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(54) Titre : SYSTEME DE GENERATION D'ENERGIE ELECTRIQUE HOULOMOTRICE FAISANT APPEL AU BALANCEMENT

(54) Title: BALANCE WAVE-ENERGY ELECTRICITY GENERATION SYSTEM

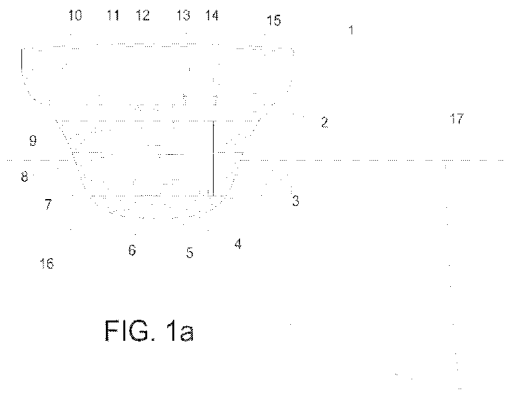

FIG. 1a

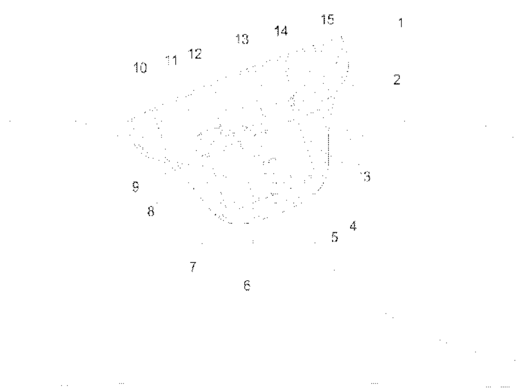

FIG. 1b

(57) Abrégé/Abstract:
An electric generator able to produce electricity by using the periodic oscillating movement of a floating hull or boat through the actuation of several mobile weights induced by said movement. It is used through the action of the aforementioned weights on hydraulic, pneumatic or mechanical mechanisms used to transform the mechanical energy generated into electricity to be distributed to land via a submarine cable.

ABSTRACT

An electric generator is described capable of producing electricity by leveraging the periodic roll movement of a floating vessel or ship through the actuation of mobile weights induced by said movement. Said movement is leveraged through the action of said weights upon hydraulic, pneumatic or mechanical mechanisms in charge of transforming the mechanical energy generated into electrical energy in order to distribute it to shore via an underwater cable.

OSCILLATING WAVE-POWERED ELECTRICITY GENERATION SYSTEM

OBJECT OF THE INVENTION

The present invention relates to the technical field of renewable energies, more specifically to wave energy.

The object of the invention pertains to the sea wave-powered electricity generation sector.

BACKGROUND OF THE INVENTION

Within the search for renewable and non-contaminating energy sources, as an alternative to that obtained from hydrocarbons, that obtainable from waves or wave energy is an interesting option, partly due to its potential in terms of global available power and to having, based on each geographic location, a predictable nature at certain time intervals.

The use of wave energy is still at an incipient stage of development, in comparison to that of other renewable energy sources such as wind or solar power. Even so, a large number of systems have been devised and patented for this purpose. These can be classified as follows:

1. Based on site type:
   - Permanently established on the coast.
   - Floating, anchored to the seabed by a mooring line.
   - Anchored to the seabed with a mobile part.
2. Based on the method used to transform wave energy:
   - Hydraulic raising systems:

These devices are based on the use of the potential energy of a mass of water raised by wave motion and converted into electricity by a turbine.

They can be of the floating type or permanently established on the coast. The device disclosed in patent GB2436595 belongs to the first type, as in the case of the system known as Wave Dragon.

- Gravitational:

Those that use wave-induced vertical movement in one or several floaters or buoys to actuate electric generators or store the energy for subsequent transformation thereof by means of hydraulic, pneumatic or mechanical systems.

Those disclosed in patents GB 2434620 A, EP 1439306 A1, WO2007/086750 A1 and DE 3642060 A1 belong to this type, as in the case of the Pelamis OPD and AWS systems.

- Displacement:

These types of systems are based on the kinetic energy of the wave, which acts on plates or pallets or compresses an air mass.

Patents DE102006024042 A1, US 2007/0081861 A1, US 2007/015463 A1 disclose systems based on this principle, as in the case of the Wave Roller and Oyster systems and those based on OWC (Oscillating Water Column) technology.

The desired characteristics for a wave-powered electricity generation system are the following:

- Efficient capture and transformation of wave energy.
- Robustness of the assembly in extreme wave conditions.
- Mechanical simplicity.
- Capacity to adapt to variations in wave characteristics.
- Easy to install.
- Minimum alteration of the marine environment.

DESCRIPTION OF THE INVENTION

The present invention is based on a self-supporting system that solves the previously described problems by leveraging the roll movement of a ship or floating vessel caused by the action of the waves that act at an angle approximately transversal to the main dimension thereof, which is determined in its physical characteristics by different parameters derived from the geometry, mass and vertical position of the centre of gravity of said ship or floating vessel. For a defined geometry, weight and position of the centre of gravity, each specific ship or floating vessel has a natural roll period wherewith it freely rolls when subject to external moment that upsets its balance. The maximum oscillation of the vessel due to the action of the waves is obtained when the natural period of the vessel is in synchronism with that of the waves acting thereupon; wave-energy capture is consequently greater under these conditions. Roll energy is related to the period, the maximum angle obtained and the righting moments in the course thereof. The present invention seeks to optimally leverage said energy of the vessel subject to wave-driven roll.

The object of the invention is based on the capture of wave-driven roll energy produced in a floating vessel or hull through the movement of one or several masses disposed in the interior thereof, and displaced in synchronism with the roll movement of said vessel. The dimensions, geometry and centre of gravity of the floating element are optimised to produce maximum oscillation amplitude by approximating the natural roll period of the hull and predominant wave period, with the object of obtaining near-resonance conditions. The displacement of the centre of gravity of the weights may be linear in a plane perpendicular to the roll axis or pendulous along an axis parallel thereto. The path of the weight is adjusted to obtain maximum efficiency in the energy obtained from its displacement and in accordance with the mechanism used for such purpose. In each roll movement of the floating vessel, each weight will be displaced by the action of gravity, either along rails in the direction of the beam, i.e. the smallest dimension of the vessel, or in a pendulous movement along a fixed axis. This energy is captured as a result of the pressure exerted by the weight on a hydraulic cylinder, directly or through a lever or connecting rod. The compressed hydraulic fluid actuates, through a circuit which includes accumulators and regulating valves, a hydraulic engine that is in turn coupled to an alternator that generates the electricity.

The circuit route and pressure are adjusted to optimally leverage the energy by means of a control unit and processor that receives a signal of the movement by means of an electronic inclinometer.

As an alternative to the aforementioned energy-leveraging means that incorporate hydraulic actuation, the system can incorporate pneumatic or mechanical-type actuation means composed of driving chains or belts, using pulleys, gears, clutches and reducers to actuate the alternator.

The natural roll period of the floating vessel is inversely proportional to the square root of the metacentric radius which, in turn, depends on the ordinate of the centre of gravity. In order to regulate the natural roll period of the vessel, approximating it to that of the waves, the position of the centre of gravity is automatically varied by transferring water to tanks disposed at different heights using an electric pump.

The position of the vessel that contains the system is maintained by two or more mooring lines, preferably anchored at their longitudinal ends and composed of chains fixed to an anchor or deadweight on the seabed. Considering that the optimum condition for maximum roll is reached when the predominant waves are incident transversely on the vessel, the mooring lines may be adjusted to achieve the adequate position with respect to variation in the direction thereof by heaving or hauling up the chain using a winch or windlass.

The system that is the object of the invention offers the following additional advantages:

- Compact external system without mobile parts sensitive to the action of the sea, which represents less maintenance and possibilities of failure. This peculiarity, very advantageous considering the variability of environmental conditions is, in itself, a unique characteristic compared to the existing ones.
- Possibility of being installed in breaker bars next to seaports in turbulent marine zones due to which, in addition to its electricity generation function, the system can also be used as a wave buffer.
- Adaptation to wave conditions in order to optimise energy production as a consequence of the increase in roll amplitude.

DESCRIPTION OF THE DRAWINGS

In order to complement this description and with the object of helping to better understand the characteristics of the invention, according to a preferred example of practical embodiment thereof, a set of drawings has been included as an integral part of said description, wherein the following have been represented in an illustrative and non-limiting manner:

Figure 1a shows a cross-section of the system adapted to the linear movement of the weight.

Figure 1b shows a cross-section of the system adapted to the linear movement of the weight in a final position of its oscillatory movement.

Figure 2a shows a cross-section of the system adapted to the pendulous movement of the weight.

Figure 2b shows a cross-section of the system adapted to the pendulous movement of the weight in a final position of its oscillatory movement.

PREFERRED EMBODIMENT OF THE INVENTION

In view of the foregoing figures, two examples by way of preferred embodiment of the object of the invention are described below.

Example 1

Figure 1a shows a cross-section of the system and represents a floating vessel (1) which can be built of steel, fibreglass-reinforced polyester, aluminium or reinforced concrete, depending on the weight and production requirements of the assembly. The shape of the cross-section is extended in order to increase the righting torque with the heel. It has a sealed deck that makes the assembly watertight and protects it from inclement weather. Different compartments have been disposed by way of water tanks (3) with the object of allowing variations in the centre of gravity and consequently vary the natural oscillation period of the floating vessel. Filling with and transfer of water is carried out using a pump (4) and a collector, pipe and electrovalve assembly. One or several straight or slightly curved metal rails (13), whereon a mobile weight (12) that moves thereover by means of wheels, are transversely disposed in the interior of the floating vessel (1). When the ship rolls due to wave action, the weight moves along the rail, acting upon hydraulic cylinders (11), exerting pressure thereon, its piston displacing a certain amount of hydraulic fluid, thereby generating certain power. Figure 1b shows the system in roll mode. Stops (14) are disposed at the rail ends while energetic use means are incorporated in the system, in this example hydraulic means having a hydraulic circuit that includes pressure valves and compensators (2), in addition to an accumulator (9) to provide constant power over a certain period of time and a hydraulic engine (5) connected to an alternator (6) to produce electric current. This current is transformed by a transformer (7) and sent to shore via an underwater cable (16). An electronic inclinometer (8) disposed in the manner of a roll sensor on the central gangway of the floating vessel (1) transmits information relative to the angle of roll and its variation over time to a control unit (10) that is in charge of regulating certain system variables. The floating vessel (1) is anchored to the seabed by two mooring lines (15) that include electric windlasses or conventional winches, which can be automatically actuated, to adjust the position of the vessel with respect to that of the waves. For the purpose of obtaining accurate information relative to the wave front, the generator may also have a floating sensor (17) that captures and transfers information relative to wave height and period.

Example 2

Figures 2a and 2b show the same system with a variation in the position of the mobile weight (12), which in this case carries out a pendulous oscillating movement around a rod (18). As shown in Figure 2a, the hydraulic cylinders (11) are actuated by the lever effect of the support arm (19) of the weight (12). The vertical position of the weight (12) may be adjusted by moving it along its support arm using mechanical or hydraulic means. Otherwise, operation of the system is similar to that described in Example 1. Figure 2b shows the system in operation with the floating vessel (1) in roll mode and the arm (19) acting upon the hydraulic cylinders (11).

CLAIMS

What is claimed is:

1. Oscillating wave-powered electricity generation system that comprises:
   - a floating vessel (1) anchored to the seabed by at least one mooring line (15) coupled to electric windlasses destined for adjusting the position of the floating vessel (1) with respect to that of the waves,
   - at least one mobile weight (12) in charge of acting upon energetic use means,
   - an alternator (6) associated to the energy use means destined for generating electricity as of the energy it receives from said energetic use means, and
   - a transformer (7) in charge of transforming the electric current generated by the alternator,

   characterised in that it comprises:
   - hydraulic cylinders (11) destined for absorbing the energy produced by the movement of the weight (12), disposed in connection with the energetic use means in order to transmit said energy,
   - an accumulator (9) connected to the energetic use means in charge of receiving and accumulating the energy produced by these and transmitting it to the alternator (6),
   - a pump (4) in charge of filling/emptying water tanks (3) disposed in the interior of the floating vessel (1) for the purpose of varying the vertical position of its centre of gravity, and
   - a control unit (10) in charge of regulating the electric windlasses, energetic use means and pump (4) in order to control the natural roll period of the floating vessel (1), determined by a roll sensor (8) connected to the control unit (10), with the object of approximating it to that of the predominant waves.

2. System, according to claim 1, characterised in that the weight (12) is displaceable with alternative movement along rails (13) and acts upon the

hydraulic cylinders (11) disposed aoneither side of the weight (12).

3. System, according to claim 2, characterised in that it additionally comprises stops (14) disposed at the rail (13) ends destined for limiting the movement of the weight (12) in both directions.

4. System, according to claim 1, characterised in that it additionally comprises a rod (18) associated to the floating vessel (1) having an articulation.

5. System, according to claim 4, characterised in that the weight (12) is associated to an arm (19) that articulates with respect to the articulation of the rod (18) with a pendulous movement over said rod (18), wherein said arm (19) is disposed in association with the hydraulic cylinders (11) in such a manner that the pendulous movement of the weight (12) determines the internal displacement of said hydraulic cylinders (11).

6. System, according to any one of the preceding claims, characterised in that the energetic use means comprise a hydraulic circuit connected to the hydraulic cylinders (11), which comprises pressure valves and compensators (2).

7. System, according to any one of claims 1 to 5, characterised in that the energetic use means comprise a pneumatic circuit connected to the hydraulic cylinders (11) that comprises pressure valves and compensators (2) and the accumulator (9).

8. System, according to any one of claims 1 to 5, characterised in that the energetic use means comprise a mechanical device connected to the hydraulic cylinders (11) that comprises connecting rods, cams and/or a chain or belt transmission and the accumulator (9).

9. System, according to any one of the preceding claims, characterised in that it additionally comprises an underwater cable (16) destined for distributing the electric current transformed by the transformer (7).

