convert the mechanical energy of said movement into electrical energy, where the device then has a function of conversion of the energy of the movement of the waves.

10 **Claim 11.** The device according to claim 10, further comprises a control unit (9) configured for driving the power collection rate in the electrical converter so as to thus balance between the propulsion produced by the countercurrent swimming and the transformed energy from the swell.

Claim 12. The device according to any one of claims 10 to 11, characterized in that the transmission means is at least one hydraulic cylinder (6).

Claim 13. The device according to one of claims 10 to 12, characterized in that the electric converter is an electrical generator coupled to a **hydraulic motor**.

Claim 14. The device according to any one of the preceding claims, characterized in that it is connected to at least one anchoring element.

20 **Claim 15.** The device according to any one of claims 1 to 13, characterized in that it is fixed to the stern of a boat or incorporated in the stern of a boat.

Claim 16. A device (10) for propulsion and for recovery of the energy of the movement of waves, comprising:

- at least one floating structure (1; 100);
25 - at least one keel (2) mounted mobile on the floating structure, according to at least one sliding movement (GT) relative to said floating structure along a heaving axis (Z),

characterized in that it comprises at least one flap (8) connected by a hinged system (A1, A2, A3, A8) both to the keel and also to the floating structure (1), where said
30 flap is configured for generating a propulsion force directed substantially towards the center of gravity of said floating structure, and in that the hinged system comprises at least one control arm (3, 36, 37) mounted in rotation on the keel by a first pivoting connection (A1), and at least one linkage (4, 46, 47) connected to the floating structure by a second pivoting connection (A2) and connected to said control
35 arm(s) by a third pivoting connection (A3), where the flap (8) is mounted in rotation on said control arm(s) by means of a hinge (A8) arranged in a rear position cantilevered relative to the third pivoting connection (A3).

Claim 17. The device according to claim 16, wherein the flap (8) is returned to a neutral angular position relative to the control (36, 37) by a spring restoring system (86).