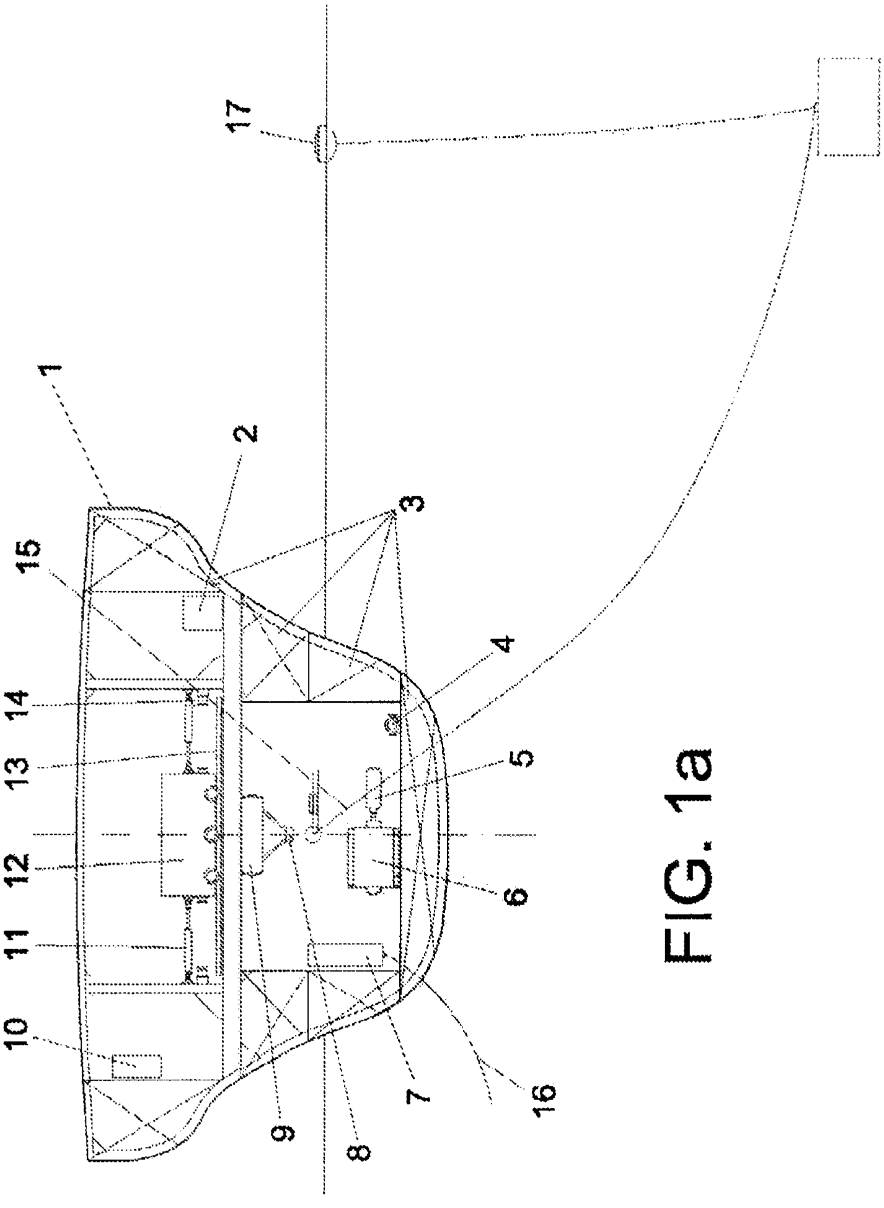

FIG. 1a

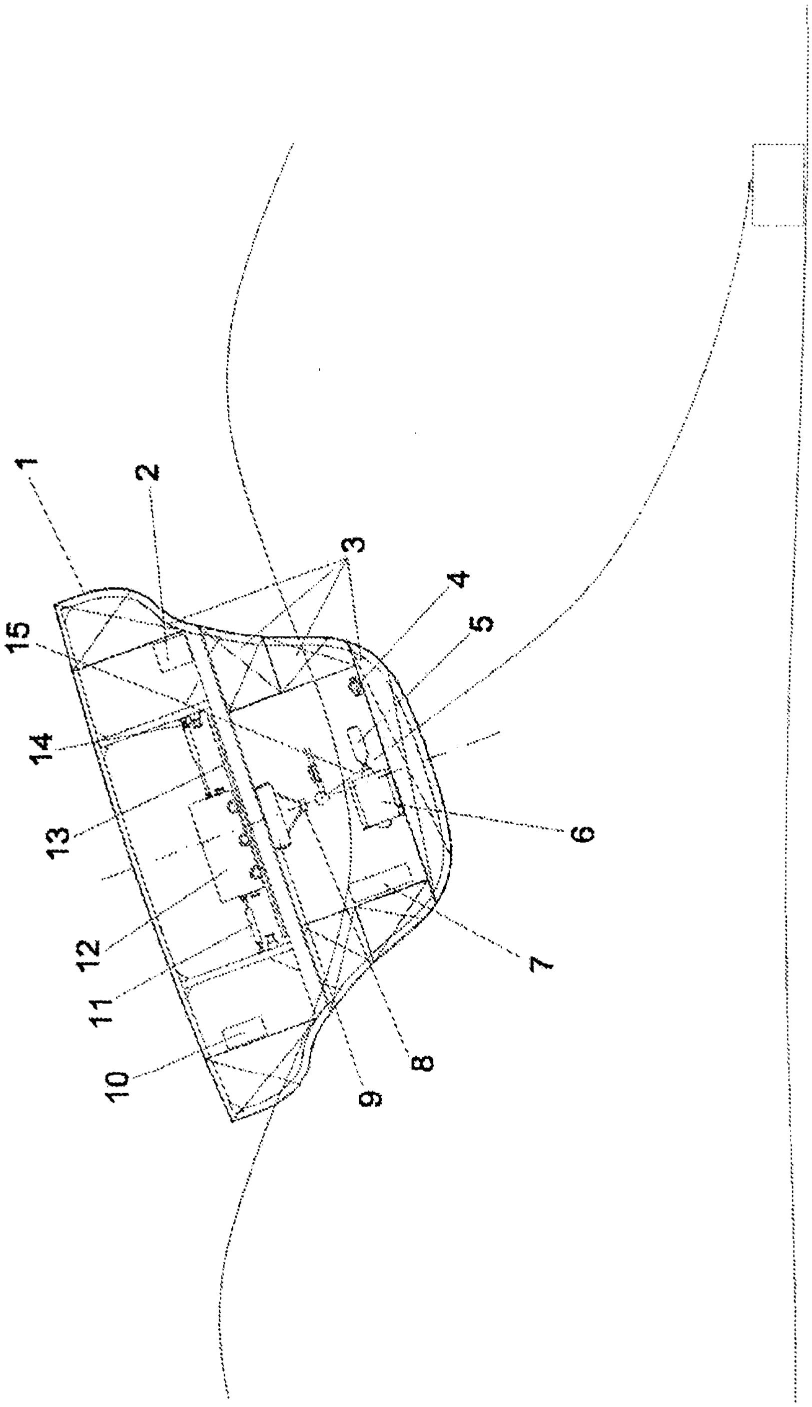

FIG. 1b

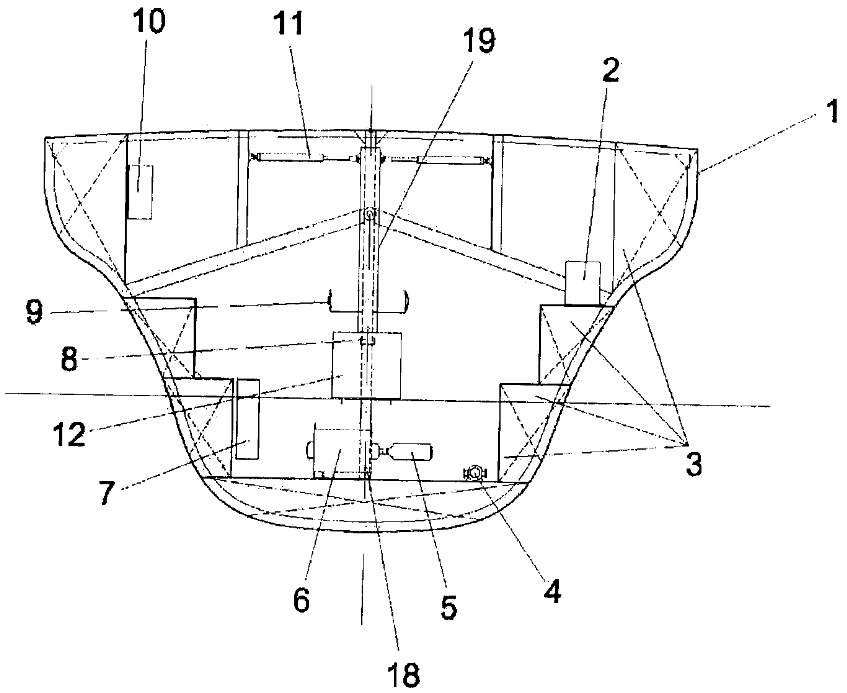

FIG. 2a

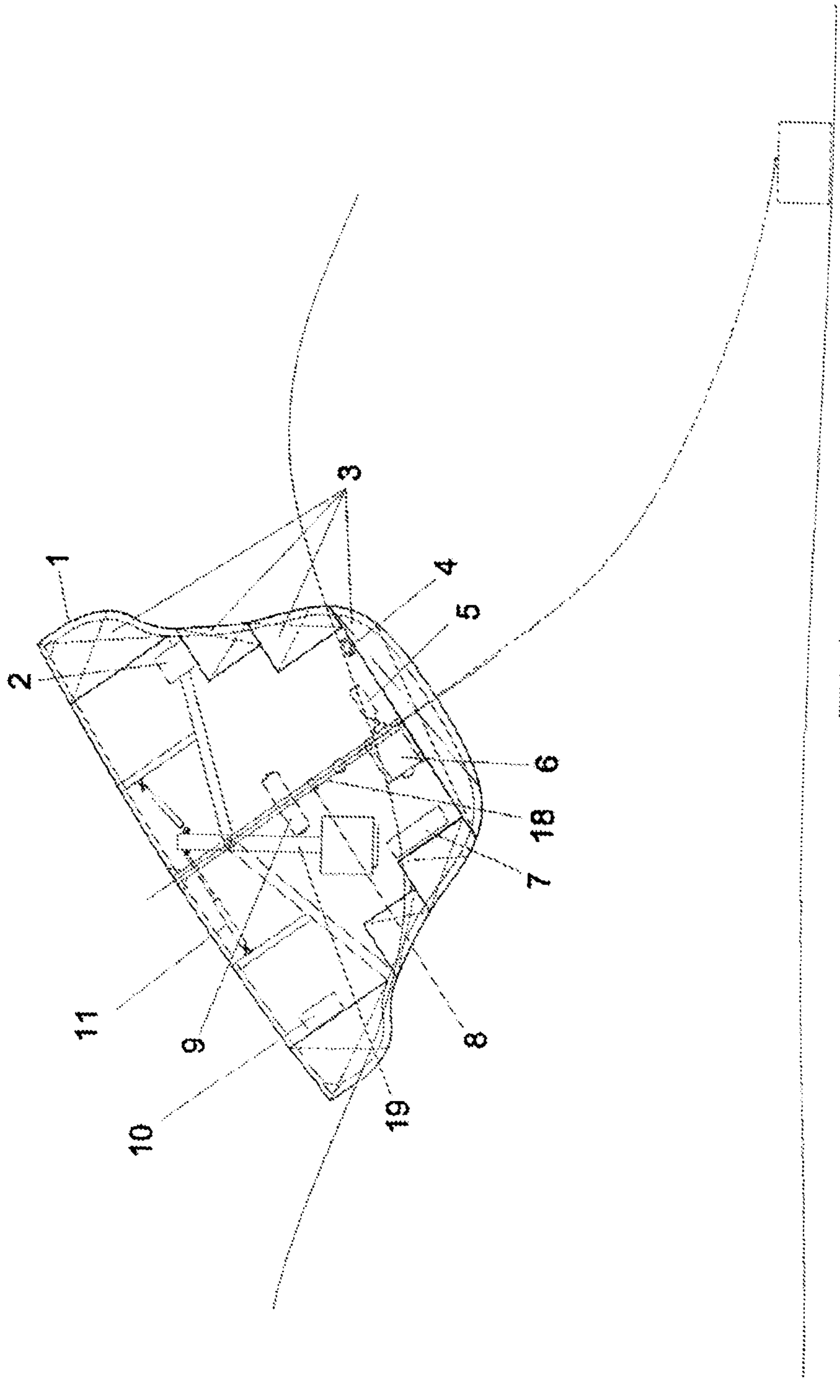

FIG. 2b

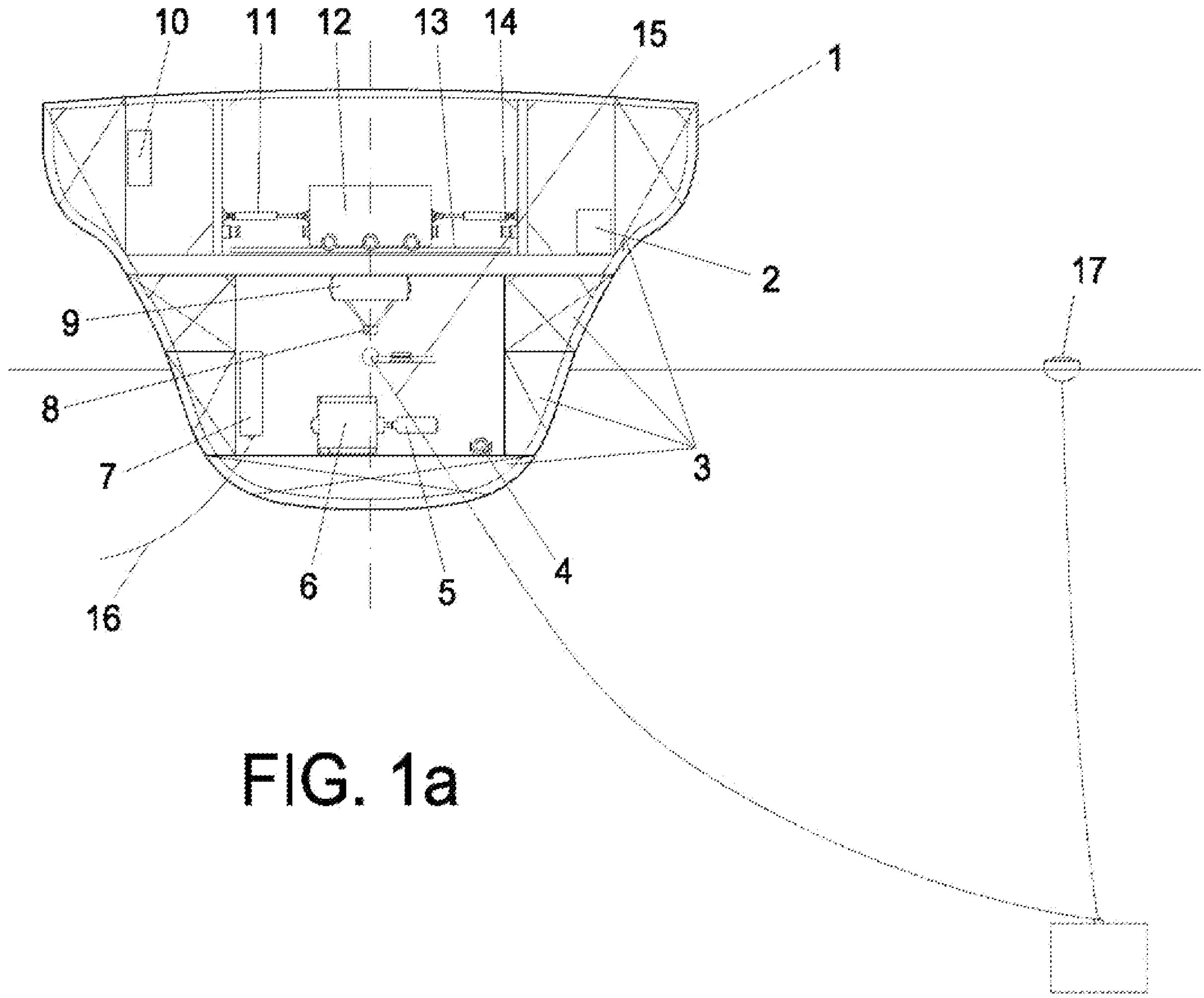

FIG. 1a

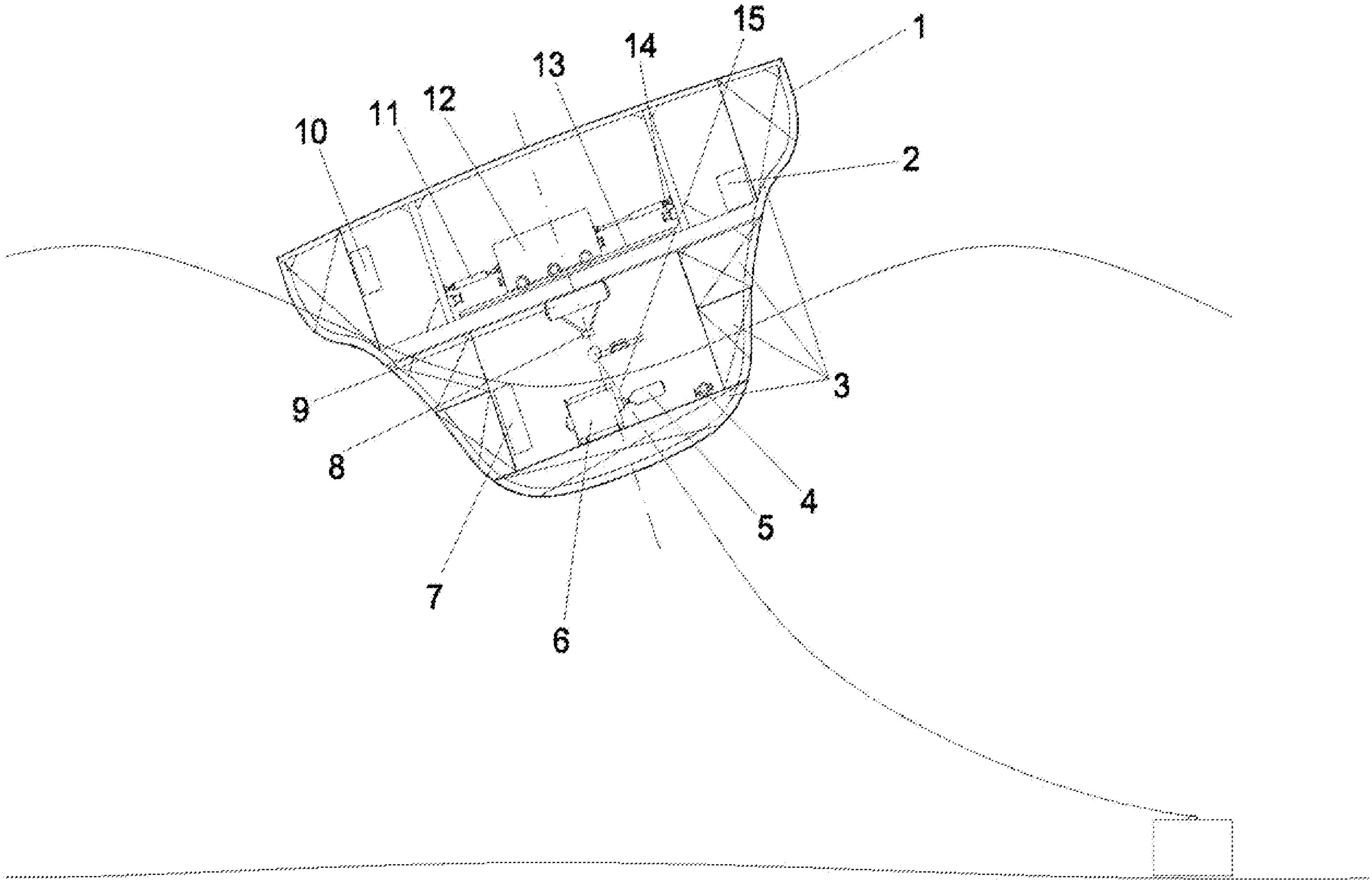

FIG. 1b

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B63B 39/00 (2006.01)

(56) Documents Cited:
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JP 020369555 A **JP 010320887 A**
JP 2009240011 A

(58) Field of Search:
INT CL **B63B, F03B**
Other: **EPODOC, WPI**

(54) Title of the Invention: **Power generating apparatus**
Abstract Title: **Power generating apparatus for a vessel, eg a ship or boat**

(57) A power generating apparatus for a vessel, eg a ship or boat, comprises a mass, eg a heavy ball 26 or pivoted hammer (50, fig.4), which moves in opposite directions due to pitch or roll movement of the vessel so as to repeatedly impact actuators, eg pistons 20,22, which generate power, eg by means of a turbine. A number of balls 26 may roll laterally across the vessel in respective guide channels 24 which may be serially arranged in a vertical direction (fig.3). The effective distance between the pistons 20,22 may be varied in response to sensed roll frequency. Movement of the balls 26 may be prevented or limited in harsh conditions. The amount of roll may be controlled, eg by means of ballast tanks or stabiliser fins. The vessel may be steered for optimum rolling. The vessel may be anchored by connecting anchor lines 46 at each end of the vessel at points 40, eg on extension arms 44, which correspond vertically to the metacentre m so that rolling motion is unrestrained.

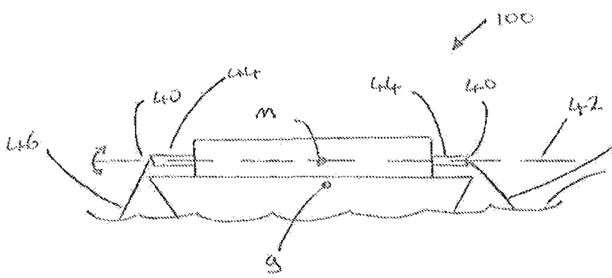

Fig 1

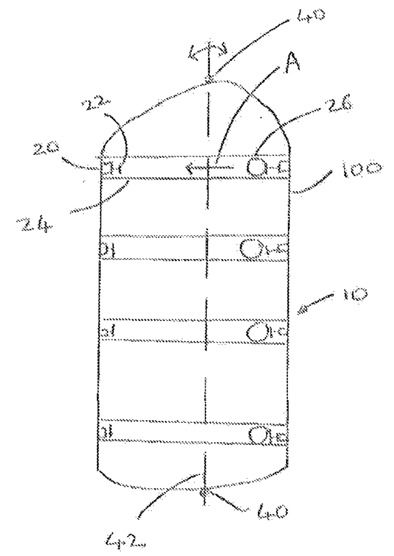

Fig 2

GB 2484324 A

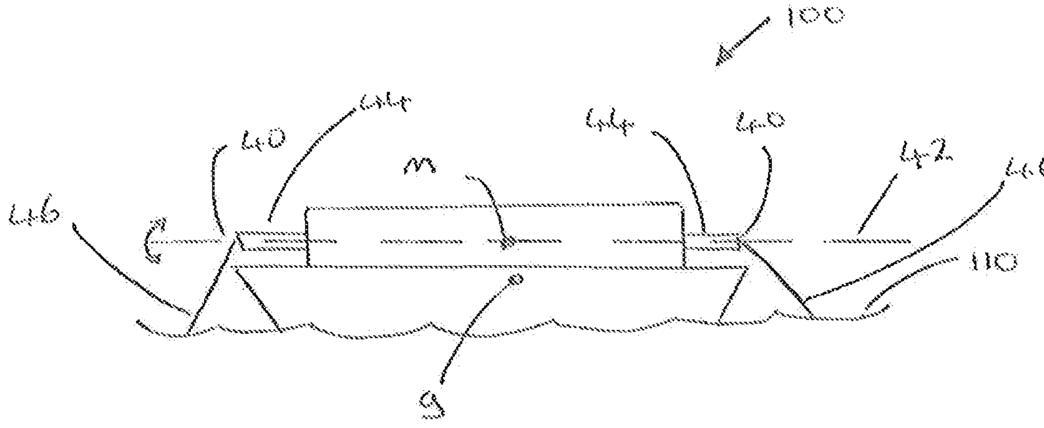

Fig 1

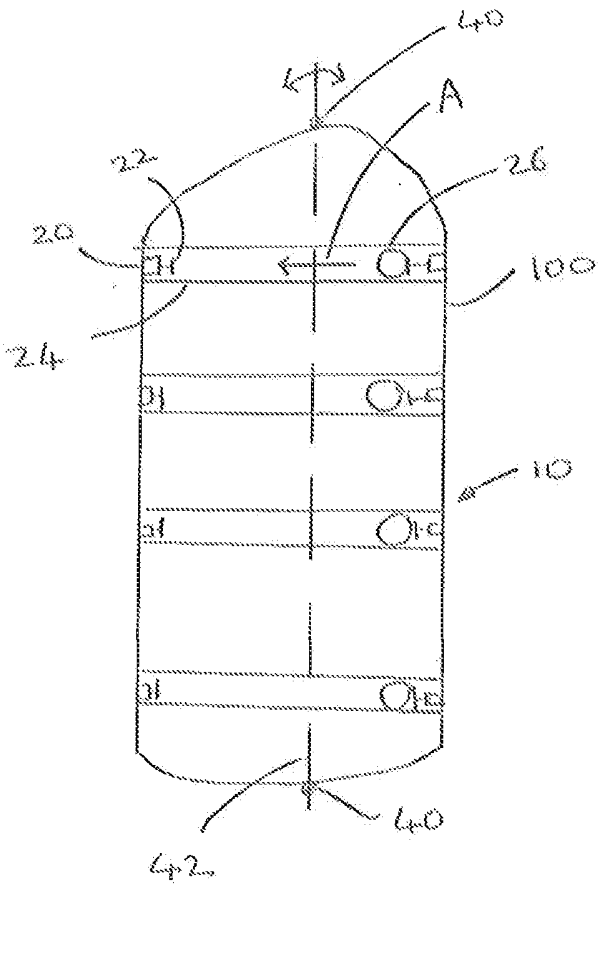

Fig 2

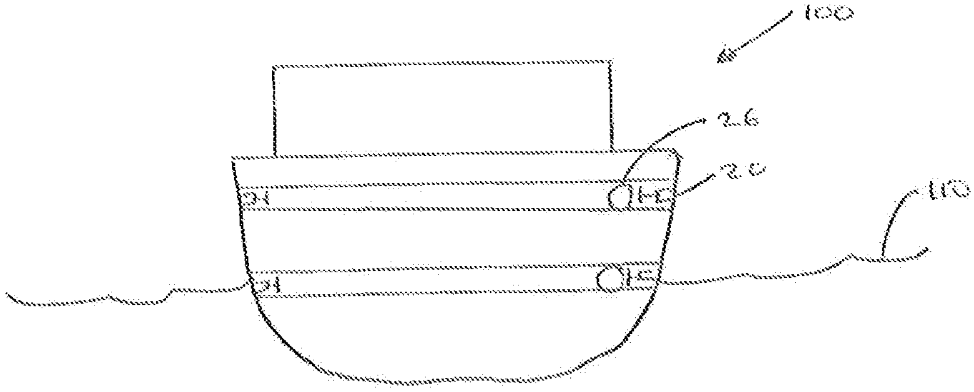

Fig 3

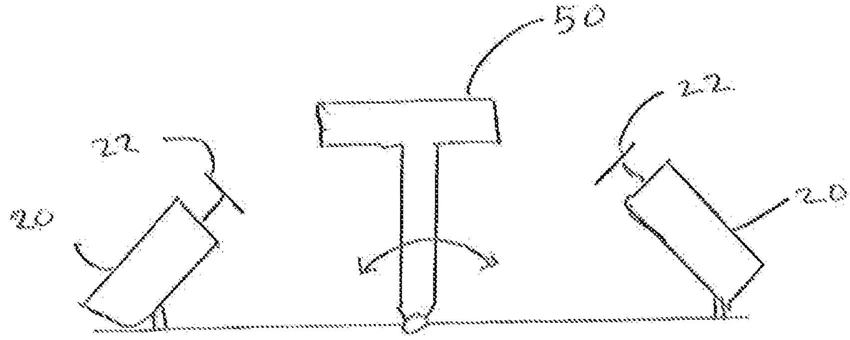

Fig 4

Power Generating Apparatus

The present invention relates to apparatus provided on a vessel for generating power using wave motion. In particular, but not exclusively, the invention relates to generating power using a vessel subject to pitch and roll due to wave motion.

Various wave power devices exist. Often, the apparatus use the vertical rise and fall of a device such as a buoy to generate power. The entire apparatus has to be manufactured and subsequently has no other purpose than to generate power, and the cost of the apparatus can be substantial.

A vessel such as a ship or boat is subject to pitch (longitudinal rotation) and roll (lateral rotation) when at sea. Even in calm weather, a ship typically experiences around 10° of roll. The vessel may have ballast tanks and/or stabiliser fins to control stability. The pivot point about which the vessel rolls is termed the metacentre, m. This is different from, and generally higher up than, the centre of gravity, g. The vertical position of g depends on the weight of the vessel and, if lower decks are flooded using the ballast tanks, the mass of the vessel will be greater at the bottom and so g will move downwards. However, the position of the metacentre will not change.

Conventionally, diesel engines are used to power a ship. A typical cost of the heavy fuel oil used for the engines is around $30,000 per day. The ship typically travels in shipping lanes and one reason these lanes are chosen is that they are generally calm waters. However, they are often not the most direct route between destinations.

According to a first aspect of the present invention, there is provided a power generating apparatus which is installable on a vessel, the apparatus comprising:

a power generating device;

a movable actuator coupled to the power generating device such that movement of the actuator causes the generating device to generate power; and

a mass which is movable in at least a first direction and a second opposite direction due to pitch or roll movement of the vessel,

wherein the apparatus is adapted such that movement of the mass causes the mass to impact and move the actuator to generate power.

The movable actuator may comprise a piston which is retractable to compress or move a fluid. The power generating device may comprise a turbine which is moved by the fluid to generate power.

The mass may comprise a rolling member, such as a ball or cylinder. Alternatively, the mass may comprise a sliding member.

The apparatus may include a guide member for the mass. The guide member may be adapted to limit movement of the mass to the first and second directions. The guide member may comprise one or more rails, troughs, conduits or the like for the mass. The mass may be rollably or slidably connected to the guide member.

The mass may be linearly movable in the first and second directions. Alternatively, the mass may be rotationally movable in the first and second directions.

In an alternative embodiment, the mass may comprise a hammer member. The hammer member may be pivotably fixed at a surface of the vessel and rotatable about the pivot fixing to impact and move the actuator.

A set of two actuators may be provided. The mass may be provided between the two actuators. The guide member may extend between the two actuators. Each actuator may be provided at opposite ends of the vessel in a lateral or longitudinal axis of the vessel.

Alternatively, the mass may comprise a component of the vessel, such as cargo or a portion of the infrastructure of the vessel. The apparatus may include a support member for the component which provides controlled movement to impact and move the actuator. Alternatively, the mass may comprise a fluid contained within the vessel which is movable due to pitch or roll to apply pressure to the actuator to move the actuator to generate power.

The effective distance between the two actuators of the set may be variable. The apparatus may include sensing means for measuring the frequency of the pitch or roll of the vessel. The apparatus may include control means for varying the distance between the two actuators based upon the measured frequency.

The apparatus may include a pitching or rolling sensor to measure the magnitude of movement of the vessel. The apparatus may include means for preventing or limiting movement of the mass when the magnitude of vessel movement exceeds a predetermined value. The means may be adapted to cease movement of the mass, or to limit the movement to within a set of stops, or to slow movement of the mass. The means may comprise a cage member, an anchor device, a set of stops, a brake member or the like.

The apparatus may include means for controlling the amount of pitch or roll of the vessel. The controlling means may comprise means for varying the distance between the metacentre and the centre of gravity. The varying means may be provided by ballast tanks of the vessel. Alternatively or in addition, the controlling means may comprise one or more stabiliser fins which are deployable to reduce pitch or roll or retractable.

A plurality of sets of actuators may be provided at the vessel, the sets being serially arranged in a horizontal direction. The horizontal direction may be one or both of lateral and longitudinal. Alternatively or in addition, a plurality of sets may be serially arranged in a vertical direction. The mass of the mass and/or the number of sets provided at a particular vertical level may vary depending on the vertical distance from the metacentre.

The vessel may comprise a ship or boat. The vessel may be anchorable at a first point of the vessel. The first point of the vessel may be provided at one end of the vessel and the vessel may be anchorable at a second point at a second opposite end of the vessel.

The first and second anchoring points of the vessel may vertically correspond to the metacentre of the vessel. The first and second anchoring points of the vessel may be provided at each longitudinal end of the vessel. This restrains the vessel from movement in all directions except for rolling rotation about the metacentre. Alternatively, the first and second anchoring points of the vessel may be provided at each lateral end of the vessel. This restrains the vessel from movement in all directions except for pitching rotation about the metacentre.

An arm assembly may be provided at the metacentre for extending the anchoring point outwards towards or beyond the boundary of the vessel. This avoids interference between the anchor line and a portion of the vessel such as the hull.

The apparatus may include an electrical conduit which is connectable between the power generating device and an onshore connector.

Alternatively or in addition, the generated power may be stored in storage devices on the vessel such as batteries. The generated power may be used to power the vessel. The vessel may be adapted to carry cargo and/or passengers.

According to a second aspect of the present invention there is provided a vessel including a power generating apparatus in accordance with the first aspect of the invention.

According to a third aspect of the present invention there is provided a method of generating power comprising the steps of:

installing on a vessel a power generating apparatus comprising a power generating device and a movable actuator coupled to the power generating device such that movement of the actuator causes the generating device to generate power;

providing a mass on the vessel, the mass being movable in at least a first direction and a second opposite direction due to pitch or roll movement of the vessel such that movement of the mass causes the mass to impact and move the actuator to generate power.

The method may include guiding the mass to limit movement of the mass to the first and second directions. The method may include providing the mass between a set of two actuators.

The method may include using a component of the vessel, such as cargo or a portion of the infrastructure of the vessel, as the mass. Alternatively, The method may include using a fluid contained within the vessel as the mass.

The method may include varying the effective distance between the two actuators of the set. The method may include measuring the frequency of the pitch or roll of the vessel. The method may include varying the distance between the two actuators based upon the measured frequency.

The method may include measuring the magnitude of movement of the vessel. The method may include preventing or limiting movement of the mass when the magnitude of vessel movement exceeds a predetermined value.

The method may include controlling the amount of pitch or roll of the vessel. The step of controlling the amount of pitch or roll of the vessel may comprise varying the distance between the metacentre and the centre of gravity.

The method may include providing a plurality of sets of actuators at the vessel.

The method may include anchoring the vessel at a first and second point of the vessel, the points provided at opposite ends of the vessel. The method may include vertically locating the first and second anchoring points at the metacentre of the vessel such that the vessel is restrained from movement in all directions except for rotation about the metacentre. The method may include providing an arm assembly at the metacentre to extend the anchoring point outwards towards or beyond the boundary of the vessel.

The method may include connecting an electrical conduit between the power generating device and an onshore connector.

Alternatively, the method may include storing the generated power in storage devices on the vessel. Alternatively or in addition, the method may include using the generated power to power the vessel.

The method may include sailing the vessel within one or more geographic regions that are known to produce substantial pitch or roll. The or each geographic region may be distinct from known shipping lanes.

According to a fourth aspect of the present invention there is provided a method of anchoring a vessel comprising the steps of:

connecting an anchor line of a first anchor at a first point located at a first end of the vessel;

connecting an anchor line of a second anchor at a second point located at a second opposite end of the vessel; and

deploying each anchor,

wherein each of the first and second points correspond to the metacentre of the vessel such that rotational movements of the vessel are unconstrained while movement in all other degrees of freedom is constrained.

The first and second anchoring points of the vessel may be provided at each longitudinal end of the vessel. Alternatively, the first and second anchoring points of the vessel may be provided at each lateral end of the vessel.

The method may include providing an extending member at one or both of the first and second points and connecting the anchor line to the free end of the extending member.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

Fig 1 shows a side view of a vessel including a first embodiment of a power generating apparatus;

Fig 2 shows a plan view of the vessel of Figure 1;

Fig 3 shows an end view of the vessel of Figure 1; and

Fig 4 shows a second embodiment of a power generating apparatus;

Figure 1 shows a vessel in the form of a ship 100 in a body of water 110 which includes a power generating apparatus 10 as shown in Figures 2 to 4. The apparatus 10 comprises a power generating device in the form of a turbine device (not shown) which converts rotation of a set of turbine blades into electricity.

The turbine blades are rotated when a movable actuator in the form of the head 22 of a piston 20 is retracted to pressurise a hydraulic fluid. The piston 20 includes a spring (not shown) for returning the piston head 22 to the extended position.

As shown in Figures 2 and 3, a piston 20 is provided at each lateral end of the ship 100, the two pistons forming a cooperating set, and a guide channel 24 extends between the two pistons 20. A mass in the form of a heavy ball 26 is located within the channel 24. The ship 100 includes a number of these piston/channel/ball systems arranged in series and running laterally across the ship 100.

The ball 26 is free to roll within the channel 24 from one end to the other and back in response to rolling of the ship 100. As the ship 100 rolls, each channel 24 will change in orientation to have a particular gradient, the value of the gradient dependent on the degree of rolling. The ball 26 at the summit of the gradient will roll along the channel 24 in direction A, picking up momentum and accelerating as it rolls. When the ball 26 reaches the end of the channel 24, it will strike the piston head 22 located there with an impact force equal to the product of its mass and deceleration as it slows to a stop at the end of the channel 24. This impact force is predetermined to be sufficient to fully retract the piston head 22. Each piston/channel/ball system will therefore contribute to generating power. The balls 26 will all tend to move simultaneously in the same manner as they are all subject to the same rolling action of the ship 100.

It is desirable that the balls' striking of the piston heads 22 is coordinated with the peaks of rolling of the ship 100 to fully utilise the available energy of the rolling balls 26. Therefore, it is desirable to ensure that the rolling distance of the balls 26 (determined by the length of the channels 24) corresponds with the frequency of rolling of the ship 100. To achieve this, the effective distance between the set of two piston heads 22 can be adapted to be variable. For instance, one or both pistons 20 can be attached to a mount (not shown) which is laterally movable inwards towards the centre of the ship 100. One or more sensors (not shown) can be used to measure the frequency of the roll of the ship 100. A controller (not shown) can be adapted to vary the distance between the two piston heads 22 by moving one or both of the associated mounts by a distance based upon the measured frequency.

One or more sensors (not shown) can also be provided to measure the magnitude of rolling movement of the ship 100. When the rolling of the ship 100 as measured by the sensors exceeds a safe value, movement of the balls 26 can be prevented or limited. For instance, a brake in the form of rubber pads (not shown) provided in the channels 24 can be deployed to slow the balls 26 or, if further deployed, bring the balls 26 to a stop. The degree of deployment of the brake can be adapted to be dependent on the measured magnitude of rolling. Slowing, rather than stopping, the balls 26 has the advantage that the apparatus continues to operate (and produce power) even in harsh conditions.

It is also possible, either instead of or in addition to directly controlling ball movement, to control the amount of roll of the ship 100. This can comprise varying the distance between the metacentre and the centre of gravity. Two means of doing this are using the ballast tanks of the ship 100 and the stabiliser fins of the ship 100.

Also, the steering of the ship 100 can be controlled, in response to the measured magnitude of rolling movement of the ship 100, so that the ship 100 is at the optimum orientation for experiencing rolling within the desired range.

As shown in Figure 3, the piston/channel/ball systems can also be serially arranged in a vertical direction. The mass of the balls 26 can be adapted to vary depending on the vertical distance from the metacentre m.

As shown in Figure 1 and 2, the ship 100 can be anchored at two points 40, the points 40 provided at opposite longitudinal ends of the ship 100. The anchoring points 40 are configured to vertically correspond to the metacentre of the ship 100. This restrains the vessel from movement in all directions except for rolling rotation about a longitudinal axis 42 passing through the metacentre m, whereas the rolling rotation is substantially unrestrained. An arm assembly 44 coincident with the metacentric axis 42 extends the anchoring points 40 outwards to avoid interference between the anchor line 46 and the hull of the ship 100.

With this configuration, the ship 100 is permanently anchored for as long as power generation is desired. The ship 100 can be anchored close to shore and an electrical conduit (not shown) can be connected between the power generating device and an onshore connector connected to the main grid.

However, the ship 100 can alternatively be used as a working vessel, such as to carry cargo and/or passengers. The generated power can be stored in batteries and can be used to power the vessel which would provide a substantial reduction in fuel costs.

Figure 4 shows an alternative embodiment of the apparatus 10. Rather than using a ball which rolls within a channel, the mass comprises a hammer 50 which is again provided between two piston heads 22. The hammer 50 is pivotably fixed at a surface of the ship 100. Rolling of the ship 100 causes the hammer 50 to rotate relative to the ship 100 about the pivot fixing 52 to sequentially impact and move each piston head 22.

Various modifications can be made without departing from the scope of the present invention.

Claims

1. A power generating apparatus which is installable on a vessel, the apparatus comprising:

a power generating device;

a movable actuator coupled to the power generating device such that movement of the actuator causes the generating device to generate power; and

a mass which is movable in at least a first direction and a second opposite direction due to pitch or roll movement of the vessel,

wherein the apparatus is adapted such that movement of the mass causes the mass to impact and move the actuator to generate power.

2. An apparatus as claimed in claim 1, wherein the movable actuator comprises a piston which is retractable to compress or move a fluid.

3. An apparatus as claimed in claim 2, wherein the power generating device comprises a turbine which is moved by the fluid to generate power.

4. An apparatus as claimed in any preceding claim, wherein the mass comprises a rolling member.

5. An apparatus as claimed in any preceding claim, including a guide member for the mass, the guide member adapted to limit movement of the mass to the first and second directions.

6. An apparatus as claimed in any preceding claim, wherein the mass is linearly movable in the first and second directions.

7. An apparatus as claimed in any of claims 1 to 5, wherein the mass is rotationally

movable in the first and second directions, and wherein the mass comprises a hammer member which is pivotably fixed at a surface of the vessel and rotatable about the pivot fixing to impact and move the actuator.

8. An apparatus as claimed in any preceding claim, wherein a set of two actuators are provided, the mass being provided between the two actuators.

9. An apparatus as claimed in claim 8, wherein the guide member extends between the two actuators, and wherein each actuator is provided at opposite ends of the vessel in a lateral or longitudinal axis of the vessel.

10. An apparatus as claimed in any of claims 1 to 3, wherein the mass comprises a component of the vessel.

11. An apparatus as claimed in claim 8 or 9, wherein the effective distance between the two actuators of the set is variable.

12. An apparatus as claimed in claim 11, wherein the apparatus includes sensing means for measuring the frequency of the pitch or roll of the vessel and the apparatus includes control means for varying the distance between the two actuators based upon the measured frequency.

13. An apparatus as claimed in any preceding claim, wherein the apparatus includes a pitching or rolling sensor to measure the magnitude of movement of the vessel and the apparatus includes means for preventing or limiting movement of the mass when the magnitude of vessel movement exceeds a predetermined value.

14. An apparatus as claimed in any preceding claim, including means for controlling the amount of pitch or roll of the vessel.

15. An apparatus as claimed in claim 14, wherein the controlling means comprises means for varying the distance between the metacentre and the centre of gravity.

16. An apparatus as claimed in any preceding claim, including a plurality of sets of actuators provided at the vessel, the sets being serially arranged in a horizontal direction.

17. An apparatus as claimed in any preceding claim, including a plurality of sets of actuators provided at the vessel, the sets being serially arranged in a vertical direction.

18. An apparatus as claimed in any preceding claim, wherein the vessel is anchorable at a first point of the vessel, the first point provided at one end of the vessel, and the vessel is anchorable at a second point provided at a second opposite end of the vessel.

19. An apparatus as claimed in claim 18, wherein the first and second anchoring points of the vessel vertically correspond to the metacentre of the vessel.

20. An apparatus as claimed in claim 19, wherein an arm assembly is provided at the metacentre for extending the anchoring point outwards towards or beyond the boundary of the vessel.

21. An apparatus as claimed in any preceding claim, including an electrical conduit which is connectable between the power generating device and an onshore connector.

22. An apparatus as claimed in any preceding claim, wherein at least a portion of the generated power is stored in storage devices on the vessel.

23. An apparatus as claimed in claim 22, wherein at least a portion of the generated

power is used to power the vessel.

24. A vessel including a power generating apparatus as claimed in any of claims 1 to 23.

25. A method of generating power comprising the steps of:

installing on a vessel a power generating apparatus comprising a power generating device and a movable actuator coupled to the power generating device such that movement of the actuator causes the generating device to generate power;

providing a mass on the vessel, the mass being movable in at least a first direction and a second opposite direction due to pitch or roll movement of the vessel such that movement of the mass causes the mass to impact and move the actuator to generate power.

26. A method as claimed in claim 25, including guiding the mass to limit movement of the mass to the first and second directions.

27. A method as claimed in claim 25 or 26, including providing the mass between a set of two actuators.

28. A method as claimed in any of claims 25 to 27, including varying the effective distance between the two actuators of the set.

29. A method as claimed in any of claims 25 to 28, including controlling the amount of pitch or roll of the vessel by varying the distance between the metacentre and the centre of gravity.

30. A method as claimed in any of claims 25 to 29, including anchoring the vessel at a first and second point of the vessel, the points provided at opposite ends of the vessel.

31. A method as claimed in claim 30, including vertically locating the first and second anchoring points at the metacentre of the vessel such that the vessel is restrained from movement in all directions except for rotation about the metacentre.

32. A method as claimed in claim 31, including providing an arm assembly at the metacentre to extend the anchoring point outwards towards or beyond the boundary of the vessel.

33. A method as claimed in any of claims 25 to 32, including connecting an electrical conduit between the power generating device and an onshore connector.

34. A method as claimed in any of claims 25 to 33, including sailing the vessel within one or more geographic regions that are known to produce substantial pitch or roll.

35. A method of anchoring a vessel comprising the steps of:

connecting an anchor line of a first anchor at a first point located at a first end of the vessel;

connecting an anchor line of a second anchor at a second point located at a second opposite end of the vessel; and

deploying each anchor,

wherein each of the first and second points correspond to the metacentre of the vessel such that rotational movements of the vessel are unconstrained while movement in all other degrees of freedom is constrained.

36. A method as claimed in claim 35, wherein the first and second anchoring points of the vessel are provided at each longitudinal end of the vessel.

`37. A method as claimed in claim 35, wherein the first and second anchoring points of the vessel are provided at each lateral end of the vessel.

38. A method as claimed in any of claims 35 to 37, including providing an extending member at one or both of the first and second points and connecting the anchor line to the free end of the extending member.

INTELLECTUAL PROPERTY OFFICE

Application No: GB1016872.2 **Examiner:** John Twin

Claims searched: 1-34 **Date of search:** 10 January 2011

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1,4-6,8,16,25-27	DE 3109398 A1 (Ulbricht)
X	1,4-6,8,9,16,25-27	JP 2009240011 A (Univ. Saitama)
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A	-	DE 3109446 A (Litmeyer)
A	-	JP 57126569 A (Sonada)
A	-	DE 802683 C (Hiemcke)

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{X} :

Worldwide search of patent documents classified in the following areas of the IPC

B63B; F03B

The following online and other databases have been used in the preparation of this search report

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
F03B	0013/20	01/01/2006
B63B	0021/50	01/01/2006
B63B	0039/00	01/01/2006

United States Patent [19]

Jakobsen

[11] **4,332,571**

[45] **Jun. 1, 1982**

[54] **WAVE MOTORS**

[76] Inventor: **Einar Jakobsen,** Roven, N-1920, Sørumsand, Norway

[21] Appl. No.: **959,293**

[22] Filed: **Nov. 9, 1978**

[30] **Foreign Application Priority Data**

Nov. 11, 1977 [NO] Norway 773849

[51] **Int. Cl.**3 .... **B63H 1/30;** B63H 5/00

[52] **U.S. Cl.** **440/9;** 440/14; 416/79

[58] **Field of Search** .... 115/4, 5, 76, 28 R, 115/28 A, 29; 60/497, 498, 499, 505, 506; 440/9, 10, 13-16, 21-22; 416/79-83, 135

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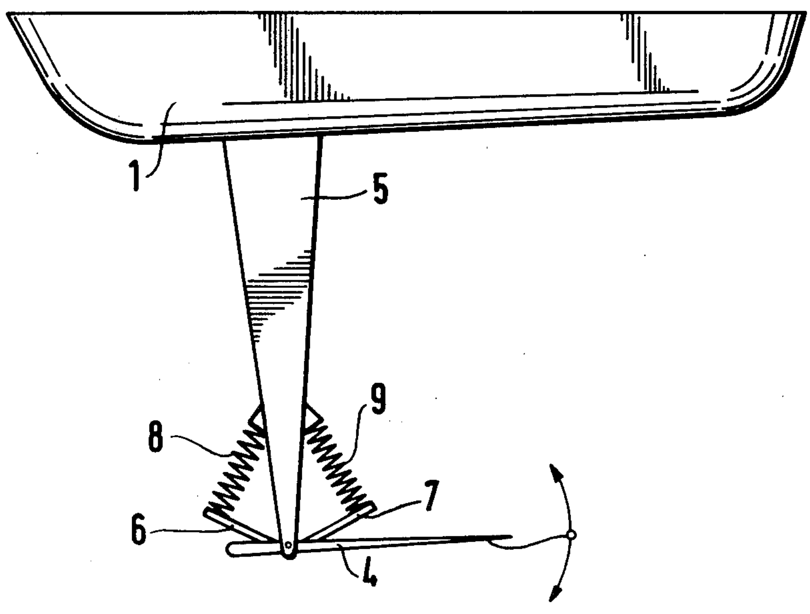
Primary Examiner—Trygve M. Blix
Assistant Examiner—D. W. Keen
Attorney, Agent, or Firm—Scully, Scott, Murphy & Presser

[57] **ABSTRACT**

There is disclosed an improvement in wave motors for propulsion of boats, of the type comprising a supporting structure connected to the boat and extending downwards into the water, and a tilting element connected to the supporting structure, the tilting element being adapted to tilt when the boat is moved by the waves. The motor according to the invention is provided with force applying devices always trying to bring the tilting element back into a neutral position when it is angularly displaced away from this, thereby increasing the efficiency of the wave motor.

7 Claims, 3 Drawing Figures



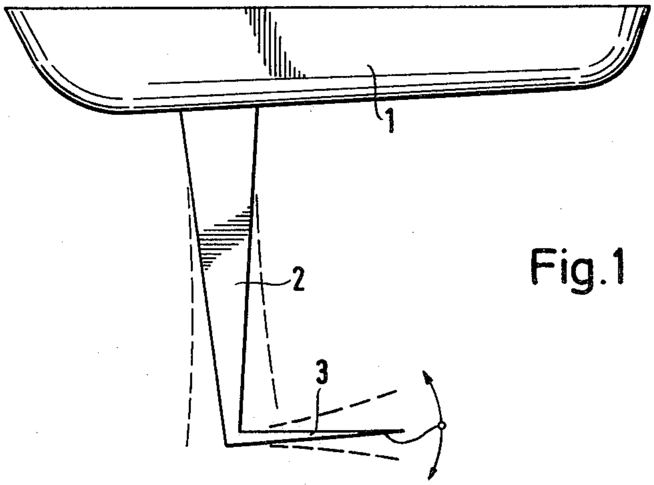


Fig.1

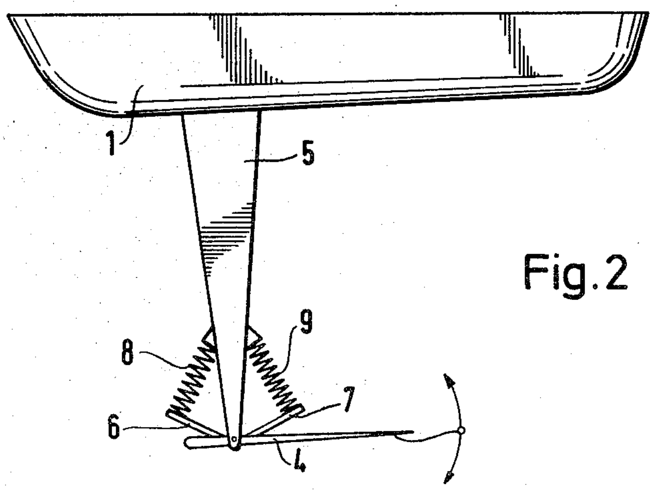
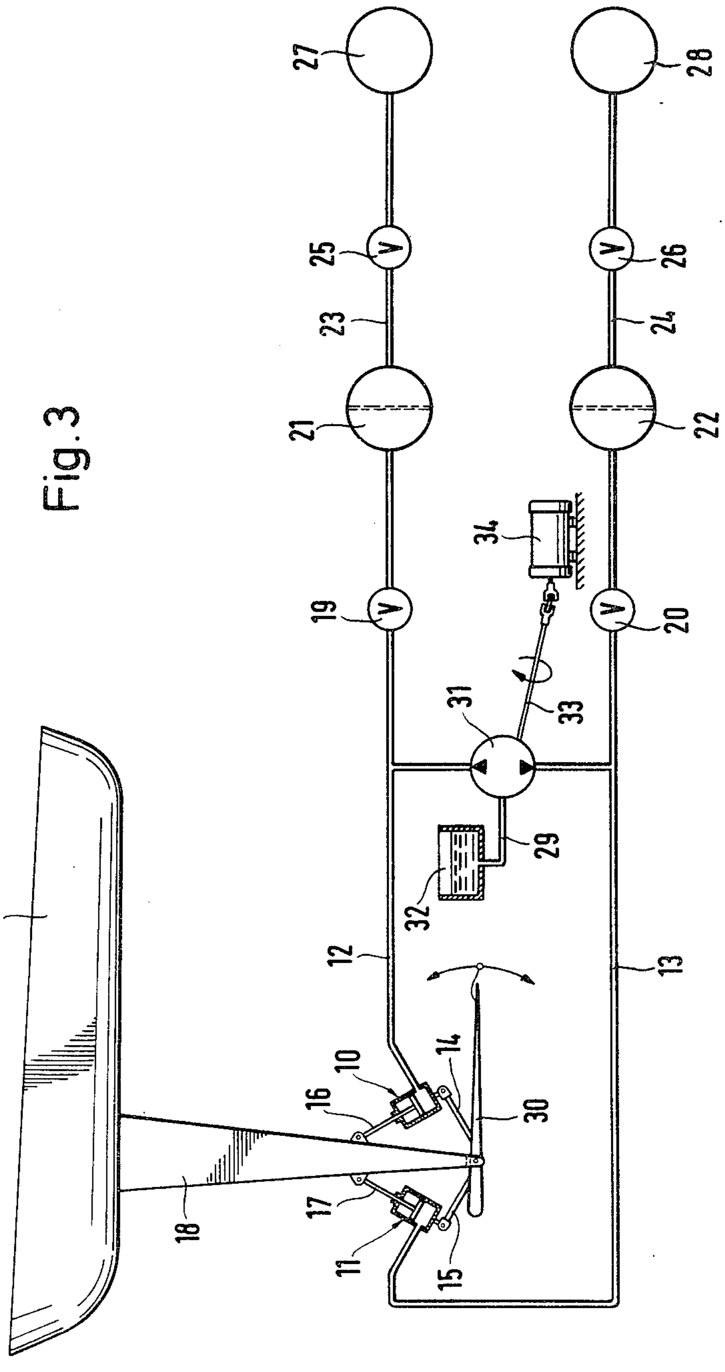


Fig.2

Fig.3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WAVE MOTORS

The present invention relates to an improvement in wave motors for propulsion of boats, which motors comprise a supporting structure connected to the boat and extending downwards into the water when the boat floats thereon, and a platelike tilting element constituting the propulsion means of the boat, the plate plane of the element extending approximately parallel to the cruising direction of the boat, and the part of which pointing in this direction being connected to the lower end of the supporting structure, and the tilting element being adapted to tilt, due to relative movement of the tilting element and the water surrounding this, when the boat floats on the water and is moved by waves.

Such wave motors are known from U.S. Pat. Nos. 2,021,815 and 2,367,765. The tilting elements mentioned therein are rotatably connected to the supporting structure for tilting about an axis extending in the transverse direction in relation to the cruising direction, and the tilting angle of the tilting element is limited by means of stops arranged on the supporting structure.

During said relative movement, the tilting element is tilted one way or the other to rest against one of the stops, whereby further relative movement causes change of the flow direction of the water flowing towards the tilting element, whereby the water is guided rearwards, in the direction opposite to the desired cruising direction, thereby creating a reaction force acting on the tilting element driving the boat in said cruising direction.

In these motors said relative movement cannot be fully utilized. When the boat is moved from a wave trough to a wave crest, the trailing edge of the tilting element is moved downwardly in relation to the axis of rotation, due to the forward location of the axis og rotation on the tilting element, until this is brought to rest against one of the stops. Upon subsequent movement of the boat from the wave crest to a new wave trough, the trailing edge of the tilting element is moved upwardly in relation to the axis of rotation until the tilting element is brought to rest against the other stop, i.e. an angle which equal to the above-mentioned tilting angle.

The distance that the boat must move in order to bring the tilting element from its rest against one stop to the other therefore represents an unutilized part of the available wave energy. In addition, the impacts caused by the tilting element when it strikes against the stops may propagate through the hull and cause discomfort for persons on board.

The object of the invention is to eliminate the above-mentioned drawbacks in connection with previously known wave motors of this type.

The characteristic features of the method and the device according to the invention are evident from the claims.

The invention will be explained in detail in the following description with reference to the accompanying drawings, which schematically show embodiments of the device according to the invention, and in which

FIG. 1 is an end view of a first embodiment,

FIG. 2 is an end view of a second embodiment, and

FIG. 3 is an end view of a third embodiment of a device according to the invention and a hydraulic/-pneumatic control system for the tilting element.

According to FIG. 1, the upper end of a beam or a supporting structure 2 extending downwards in the water is fixedly connected to the outer surface of the bottom of a boat 1. The lower end of the supporting structure 2 is fixedly connected to the forward end, as seen in the cruising direction, of a platelike tilting element 3, whose plate plane in unloaded, neutral position is arranged for instance approximately parallel to the water line plane of the boat.

The tilting element 3 is made of a flexible and elastic material and in such a way that it will bend during the above-mentioned relative movement, as indicated in thick dotted lines, while the supporting structure 2 is rigid.

Alternatively, the supporting structure can be flexible and bend, as indicated in thin dotted lines, in order to provide the tilting of the tilting element 3 from the neutral position, whereby this flexible supporting structure also absorbs the shock if the boat runs aground, thus providing safety in such an event.

FIG. 2 shows a second embodiment of a wave motor according to the invention. A tilting element 4 is with its forward part, as seen in the cruising direction of the boat, rotatably connected to a supporting structure 5 about a horizontal axis.

In order to keep the tilting element in neutral position, it is provided with two upwards and rearwards, resp. forwards extending arms 6, 7, the outer ends of which each being connected to the supporting structure 5 by means of a spring 8, 9. By choosing springs with proper characteristics, different amplitudes for the two tilting directions can be obtained when the boat is moved by the waves.

FIG. 3 shows a wave motor which resembles the wave motor shown in FIG. 2, but where hydraulic cylinder assemblies 10, 11 are substituted for the springs 8, 9. Each head end of the hydraulic cylinder assemblies 10, 11, which ends are closed apart from an opening formed in each of these communicating with a conduit 12 resp. 13, are connected to respective arms 14, 15 corresponding to the above-mentioned arms 6, 7. Each cylinder assembly 10, 11 is provided with a piston connected to one end of a piston rod 16, 17, the other end of which is connected to the supporting structure 18.

Each cylinder assembly 10, 11 is through the conduit 12, 13 and a valve 19, 20 connected to an conventional hydraulic accumulator 21, 22, which is provided with a diaphragm dividing the inner space in two rooms. The cylinder assembly 10, 11, the conduits 12, 13 and the accumulator room which is connected thereto are filled with hydraulic fluid, e.g. oil. The other room of the accumulator is filled with a pressurized gas and through a conduit 23, 24 and a valve 25, 26 connected to a gas container 27, 28.

The conduits 12, 13 connecting the cylinder assemblies 10, 11 and the accumulators 21, 22 are branched and connected to the outlet of a pump device 31, the inlet of which is connected to a tank 32 containing hydraulic fluid, through a conduit 29.

The pump device 31 is adapted to supply pressure fluid to either of the conduits 12, 13.

The function of the wave motors is explained below, referring firstly to the device shown in FIG. 1.

When the boat 1 is moved from a wave through to a wave crest the tilting element 3 will bend due to its flexibility and its trailing edge will move downwards in relation to its point of fixation at the supporting structure 2. This causes the water directly above the tilting element 3 to be pressed rearwards, which in turn causes application of a forwards directed reaction force to the boat 1.

When the boat 1 reaches the wave crest and its upwards directed movement is stopped, the tilting element 3, however, will not remain in a deflected position, but swing upwards towards its neutral position due to its elasticity, and provide a gradually reduced reaction force until this position is reached.

When the boat subsequently is moved towards a new wave trough, the tilting element will immediately bend and its trailing edge move upwards in relation to said point of fixation, and thereby at once provide application of a forwards directed reaction force to the boat.

The wave motor shown in FIG. 2 differs from the wave motor shown in FIG. 1 in that the tilting element 4 is rigid and upon tilting from its neutral position is brought back to this position by means of the springs 8, 9. In order to prevent that the tilting element offers too much resistance against upwards directed movement and that the boat shall be pulled under the water, the spring characteristics may be adapted accordingly.

During operation of the wave motor shown in FIG. 3 in a way similar to the way explained in connection with FIGS. 1 and 2, the valves 19, 20 are open, while the valves 25, 26 are closed and the pump device 31 is not running. Upon application of a force to the tilting element 30, which force causes anticlockwise movement of the tilting element from its neutral position, oil will be pressed out from the cylinder assembly 10 and into the hydraulic accumulator 21 through the conduit 12, due to movement of the piston of this cylinder assembly into the cylinder, thereby gradually compressing the gas in this accumulator and progressively increasing its pressure.

Simultaneously, oil will be drawn out of the other accumulator 22 through the conduit 13 to the cylinder assembly 11, whereby the gas pressure in this accumulator 22 decreases until moment balance is obtained around the tilting axis of the tilting element 30. When the force is no longer applied to the tilting element, this element is brought back into its neutral position due to the moment unbalance about its tilting axis.

By opening one or both of the valves 25, 26 in the conduits 23, 24 interconnecting the accumulators 21, 22 and the gas containers 27, 28, the available gas colume may be increased, thereby changing the spring characteristic of the system.

By closing the valves 19, 20 the tilting element 30 can be locked in any desired position, and by means of the pump device 31 the tilting element 30 can be moved and then locked, for instance for retarding the boat by means of wave action. By means of the hydraulic pump device 31 the tilting element can also be continuously moved from one extreme position to the other, the tilting element then acting as a mechanically/hydraulically driven propulsion device. A driving means for pump 31 is illustrated schematically by motor 34 operating through shaft 33 to drive pump 31.

What I claim is:

1. A wave motor for propulsion of a water-bourne vessel influenced by wave action, comprising:

a. a support structure rigidly connected to the vessel and extending downwards therefrom to have a lower end thereof located at a distance beneath the hull of the vessel at a level at which the water is relatively calm in relation to water movements at the water surface because of wave action;

b. propulsion means comprising an essentially horizontally disposed, platelike tilting element which, at a forward portion thereof as viewed in the cruising direction, is rotatably connected about a horizontal axis to said lower end of said supporting structure, and is adapted to effect a tilting movement as a result of relative movement between said element and the surrounding water when said vessel is rising and lowering due to wave action at the water surface; and

c. means causing said tilting element to be held in a substantially horizontal neutral position when no relative movement exists between the element and the surrounding water, said means comprising a force-exerting device connected between said supporting structure and said tilting element and exerting opposed, resilient returning forces on said tilting element upon angular displacement thereof, to bring it back to said neutral position.

2. A wave motor according to claim 1, wherein said force-exerting device comprises hydraulic cylinder/piston assemblies whose cylinders are connected through respective conduits to associated hydraulic/pneumatic accumulators.

3. A wave motor according to claim 2, wherein a valve is inserted in each of said conduits for closing the connection between said cylinder assemblies and said accumulators.

4. A wave motor according to claim 3, wherein said cylinder/piston assemblies are connected to a supply of pressurized hydraulic fluid.

5. A wave motor according to claim 1, wherein said returning forces acting in both tilting directions are approximately equal for the same tilting angle.

6. A wave motor according to claim 1, wherein said returning forces acting in both tilting directions are unequal for the same tilting angle.

7. A wave motor according to claim 1, wherein said force-exerting device comprises mechanical spring means.

* * * * *

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(19) **United States**

(12) **Patent Application Publication**

Hine et al.

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(43) **Pub. Date: Mar. 7, 2013**

(54) **WATERCRAFT THAT HARVEST BOTH LOCOMOTIVE THRUST AND ELECTRICAL POWER FROM WAVE MOTION**

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(73) Assignee: **Liquid Robotics, Inc.**, Sunnyvale, CA (US)

(21) Appl. No.: **13/536,935**

(22) Filed: **Jun. 28, 2012**

Related U.S. Application Data

(60) Provisional application No. 61/502,279, filed on Jun. 28, 2011, provisional application No. 61/535,116, filed on Sep. 15, 2011, provisional application No. 61/585,229, filed on Jan. 10, 2012.

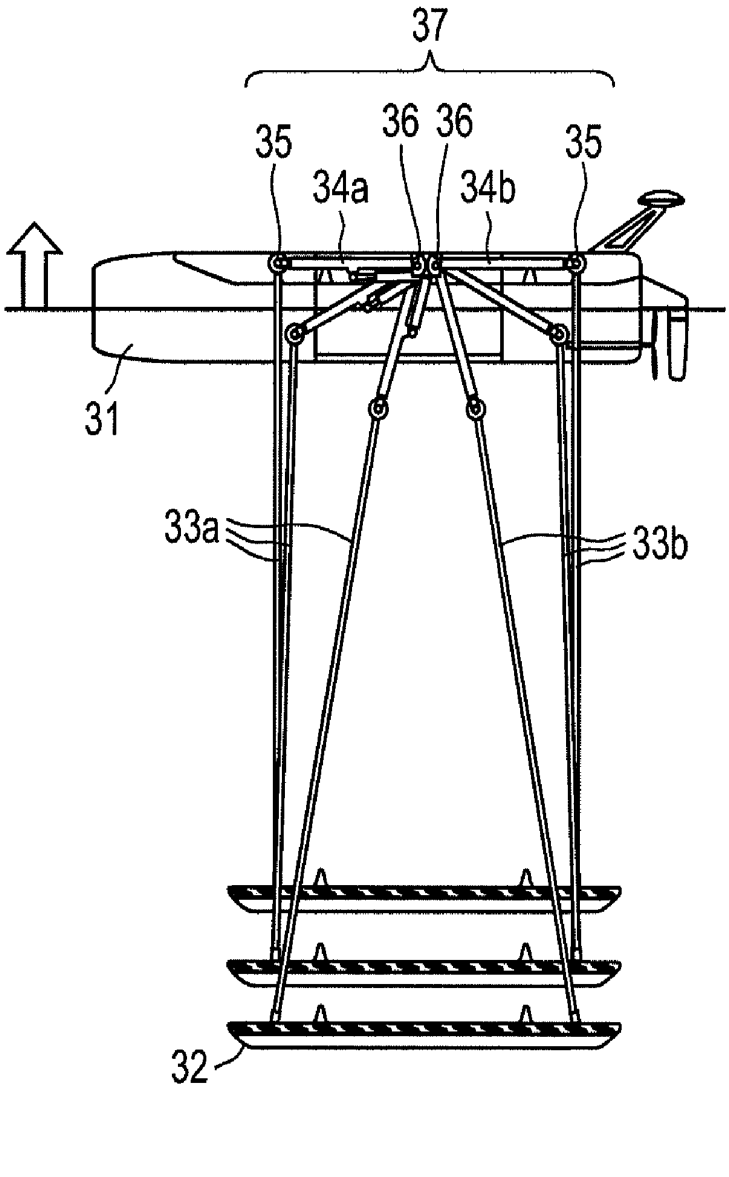
Publication Classification

(51) **Int. Cl.**
B63H 19/02 (2006.01)
G05D 1/12 (2006.01)

(52) **U.S. Cl.** **440/6**; 440/9; 440/10; 114/242; 701/23

(57) **ABSTRACT**

This disclosure provides improved nautical craft that can travel and navigate on their own. A hybrid vessel is described that converts wave motion to locomotive thrust by mechanical means, and also converts wave motion to electrical power for storage in a battery. The electrical power can then be tapped to provide locomotive power during periods where wave motion is inadequate and during deployment. The electrical power can also be tapped to even out the undulating thrust that is created when locomotion of the vessel is powered by wave motion alone.



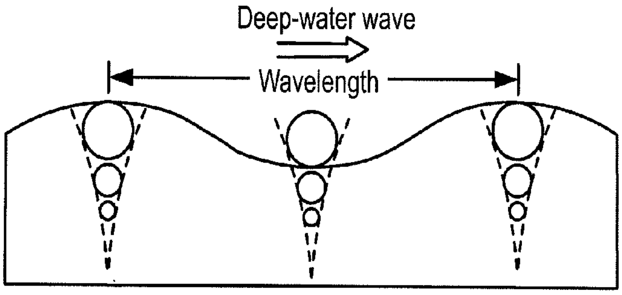


FIG. 1A (Prior Art)

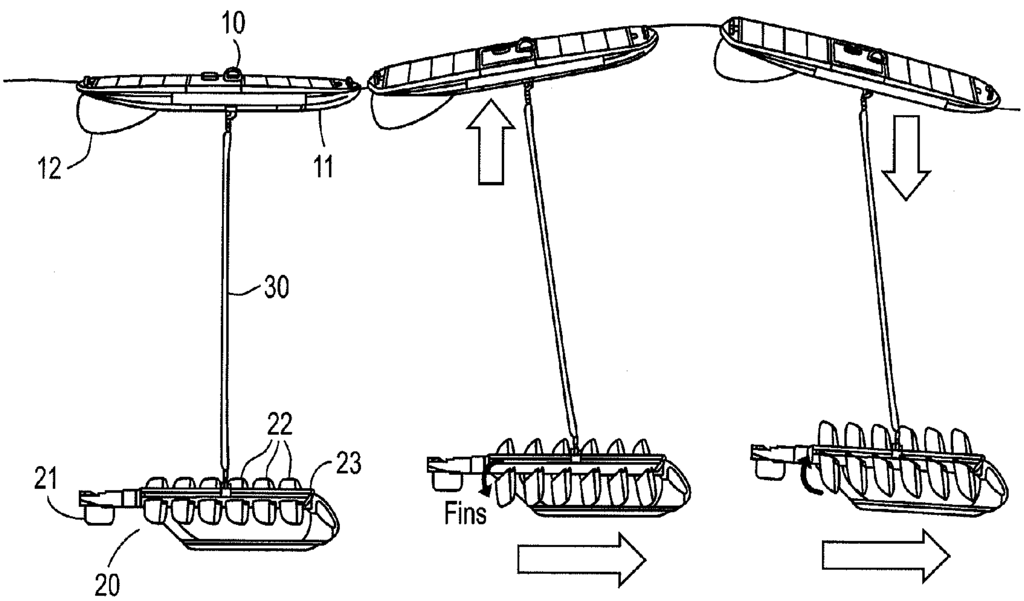


FIG. 1B (Prior Art)

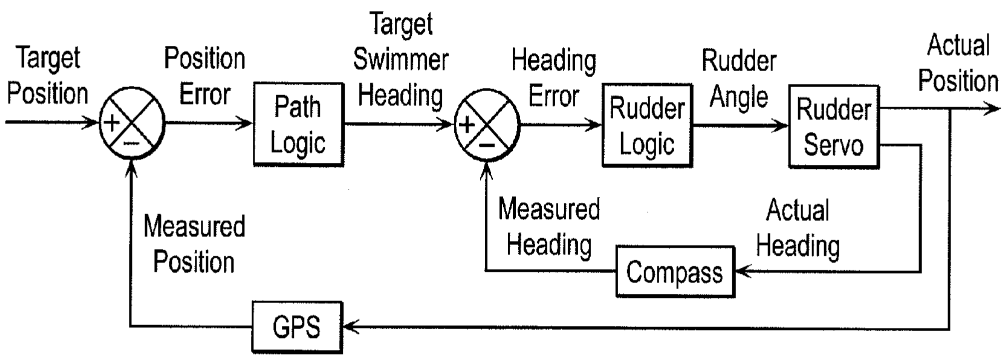
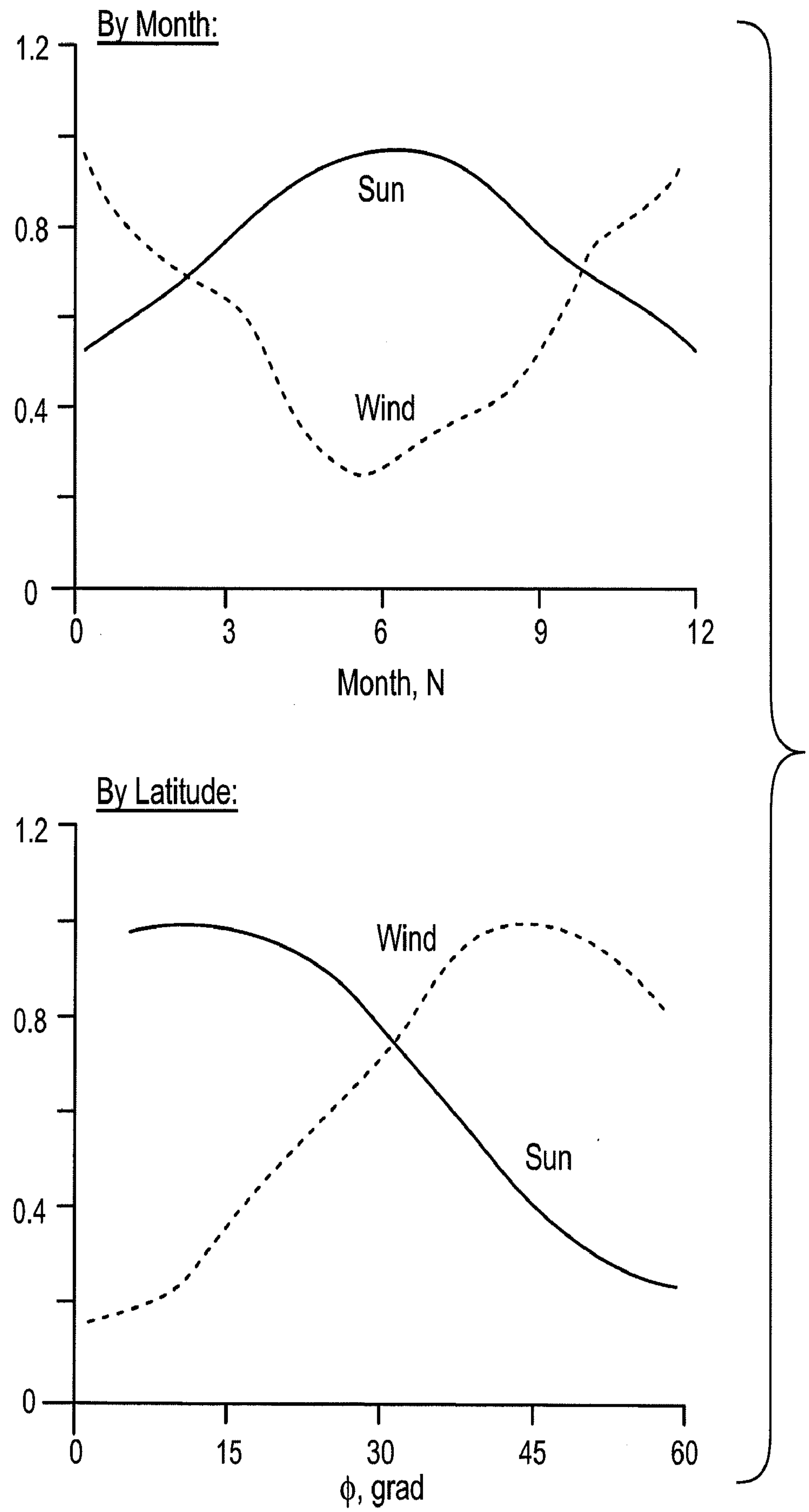


FIG. 2 (Prior Art)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ϕ, grad

FIG. 3

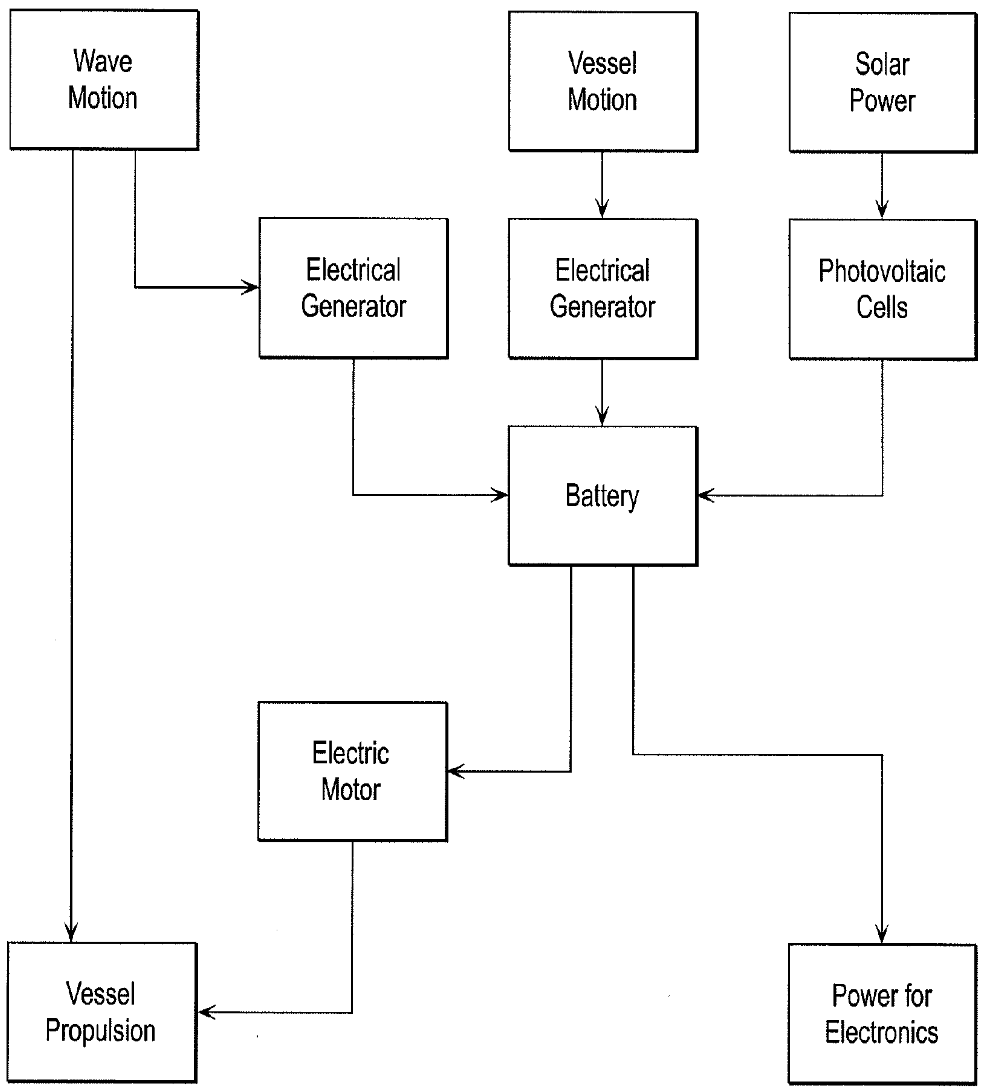
Wave Motion
Vessel Motion
Solar Power
Electrical Generator
Electrical Generator
Photovoltaic Cells
Battery
Electric Motor
Vessel Propulsion
Power for Electronics

FIG. 4

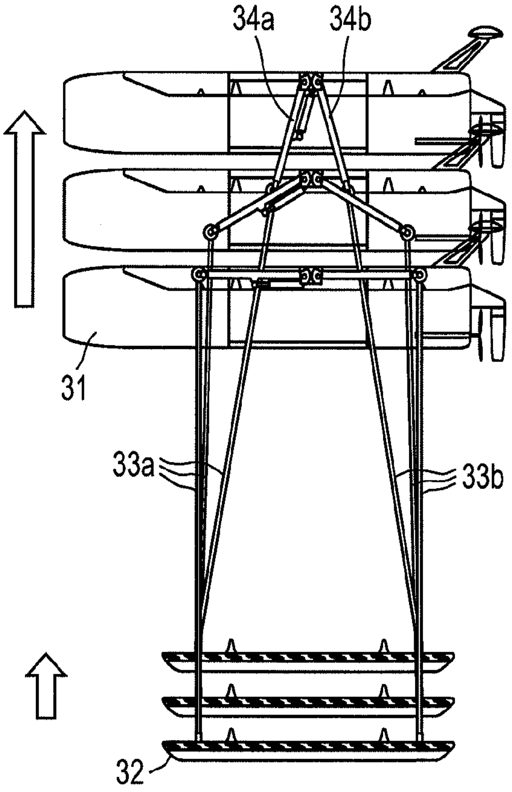

FIG. 5A

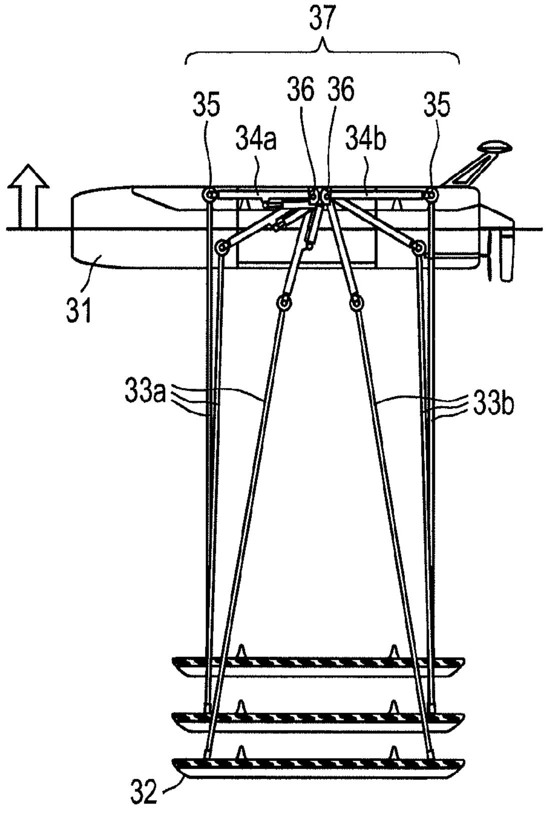

FIG. 5B

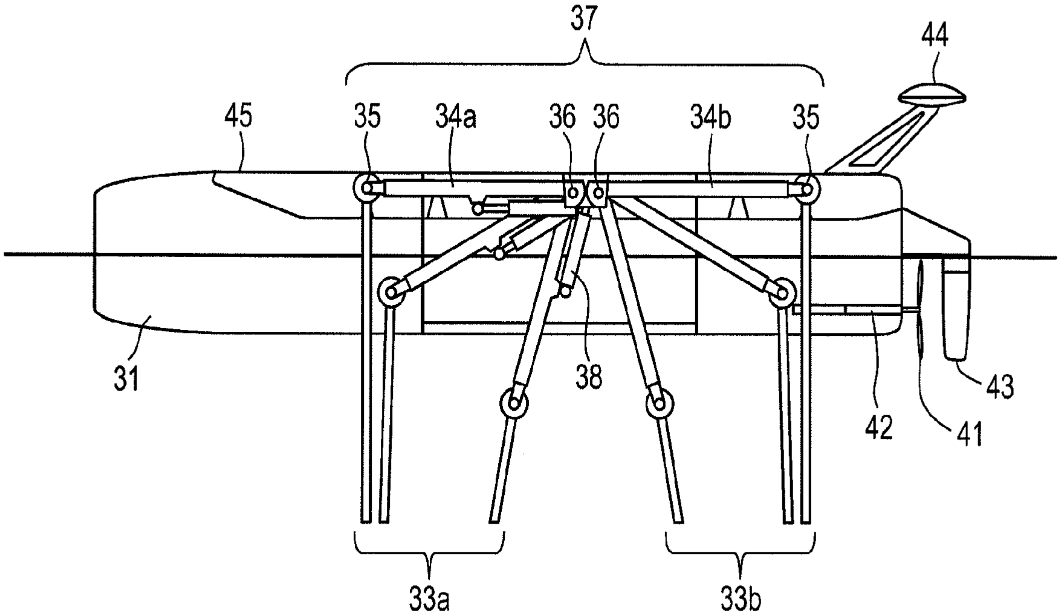
37
44
45
35
34a
36
36
34b
35
31
38
42
43
41
33a
33b

FIG. 6A

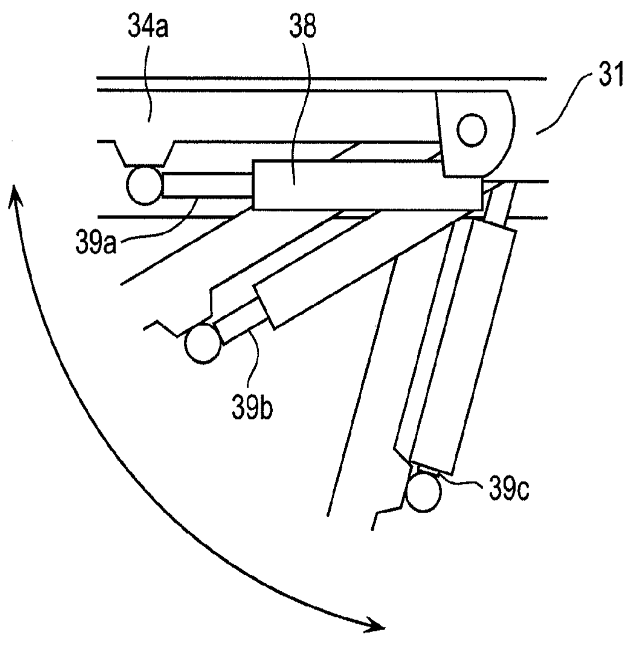
34a
38
31
39a
39b
39c

FIG. 6B

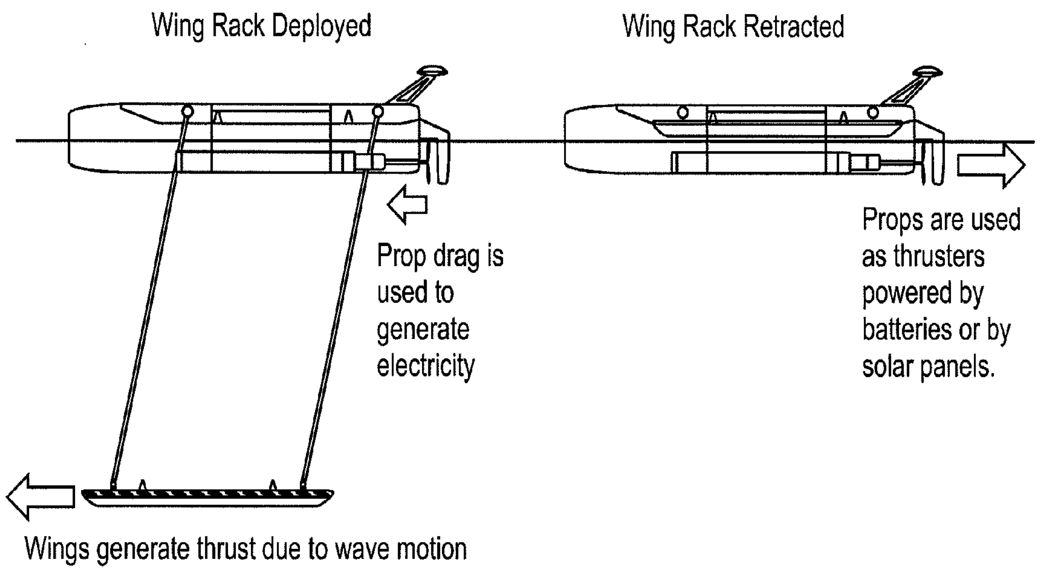
Wing Rack Deployed
Wing Rack Retracted
Prop drag is used to generate electricity
Props are used as thrusters powered by batteries or by solar panels.
Wings generate thrust due to wave motion

FIG. 7

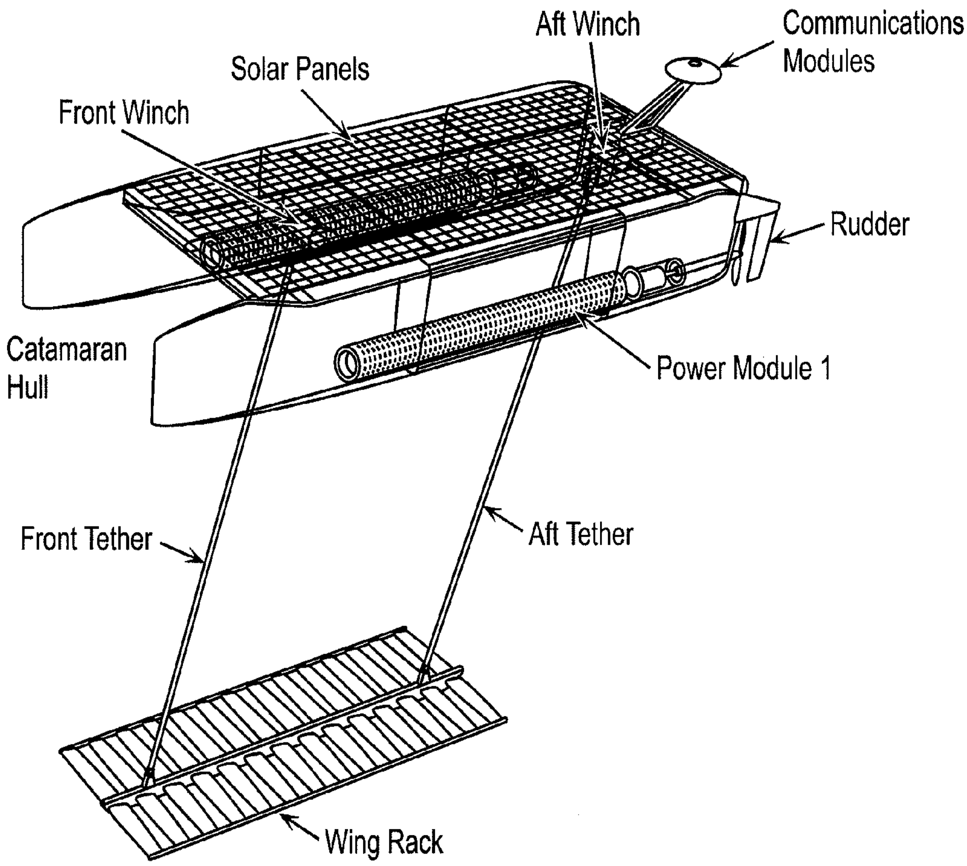
Aft Winch
Communications Modules
Solar Panels
Front Winch
Rudder
Catamaran Hull
Power Module 1
Front Tether
Aft Tether
Wing Rack

FIG. 8A

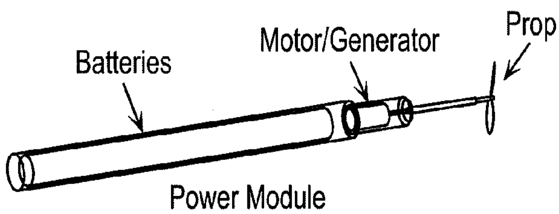
Prop
Motor/Generator
Batteries
Power Module

FIG. 8B

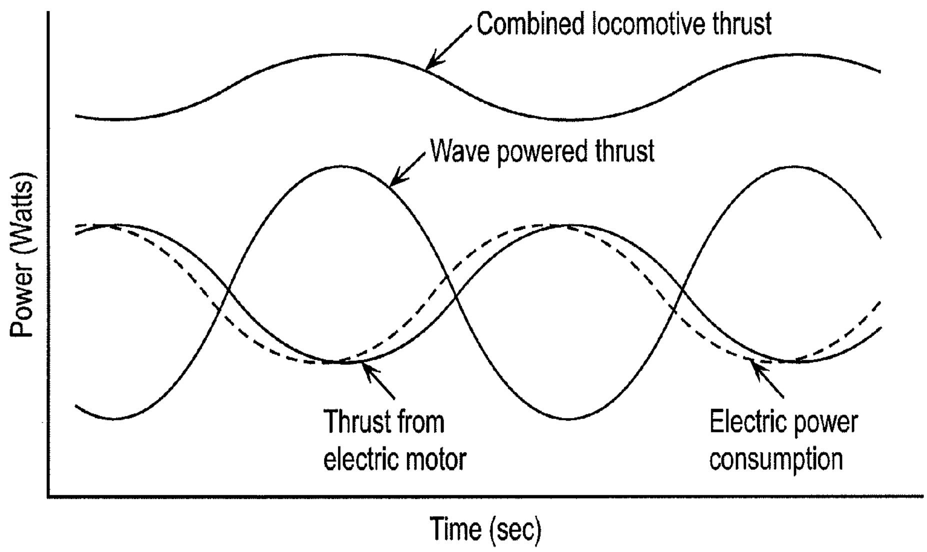
Combined locomotive thrust
Wave powered thrust
Power (Watts)
Thrust from electric motor
Electric power consumption
Time (sec)

FIG. 9

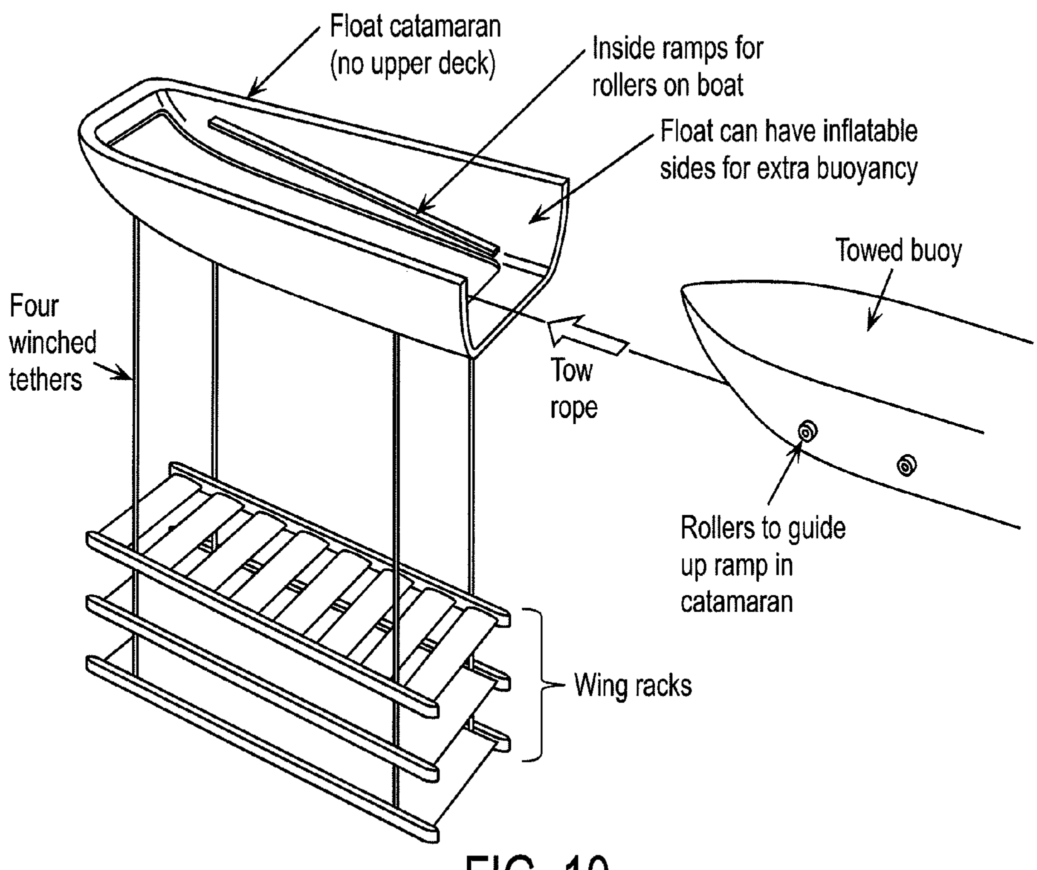
Float catamaran (no upper deck)
Inside ramps for rollers on boat
Float can have inflatable sides for extra buoyancy
Towed buoy
Four winched tethers
Tow rope
Rollers to guide up ramp in catamaran
Wing racks

FIG. 10

WATERCRAFT THAT HARVEST BOTH LOCOMOTIVE THRUST AND ELECTRICAL POWER FROM WAVE MOTION

RELATED APPLICATIONS

[0001] This application claims the priority benefit under 35 U.S.C. §119(e) of the following U.S. provisional patent applications:

[0002] U.S. Provisional Patent Application No. 61/502,279: "Energy-harvesting water vehicle," filed Jun. 28, 2011;

[0003] U.S. Provisional Patent Application No. 61/535,116: "Wave-powered vehicles," filed Sep. 15, 2011; and

[0004] U.S. Provisional Patent Application No. 61/585,229: "Retractable nesting wing racks for wave-powered vehicle," filed Jan. 10, 2012.

[0005] This application also claims the priority benefit of the following patent applications, all filed Mar. 19, 2012 and co-owned with this application by Liquid Robotics, Inc., Sunnyvale, Calif., U.S.A.:

[0006] International Patent Application No. PCT/US2012/029718 and U.S. patent application Ser. No. 13/424,239, both entitled "Autonomous wave-powered substance distribution vessels"

[0007] International Patent Application No. PCT/US2012/029696 and U.S. patent application Ser. No. 13/424,170, both entitled "Wave-powered vessels configured for nesting"; and

[0008] International Patent Application No. PCT/US2012/029703 and U.S. patent application Ser. No. 13/424,156, both entitled "Wave-powered device with one or more tethers."

[0009] The aforelisted priority applications, along with U.S. Pat. No. 7,371,136; U.S. Pat. No. 8,043,133; and published applications US 2008/188150 A1; US 2008/299843 A1; and WO/2008/109022 are hereby incorporated herein by reference in their entirety for all purposes.

FIELD OF THE INVENTION

[0010] The information disclosed and claimed below relates generally to the fields of vessel motility and power generation. More specifically, it provides watercraft configured for autonomous operation, harvesting both locomotive thrust and electrical power from wave motion.

BACKGROUND OF THE INVENTION

[0011] Wave-powered vessels have been described in U.S. Pat. No. 7,371,136; U.S. Pat. No. 8,043,133; and published applications US 2008/188150 A1; US 2008/299843 A1; and WO/2008/109022. Exemplary vessels are manufactured and sold by Liquid Robotics, Inc., Sunnyvale, Calif., USA under the brand Wave Glider®.

[0012] A previously unrelated field of development covers large stationary systems near shore that use wave motion to generate electrical power for communities on land. U.S. Pat. No. 4,134,023 discusses an apparatus for extracting energy from waves on water. U.S. Pat. No. 6,194,815 provides a piezoelectric rotary electrical energy generator. Published application US 2004/0217597 A1 discusses wave energy converters that use pressure differences. U.S. Pat. No. 3,928,967 is the so-called "Salter's Duck" patent, an apparatus and method of extracting wave energy. The status and perspectives of wave energy technology is generally reviewed by Clément et al. in *Renewable and Sustainable Energy Reviews* 6 (5): 405-431, 2002.

SUMMARY OF THE INVENTION

[0013] This disclosure provides improved technology for manufacturing and deploying nautical craft that can travel and navigate on their own. A hybrid vessel is described that converts wave motion to locomotive thrust by mechanical means, and also converts wave motion to electrical power for storage in a battery. The electrical power can then be tapped to provide locomotive power during periods where wave motion is inadequate and during deployment. The electrical power can also be tapped to even out the undulating thrust that is created when locomotion of the vessel is powered by wave motion alone.

[0014] One aspect of the invention is a wave-powered vessel that has a buoyant vessel body, a mechanical means for converting movement of the vessel body caused by wave motion to horizontal thrust; and an electrical generator for converting movement of the vessel body caused by wave motion to electrical power. Converting wave motion to horizontal thrust may be done in a configuration where an underwater component or swimmer is attached below the vessel body by one or more tethers. In this configuration, the swimmer is weighted to travel in water below the vessel body, and is configured to pull the vessel body by way of the tether. The swimmer has fin surfaces that mechanically provide forward thrust when actuated by rising and falling of the swimmer in the water.

[0015] The on-board electrical generator may comprise a means for converting vertical movement of the vessel body caused by wave motion to electrical power, a means for converting horizontal movement of the vessel body through water to electrical power, or both. Shown in the figures is a wave-powered vessel where the electrical generator comprises a piston powered by a swing arm that moves from a horizontal to a vertical position in accordance with the vertical movement of the vessel body. The swing arm is mechanically connected to a swimmer weighted to travel in water below the vessel body. Optionally, the swimmer may be adapted so that motion of the fin surfaces may be dampened to increase electrical power generated by the electrical generator.

[0016] Another type of electrical generator comprises a rotatory fin or turbine powered by horizontal movement of the vessel body through the water. In this case, the rotatory fin or turbine is adapted to generate electrical power when rotated in one direction, and to act as a motor providing horizontal thrust to the vessel through the water when rotated in the opposite direction. Further types of electrical generators for harnessing swave powers are detailed later in this disclosure.

[0017] Wave-powered vessels according to this invention typically have an electrically powered motor to provide horizontal thrust that powers the vessel through the water. There is also a battery configured to store electrical power generated by the electrical generator and to feed electrical power to the motor to provide propulsion. Optionally, the vessel may have one or more solar panels that also supply electrical power to the battery.

[0018] The battery may be used to power an inboard or outboard electrical motor at any time there is reserve electrical power and it is desirable to increase the sped of the vessel. For example, the battery can power the motor during periods where the motion in each full wave cycle is inadequate to provide sufficient horizontal thrust to the vessel.

[0019] Another aspect of the invention is a wave-powered vessel with locomotive thrust powered alternately by wave motion and by electrical power so as to buffer the trust powered by the wave motion. The electrical power is supplied by a battery, which in turn is charged up by a system that converts wave motion to electrical power, as already outlined.

[0020] Another aspect of this invention is a wave-powered vessel configured for deployment from shore. The vessel is kept in compact form, and launched by way of the electric motor to deeper water, whereupon the other components of the vessel are deployed outward and downward. A vessel of this nature typically has a buoyant vessel body, a swimmer configured to retract and be secured against the vessel body, one or more tethers connecting the float to the swimmer, an electrically powered motor configured to propel the vessel through the water; and a battery supplying power to the motor, having sufficient capacity to power the vessel from shore to a location where the swimmer can be deployed. Again, the swimmer is weighted to travel in the water below the vessel body, and is configured with fins to pull the vessel by way of the tether when actuated by vertical movement.

[0021] Such a vessel may also have a releasable tow buoy. The vessel body and the tow buoy are configured so that the tow buoy may be releasably housed within the vessel body while on shore, and pulled behind the vessel body after the vessel is deployed.

[0022] The vessels of this invention are ideal for use in autonomous operation (without a human attendant on board). The vessel has electronics configured to sense the geographical location of the vessel. There is also a microprocessor programmed to determine the vessels current location, and steer the vessel from its current location towards a target location.

[0023] Further aspects of the invention will be evident from the description that follows.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] FIG. **1**A shows how water moves in roughly circular orbits in waves;

[0025] FIG. **1**B is a side view of a wave-powered vehicle showing the overall operation;

[0026] FIG. **2** shows an example of an algorithm for directing a vessel towards or maintaining it at a target position (a geographical location);

[0027] FIG. **3** shows the availability of solar power as a function of the annual cycle;

[0028] FIG. **4** is a block diagram summarizing how the interaction of power sources can occur;

[0029] FIG. **5**A, FIG. **5**B, FIG. **6**A, and FIG. **6**B are side views of a vessel that illustrates how wave motion can be converted to electrical power;

[0030] FIG. **7**, FIG. **8**A, and FIG. **8**B show an example of a vessel that uses wave motion to generate both locomotive thrust and electrical power from vessel motion;

[0031] FIG. **9** is a graph of hypothetical data that illustrates how stored electrical power in the battery can be used to power the electric motor and provide propulsion whenever desired; and

[0032] FIG. **10** is a perspective view showing how a vessel body and a tow buoy may be configured so that the tow buoy may be releasably housed within the vessel body while on shore, and pulled behind the vessel body after the vessel is deployed.

DETAILED DESCRIPTION

[0033] This invention provides watercraft that derive both locomotive thrust and electrical energy by wave motion. Detailed illustrations of the invention include a vessel that harvests the power of vertical movement using tethers attached to a spring-loaded suspension device. Wave energy is converted to potential energy in the springs, which is then used to drive an electricity generator. In another example, the vessel has a propeller that can be driven backwards as a generator when in motion so as produce electrical power. Electrical energy obtained by either of these means may be used to power electronics or stored in a battery for later use. The stored energy can be used to provide propulsion on calm days when wave action does not in itself provide enough power for the vessel to travel at the desired speed.

Converting Vertical Wave Power to Locomotive Thrust

[0034] One feature of the watercraft of this invention is the ability to use wave motion to drive the vessel from place to place across a body of water.

[0035] Wave motion can be approximated for many purposes as a linear superposition of roughly sinusoidal waves of varying wavelength, period and direction. As a wave moves horizontally along the surface, the water itself moves in roughly circular orbits of logarithmically decreasing diameter with depth. This is shown in FIG. **1**A. The orbit at the surface has a diameter equal to the height of the wave. The orbital diameter at depth is a function of wave length:

$$H_y=H_s e^{-2\pi y/L}$$

where L is the wave length, H_s is the surface wave height and H_y is the orbital diameter at depth y below the surface.

[0036] Vessels can be configured to exploit the difference in motion between H_s and H_y, for example, in the following way. A vessel body is positioned at or near the surface, and a submerged swimmer or glider component is positioned at depth y, and connected to the vessel body by one or more tethers. As waves lift and lower the float portion, wings or fins on the submerged portion passively rotate so as to convert the relative motion of the surrounding water into forward thrust. The azimuth of the thrust vector can be directed completely independently of the direction of the waves by a rudder at the back of the glider. The vessel has multiple wings each with a short chord dimension. This minimizes lost motion between the up stroke and the down stroke and enables successful conversion of even very small waves into forward thrust.

[0037] FIG. **1**B is a side view of a wave-powered vehicle that illustrates this principle. The vehicle comprises a float or vessel body **10** resting on the water surface, and a swimmer **20** hanging below, suspended by one or more tethers **30**. The float **10** comprises a displacement hull **11** and a fixed keel fin **12**. The swimmer comprises a rudder **21** for steering and wings or fins **22** connected to a central beam of the rack **23** so as to permit rotation of the wings around a transverse axis within a constrained range, and provide propulsion.

[0038] In still water (shown in the leftmost panel), the submerged swimmer **20** hangs level by way of the tether **30** directly below the float **10**. As a wave lifts the float **10** (middle panel), an upwards force is generated on the tether **30**, pulling the swimmer **20** upwards through the water. This causers the wings **22** of the swimmer to rotate about a transverse axis were the wings are connected to the rack **23**, and assume a downwards sloping position. As the water is forced downward through the swimmer, the downwards sloping wings generate forward thrust, and the swimmer pulls the float forward. After the wave crests (rightmost panel), the float descends into a trough. The swimmer also sinks, since it is heavier than water, keeping tension on the tether. The wings rotate about the transverse axis the other way, assuming an upwards sloping position. As the water is forced upwards through the swimmer, the upwards sloping wings generate forward thrust, and the swimmer again pulls the float forwards.

[0039] Thus, the swimmer generates thrust when both ascending and descending, resulting in forward motion of the entire craft.

Autonomous Navigation

[0040] A wave-powered vessel may be configured to navigate across a body of water autonomously (without human attendance), and to perform its own power management.

[0041] Self-directed navigation is possible when the vessel is equipped with a means of determining the geographical location of the vessel, a means for determining direction, a means for steering the vessel, and a means for operating the steering so that the vessel travels or stays at a target location. The steering means is typically a rudder that turns sideways against the water so as to cause the vessel to spin towards a new heading. Alternatively or in addition, it may be a mechanical arrangement that presses upwards and downwards on opposite sides of the vessel in the manner of an aileron, thereby causing the vessel to roll sideways and attain a new heading. Where the vessel comprises a float and a swimmer connected by a single tether, it is usual to put the steering means on the swimmer providing the locomotive power. In configurations having two or more tethers, a rudder may be placed on the float, the swimmer, or on the float and the swimmer together.

[0042] Electronics to sense the geographical location of a vessel can triangulate off a series of reference points. Particularly effective is the global positioning system (GPS), or a similar network of positional transmitting sources. The vessel will also usually have an electronic compass or gyroscope to determine the vessel heading. Positional data about the geographical location and the vessel heading is processed in a decision algorithm or programmed microprocessor, which may then provide navigation instructions. Consequently, the steering means adjusts to head the vessel in accordance with the instructions.

[0043] FIG. **2** shows an example of an algorithm for directing a vessel towards or maintaining it at a target position (a geographical location). Once the target position is inputted, it is compared with the current location of the vessel inputted from a GPS receiver. The processor calculates the proper heading, and compares it with the heading inputted from the compass. The processor then outputs instructions to the rudder servo to adjust the vessel onto the correct heading. For vessels that are capable of regulating transit speed or locomotive force, the processor may also output instructions to adjust the speed (not shown). Measurement and correction by comparison with GPS and compass data is performed iteratively as the journey continues.

[0044] Electrical power is typically needed for the electronics used for self-navigation. This can be supplied by photovoltaic cells located on the deck of the vessel. For low wind resistance, for low visibility, and to reduce the sensitivity to the direction of the sun, it is best if this surface is horizontal. For example, the top deck can be installed with SunPower™ E20 panels each containing 96 Maxeon™ cells. Under standard conditions (irradiance of 1000 Watts/m^2, AM 1.5, and cell temperature of 25° C.) six panels produce a total of 1962 Watts.

Converting Wave Movement to Electrical Power

[0045] This invention advances the field of wave-powered watercraft by providing two sources of locomotive power. One is a highly efficient mechanical conversion of wave motion directly to locomotive thrust, as described earlier in this disclosure. The second is conversion of wave motion to electrical power, which can be stored and used at a later time. Having the two systems on board provides a number of advantages.

[0046] FIG. **3** shows the availability of solar power as a function of the annual cycle, and as a function of time (adapted from M D Ageev, *Advanced Robotics* 16(1):43-55, 2002). Depending on the size and efficiency of the photovoltaic cells, there may be periods when solar power is inadequate to power the electronics on board. A battery system can be used to buffer and sustain the electronics through diurnal variation, but if the vessel spends long periods in the far north, for example, solar power may be inadequate. On the other hand, using wave motion for locomotive thrust may be insufficiently reliable at or near the equator or in summer months.

[0047] The makers of this invention have discovered that when wave motion is high, enough power can be harvested not only to propel the vessel through the water, but also to provide ample electrical power. In fact, enough electrical power can be harvested from the waves not only to power the electronics, but also to create an energy supply that can later be used for locomotion. An electrical generator can be driven by vertical and/or horizontal movement of the vessel caused by the waves. The vessel is configured so that the vertical undulations of the vessel are mechanically coupled to a means of providing horizontal locomotive power to the vessel (such as a fin or wing rack), and are also mechanically coupled to a generator of electrical power.

[0048] In vessels equipped in this way, other sources of electrical power (like photovoltaic cells for solar power) are entirely optional—the wave motion mechanically provides power to drive the vessel through the water, and also provides electricity to run electronics and microprocessors aboard.

[0049] When electrical power generated from wave motion and/or from solar panels is in excess of immediate needs, it can be stored in an on-board rechargeable battery. The stored electrical power can be used at a later time to power on-board electronics and microprocessors. It can also be used to power an electrically driven propulsion system, such as an electric motor coupled to a propeller or turbine. Thus, on calm days when there is insufficient wave motion to drive the vessel at the desired speed, the battery (optionally in combination with photovoltaic cells) can power the propulsion system. Conversely, the wave generated electrical power can be stored for use during periods that are too dark to rely entirely on solar power—for example, at night—and/or to supplement locomotive thrust.

[0050] FIG. **4** is a block diagram summarizing how the interaction of power sources can occur. Sources of power are indicated on the top line; results at the bottom. Wave motion can provide locomotive thrust by mechanical interconnection, such as in a two-part vessel where a floating portion is tethered to a submarine portion. Wave motion can also power a generator adapted for implementation on a vessel, which generates electricity delivered to a rechargeable battery. Vessel motion through the water (a result of propulsion mechanically generated from the wave action) can power an electrical generator of its own, which also feeds the battery. Solar panels (if present) also provide electrical power to a battery. Although they may be separate, typically the battery for any two or three of these power sources are shared by the sources that are present.

[0051] Electrical power from the battery supplies on-board electronics, such as navigation equipment, a microprocessor that manages power allocation, and sensors or detectors of various kinds. Electrical power can also be tapped at any time it's available to provide vessel proportion: either to supplement thrust obtained from the wave motion mechanically, or to substitute for mechanical thrust at times when wave motion is insufficient. As explained below, the electric motor may be the same apparatus as the electrical generator powered by vessel motion, run in reverse to provide vessel propulsion.

[0052] FIG. **5**A, FIG. **5**B, FIG. **6**A, and FIG. **6**B are side views of a vessel that illustrates how wave motion can be converted to electrical power. The vessel has been equipped to harvest wave motion for both locomotive and electrical power. There are two tethers **33***a* and **33***b* connecting the vessel body **31** to the swimmer **32**, fastened to opposite arms **34***a* and **34***b* of a suspension device **37** by way of rotating hinges **35**. The arms of the suspension are spring loaded to return to a neutral horizontal configuration in opposite directions along an axis parallel to the vessel's length, pivoting around a central suspension point **36**.

[0053] Also shown on the vessel body **31** are a propeller **41** powered by an electric motor **42**, a rudder **43**, and an assembly **44** for receiving and transmitting data and operating instructions that is mounted on the top deck **45**. The configuration can be adapted with more tethers attached to more link arms that fold forwards and/or backwards, and are mounted on the vessel body **31** beside, in front, or behind the suspension device **37** shown here.

[0054] FIG. **5**A superimposes three images showing what happens when the vessel body **31** is lifted by a wave. At the starting position, the suspension device **37** is configured in the neutral position with arms **34***a* and **34***b* horizontally positioned in opposite directions. As the wave lifts the vessel body **31**, it pulls the swimmer **32** upwards. However, the density of water slows the upward movement of the swimmer **32**, thereby pulling the arms **34***a* and **34***b* of the suspension device **37** downwards. This loads the spring on each arm with potential energy.

[0055] FIG. **5**B superimposes three images showing what happens as the vessel approaches the crest of the wave. The upwards motion of the vessel body **31** slows, but the swimmer **32** still travels upwards due to the tension in the arms when they were being pulled downward. As the swimmer **32** continues upwards to a point where the arms **34***a* and **34***b* resume the neutral horizontal position, the potential energy in the suspension device **37** is released, and can be captured by a generator means that converts the potential energy in the spring into electrical power.

[0056] FIG. **6**A superimposes three images of the configuration of the suspension device **37** as the potential energy is released. In this example, the two tether winches **33***a* and **33***b* pivotally mounted **35** to the ends of link-arms **34***a* and **34***b* drive a piston: specifically, a linear hydraulic cylinder **38**, which in turn creates pressure to drive a hydraulic turbine generator (not shown). For simplicity the hydraulic cylinder **38** is shown here attached to only one of the link arms **34***a*, although more typically there is another hydraulic cylinder attached to the other link arm **34***b*. The link arms **34***a* and **34***b* could package nicely in the center span structure without protruding above the deck **45** of the vessel body **31**. Optionally, the link arms **44***a* and **44***b* can be configured to lock in the neutral horizontal position during times where all of the wave energy is needed for thrust, or when electric generation is not necessary.

[0057] FIG. **6**B provides a detail of the action of the hydraulic cylinder **38** during a cycle of movement of the link arm **34***a* from the neutral horizontal position to the vertical tending spring loaded position as the swimmer is pulled upwards by the vessel body **31** as the wave peaks. When the link arms are in the neutral position, the hydraulic cylinder is extended **39***a*, and is pushed together **39***b* into a compressed position **39***c* as the link arm **34***a* descends towards the vertical. When the link arm **34***a* returns to the horizontal position as the wave troughs, the hydraulic cylinder returns to the extended position **39***a*, completing the cycle.

[0058] The arrangement shown in these figures may be adjusted to the user's liking to fit a particular installation. The swing arm system shown in FIG. **5**A, FIG. **5**B, FIG. **6**A, and FIG. **6**B may be placed on the swimmer rather than on the float. The link arms are pivotally mounted at the proximal end towards the upper surface of the swimmer, and are spring loaded to assume a horizontal neutral position. The tether is attached to the distal end of the arm, and connects to the float above. Wave motion again stretches the distance between the float and the tether, but in this case the link arms are pulled into an upwards orientation, creating potential energy in the spring that can be converted to electrical power.

[0059] Whether mounted on the float or the swimmer, the electrical power generation system may harvest the up and down motion of the link arms by a suitable arrangement that ultimately results in a mechanical force turning conductive wire or bar within a magnetic field, or turning a magnet through a conductor. Included are mechanical arrangements that result directly in rotatory motion (such as a rotating axle), or a back-and-forth action (such as a liquid or gas filled piston) that can be converted mechanically into rotatory motion.

[0060] The electrical power generation system shown in FIG. **5**A, FIG. **5**B, FIG. **6**A, and FIG. **6**B are provided by way of an example of how such a system may be implemented with high conversion efficiency. The example is not meant to limit practice of the claimed invention except where explicitly indicated. Other systems for harnessing electricity from wave power on a moving vessel may be adapted from stationary on-shore technology now deployed or under development.

[0061] Electrical power generating systems may be configured to harness vertical oscillation of the water surface in a wave cycle, or horizontal movement of the wave peaks, or a combination of the two. By way of illustration, a system that harvests electrical power from vertical movement can comprise a tube that floats vertically in the water and tethered to the vessel. The tube's up-and-down bobbing motion is used to pressurize water stored in the tube below the surface. Once the pressure reaches a certain level, the water is released, spinning a turbine and generating electricity. In another illustration, an oscillating water column drives air in and out of a pressure chamber through a Wells turbine. In a third illustration, the power generating system comprises a piston pump secured below the water surface with a float tethered to the piston. Waves cause the float to rise and fall, generating pressurized water, which is then used to drive hydraulic generators.

[0062] To harvest horizontal wave movement, the electrical power generating system may comprise one or more large oscillating flaps positioned to catch waves as they go by. The flap flexes backwards and forwards in response to wave motion, which in turn drives pistons that pump seawater at high pressure through a pipe to a hydroelectric generator. Another implementation comprises a series of semi-submerged cylindrical sections linked by hinged joints. As waves pass along the length of the apparatus, the sections move relative to one another. The wave-induced motion of the sections is resisted by hydraulic cylinders, which pump high pressure water or oil through hydraulic motors via smoothing hydraulic accumulators. The hydraulic motors drive electrical generators to produce electrical power.

Converting Horizontal Movement of the Vessel to Electrical Power

[0063] Another way of converting wave motion to electrical power is a two-step process. The first step is to use the wave motion to create locomotive thrust, thereby causing the vessel to move through the water. The second step is to harvest the movement of the water about the vessel resulting from the locomotion, and convert it to electrical power.

[0064] FIG. **7**, FIG. **8**A, and FIG. **8**B show an example of a vessel that uses wave motion to generate both locomotive thrust and electrical power from vessel motion. In this example, the swimmer or wing-rack is tethered to the buoy or vessel body by a forward and aft tether with a winch for adjusting the length of tether that is deployed. As the buoy moves up and down with the waves, the swimmer rack has wings that translate the vertical movement into transverse locomotive movement. The wing-rack then pulls the vessel body as directed by the rudder under control of the microprocessor.

[0065] The electrical system shown here comprises upward facing solar panels, providing an auxiliary source of electrical power. The power module for generating electricity is shown in detail in FIG. **8**B. The module comprises rechargeable batteries, a rotating magnet conductor arrangement that plays the role of both motor and generator, and a third component that plays the role of both propeller and turbine. As shown in FIG. **7**, when there is an abundance of wave power, the wings on the swimmer generate thrust or locomotive power to move the vessel forward. As the waves power the vessel through the water, the propeller is turned backwards, applying torque to the motor so as to generate electrical power for storage in the battery. When there is an absence of wind power, or when the wing rack is retracted into the vessel body, the batteries or solar panel powers the motor, which turns the propeller so as to provide locomotive power.

[0066] The power module is shown in FIG. **8**A secured to one side of a catamaran type float. This can be varied to secure the power module for example to the other side, to the middle of a float with a central keel, or to the side rails or middle spine of the swimmer. Two or more power modules can be used, secured for example to both sides of a catamaran type float, or to a float and swimmer together in any combination.

[0067] In the example shown, the hull type is a displacement catamaran, which has the advantage of being very efficient below the hull speed, and can be powered up to 3 times faster than the hull speed with minimal wake. It has six 325 watt SunPower panels for almost 2000 watts peak solar power collection. It also has two Tesla-sized lithium ion battery packs housed in cylindrical power modules that are pressure tolerant to 200 m. These packs each have roughly 7000 cells totally 25 kWh of energy. The power modules are 12.75 inches in diameter—the same as a Remus 600 or a BlueFin 12D AUV.

Balancing Between Locomotive Thrust and Electrical Power Generation

[0068] In some implementations of the invention, the various power harvesting systems on a vessel may be configured to be regulated so as to prioritize delivery of power from wave motion to locomotive thrust or electricity generation in the desired proportion.

[0069] The electrical power generating system may be configured to lock out or variably dampen movement of the components that convert the wave motion to rotatory motion, and hence to electricity. For example, the link arm system shown in FIG. **5**A, FIG. **5**B, FIG. **6**A, and FIG. **6**B may be designed so that the link arms may be secured by a clamp or other means in the horizontal neutral position. This effectively locks out the power generating system in favor of the wave-powered propulsion system, which may be desirable when the wave motion is not in excess of what is required to propel the vessel at the intended speed, and/or when electrical power is not needed (for example, when the battery is charged to full capacity). In a variation of this system, the damping is variable, so that the proportion of wave motion used for electrical power generation may be precisely adjusted.

[0070] Conversely, the wave-powered propulsion system may be configured to lock out or variably dampen movement of the components that convert the wave motion to thrust. For example, the wings or fins shown in FIG. **1**B may be designed so that they may be secured in a neutral position. This effectively locks out the propulsion system in favor of the electrical power generating system, which may be desirable when the wave motion is well in excess of what is required to propel the vessel at the intended speed, and/or when electrical power is needed in greater abundance to power on-board electronics and/or recharge the battery. In a variation of this system, the damping is variable, so that the proportion of wave motion used for locomotive thrust may be precisely adjusted.

[0071] Besides adjusting use of the wave motion between thrust and electricity generation, a variable damping system on the propulsion system may have a further benefit: namely, to regulate speed of the vessel depending on the amount of wave motion currently available, and the desired target location. For example, when it is desired that the vessel stay in position at its current location, the propulsion regular and rudder may be caused assume a direction and speed that exactly compensates for the net effect of underlying current, wind, and horizontal wave force affecting the vessel's position. This effectively secures the vessel at its current GPS location, and saves the vessel from having to travel in circles to maintain its position.

[0072] Thus, either the propulsion system, or the electrical power generating system, or both may be configured with a lock out or variable damping arrangement to adjust the priority between the two systems.

[0073] Where such regulation systems are installed, they may be controlled by an on-board microprocessor programmed to determine the appropriate priority between locomotion and electrical power generation, and then to regulate the damping or lockout devices on each system accordingly. The microprocessor may be programmed to take into account such factors as vertical wave motion, latitude (determined by GPS), temperature, other weather factors, battery level, distance from the intended target location, amount of available solar power, time of day, payload, sensor data, and operating parameters programmed into or transmitted to the microprocessor.

Alternating Locomotive Thrust from Wave Motion and an Electrical Motor to Buffer Vessel Speed

[0074] Stored electrical power in the battery can be used to power the electric motor and provide propulsion whenever desired. Besides powering the motor during periods when wave motion is quiescent, it can be used on an ongoing basis to buffer the trust powered by the wave motion.

[0075] FIG. **9** is a graph of hypothetical data that illustrates how this might work. Mechanisms that convert wave motion into locomotive power by gradually pressurizing a gas or a liquid may provide fairly uniform thrust. However, other mechanisms result in undulations in thrust that occur once or twice per wave cycle. For example, in a configuration where a wing rack is tethered beneath a float (as in FIG. **1**B), the mechanism provides forward thrust while the rack is travelling upwards or downwards in the wave cycle. When the wave is peaking or at its nadir, tension on the tethers is fairly constant, and forward thrust is minimal. Thus, in a single wave cycle (as shown in FIG. **9**), forward thrust peaks twice.

[0076] In many uses of a wave-powered vessel, the undulations are of little consequence. However, there are instances in which a constant speed (and thus relatively constant thrust) is desirable: for example, when using sensors that comprise streamers flowing backwards from the vessel. The undulations in thrust obtained by mechanical conversion can be buffered by powering the electrical motor in an undulating pattern of the same frequency but essentially out of phase. In this manner, thrust from mechanical conversion and thrust from the electric motor alternate, so that the combined locomotive thrust is buffered to a more consistent level. The pattern of power to the electric motor may be controlled by an on board microprocessor programmed to detect the wave cycle, predict the undulations in mechanically derived locomotive thrust, and synchronize the electric motor out of phase to compensate.

Watercraft Configured for Self-Deployment

[0077] Another advantage of the hybrid powered vehicles of this invention is that in many instances they may be deployed directly from shore. This saves the trouble and expense of hiring a special vessel and crew to do the deployment in deep water. Instead, the components of the vessel are kept bound together, and the electric motor powers the vessel to deep water for full deployment.

[0078] For example, a wave-powered vessel configured for deployment from shore may comprise a buoyant vessel body, a swimmer configured to retract and be secured against the vessel body, one or more tethers connecting the float to the swimmer, an electrically powered motor configured to propel the vessel through the water, and a battery supplying power to the motor, having sufficient capacity to power the vessel from shore to a location where the swimmer can be deployed. The battery is charged up before launch, and the swimmer is kept secured to the float. The electric motor takes the vessel to deep water, and then the tethers are let out to deploy the swimmer to its operative position below the float—either automatically, or by remote control. After deployment, the battery can be recharged on an ongoing basis using the electrical power generating systems aboard the vessel.

[0079] FIG. **10** provides a further illustration. Some projects with wave powered vessels require the vessels to take a substantially massive payload. If kept aboard the float or the swimmer, the payload could impair vertical movement, and thus reduce efficiency of the vessel for converting wave motion to thrust and electrical power. Typically, the payload is towed in a container or platform referred to as a "tow buoy" behind the float or the swimmer, either on or below the water surface. However, deploying the vessel and the tow buoy separately from shore is difficult.

[0080] The figure shows how the vessel body and the tow buoy may be configured so that the tow buoy may be releasably housed within the vessel body while on shore, and pulled behind the vessel body after the vessel is deployed. The refinements shown include rollers to guide the tow buoy up one or more complementary ramps inside the float. To transport the vessel to the launch site, the tow buoy is positioned securely inside the float, and the tethers connecting the wing racks to the float are retracted so that the wing racks nest securely to the bottom of the float. Following launch, the precharged battery powers the vessel to deep water, whereupon the wing racks are deployed downward, and the tow buoy is deployed out the back of the float so as to be towed by the float without impairing the float's vertical movement due to wave motion.

Use of Wave-Powered Watercraft

[0081] The hybrid wave-powered vessels of this invention can be manufactured, sold, and deployed for any worthwhile purpose desired by the user. For example, the vessels can be used to survey and monitor regions of the ocean or other bodies of water, including the chemistry of water and air, weather, and marine life. The vessels can be used to relay signals from sensors under the water or on other vessels to a data processing center. They can be used to monitor activities on shore, and the behavior of other watercraft. They can also be used to distribute substances into the ocean from the vessel body or from a tow buoy.

[0082] Sensors and related equipment that may be used include one or more of the following in any suitable combination:

[0083] Sensors for gas concentrations in air or water

[0084] Heat flux sensors

[0085] Meteorological sensors: wind speed & direction, air temperature, solar intensity, rain fall, humidity, pressure

[0086] Physical oceanography sensors; wave spectrum & direction, current sensors, CTD profiles

[0087] Micro-organism counts and classification through water sampling and vision systems

[0088] Fish and wildlife tracking by acoustic tag detection, such as those manufactured by Vemco

[0089] FAD structures to provide shade and attract marine life

[0090] Acoustic sensors for active or passive detection and classification of marine wildlife. For example, hydrophone for listening to whales, or active sonar for fish counts

[0091] Chemical sensors to detect the concentration of a substance being released by the vessel

[0092] Equipment installed on a vessel of this invention to facilitate data collection may include a means for obtaining sensor data at variable depths. This can be achieved using a winch system to lower and raise sensors mounted on a heavier-than-water platform. Another option is a tow buoy mounted with sensors, with servo-controlled elevator fins to alter the pitch of the tow body, thereby controlling its depth while being pulled. The vessel may also have data storage systems and a microprocessor programmed to process and interpret data from the sensors, either integrated into the location and navigation processing and control system on the vessel, or as a stand-alone microprocessor system.

[0093] Watercraft of this invention equipped with sensors and/or payloads have a variety of sociological and commercially important uses. Such uses include fertilizing plankton, feeding fish, sequestering carbon from the atmosphere (PCT/US2012/029718), conducting seismic surveys (US 2012/0069702 A1) or prospecting for new sources of minerals or fuel oil.

Glossary

[0094] The terms "vessel", "watercraft", and sea going "vehicle" are used interchangeably in this disclosure and previous disclosures to refer to a nautical craft that can travel across and about any body of water at or near the surface.

[0095] A "wave-powered" vessel is a vessel that derives at least a majority of its power for locomotion from motion of the water in relation to the surface. Optionally, the vessel may also derive power from solar energy and other natural sources, and/or man-made sources such as batteries and liquid fuel powered engines. In this context, a "wave" is any upward and downward motion of the surface of a body of water at a point of reference (such as the center of floatation of a vessel).

[0096] A "vessel body" or "float" is a component of a vessel that travels on or near the surface of the water. It may have its own source of locomotive power and/or rely on being pulled by a submarine component. It is made buoyant by having a density (including enclosed air pockets and upward opening cavities) that is

[0097] A "swimmer", "pod", "submarine component", "sub", "glider" or "wing rack" is a component of a vessel that travels below the surface of the water and below the vessel body, to which it provides locomotive power or propulsion. The swimmer is heavier than water, so as to travel downwards through the water to the extent allowed by the tethers and the vessel body and suspension systems to which the tethers are attached above. It is typically equipped with a plurality of "fins" or "wings" that rotate upwards or downwards around an axle transverse to the direction of travel. This disclosure generally refers to vessels having single swimmers or wing racks. However, vessels may be configured with multiple swimmers, typically joined to the same two or more tethers at different depths, each providing locomotive thrust in response to wave action, and optionally configured for nesting when retracted (PCT/US2012/029696). Thus, all the aspects of this invention deriving wave power from a swimmer includes or can be adapted mutatis mutandis to include two, three, or more than three swimmers or wing racks.

[0098] An "autonomous" vessel is a vessel that is designed and configured to travel across a body of water without needing a human on board or in constant active control at a remote location. It has a self-contained source of locomotive power. Navigation is controlled, either by a combination of sensors, electronics, and microprocessors aboard or at a remote location and in wireless communication with the vessel. The vessel may also be programmed to manage the ratio of locomotive power derived mechanically from wave action, and from an electric motor. It may also be programmed to control dampening of the action of fins on the swimmer.

[0099] A "tow buoy" is a storage container or equipment platform that is towed behind a vessel, attached either the float or the swimmer, and traveling on or below the water surface. The term does not necessarily indicate that the container or platform has a degree of buoyancy.

[0100] A "microprocessor" or "computer processor" on a vessel or control unit of the invention inputs data, processes it, and then provides output such as data interpretation or instructions to direct the activity of another apparatus or component. For vessels or units that have different data sets for processing in different ways, the microprocessor for each algorithm may be separate, but more commonly they are a single microprocessor configured and programmed to process each the different data sets with the corresponding algorithms when it is appropriate

[0101] The wave-powered vessels of this invention may be organized in fleets of two or more that interact with each other and/or with a central control unit. The terms "control unit", "central control unit" and "control center" are used interchangeably to refer to an electronic assembly or combination of devices that receives information about one or more conditions of the water, the weather, or other aspects of the environment at one or more locations, makes decisions about where it is appropriate to distribute fertilizer or another substance from one or more distribution vessels, and sends instructions to the vessels in the fleet accordingly. The control unit may be placed anywhere on shore within range to receive and transmit data and instructions, or it may be aboard one of the vessels in the fleet, optionally integrated with the microcircuitry of that vessel.

[0102] For all purposes in the United States of America, each and every publication and patent document cited herein is incorporated herein by reference as if each such publication or document was specifically and individually indicated to be incorporated herein by reference.

[0103] While the invention has been described with reference to the specific embodiments, changes can be made and equivalents can be substituted to adapt to a particular context or intended use, thereby achieving benefits of the invention without departing from the scope of what is claimed.

What is claimed is:

1. A wave-powered vessel, comprising:

(a) a buoyant vessel body;

(b) a mechanical means for converting movement of the vessel body caused by wave motion to horizontal thrust; and

(c) an electrical generator for converting movement of the vessel body caused by wave motion to electrical power.

2. The wave-powered vessel of claim **1**, wherein component (b) comprises:

(i) a swimmer; and
(ii) one or more tethers connecting the float to the swimmer;
wherein the swimmer is weighted to travel in water below the vessel body, and is configured to pull the vessel body by way of the tether, the swimmer comprising fin surfaces that mechanically provide forward thrust when actuated by rising and falling of the swimmer in the water.

3. The wave-powered vessel of claim **1**, wherein the electrical generator comprises either:
(i) a means for converting vertical movement of the vessel body caused by wave motion to electrical power,
(ii) a means for converting horizontal movement of the vessel body through water to electrical power, or both (i) and (ii).

4. The wave-powered vessel of claim **1**, wherein the electrical generator comprises a piston powered by a swing arm that moves from a horizontal to a vertical position in accordance with the vertical movement of the vessel body.

5. The wave-powered vessel of claim **4**, wherein the swing arm is mechanically connected to a swimmer weighted to travel in water below the vessel body.

6. The wave-powered vessel of claim **2**, wherein the swimmer is adapted so that motion of the fin surfaces may be dampened to increase electrical power generated by the electrical generator.

7. The wave-powered vessel of claim **1**, wherein the electrical generator comprises a rotatory fin or turbine powered by horizontal movement of the vessel body through the water.

8. The wave-powered vessel of claim **1**, further comprising an electrically powered motor to provide horizontal thrust to the vessel through the water.

9. The wave-powered vessel of claim **7**, wherein the rotatory fin or turbine is adapted to generate electrical power when rotated in one direction, and to act as a motor providing horizontal thrust to the vessel through the water when rotated in the opposite direction.

10. The wave-powered vessel of claim **8**, comprising a battery configured to store electrical power generated by the electrical generator and feed electrical power to the motor to provide horizontal thrust to the vessel through the water.

11. The wave-powered vessel of claim **10**, further comprising one or more solar panels supplying electrical power to the battery.

12. The wave-powered vessel of claim **10**, wherein the battery powers the motor and provides horizontal thrust to the vessel alternately with thrust powered by the wave motion so as to buffer the trust powered by the wave motion.

13. The wave-powered vessel of claim **10**, wherein the battery powers the motor during periods where the motion in each full wave cycle is inadequate to provide sufficient horizontal thrust to the vessel.

14. A vessel with locomotive thrust powered alternately by wave motion and by electrical power so as to buffer the trust powered by the wave motion.

15. The vessel according to claim **14**, which is a wave-powered vessel according to any of claims **1** to **10**.

16. A wave-powered vessel configured for deployment from shore, comprising:
(a) a buoyant vessel body;
(b) a swimmer configured to retract and be secured against the vessel body;
(c) one or more tethers connecting the float to the swimmer;
(d) an electrically powered motor configured to propel the vessel through the water; and
(e) a battery supplying power to the motor, having sufficient capacity to power the vessel from shore to a location where the swimmer can be deployed;
wherein the swimmer is weighted to travel in the water below the vessel body, and is configured to pull the vessel by way of the tether, the swimmer comprising fin surfaces that mechanically provide forward thrust when actuated by rising and falling of the swimmer in the water.

17. The wave-powered vessel of claim **16**, further comprising a releasable tow buoy;
wherein the vessel body and the tow buoy are configured so that the tow buoy may be releasably housed within the vessel body while on shore, and pulled behind the vessel body after the vessel is deployed.

18. The wave-powered vessel of claim **16**, further comprising an electrical generator for converting movement of the vessel body caused by wave motion to electrical power according to any of claims **1** to **10**.

19. A vessel according to claim **1**, configured for autonomous operation.

20. The vessel of claim **19**, comprising:
(i) electronics configured to sense the geographical location of the vessel; and
(ii) a microprocessor programmed to determine the vessels current location, and steer the vessel from its current location towards a target location.

* * * * *

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(12) Patent Application Publication
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(43) Pub. Date: Nov. 22, 2012

(54) **WAVE-POWERED DEVICE WITH ONE OR MORE TETHERS HAVING ONE OR MORE RIGID SECTIONS**

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(73) Assignee: **LIQUID ROBOTICS, INC.**, Sunnyvale, CA (US)

(21) Appl. No.: **13/424,156**

(22) Filed: **Mar. 19, 2012**

Related U.S. Application Data

(60) Provisional application No. 61/453,871, filed on Mar. 17, 2011, provisional application No. 61/535,116, filed on Sep. 15, 2011.

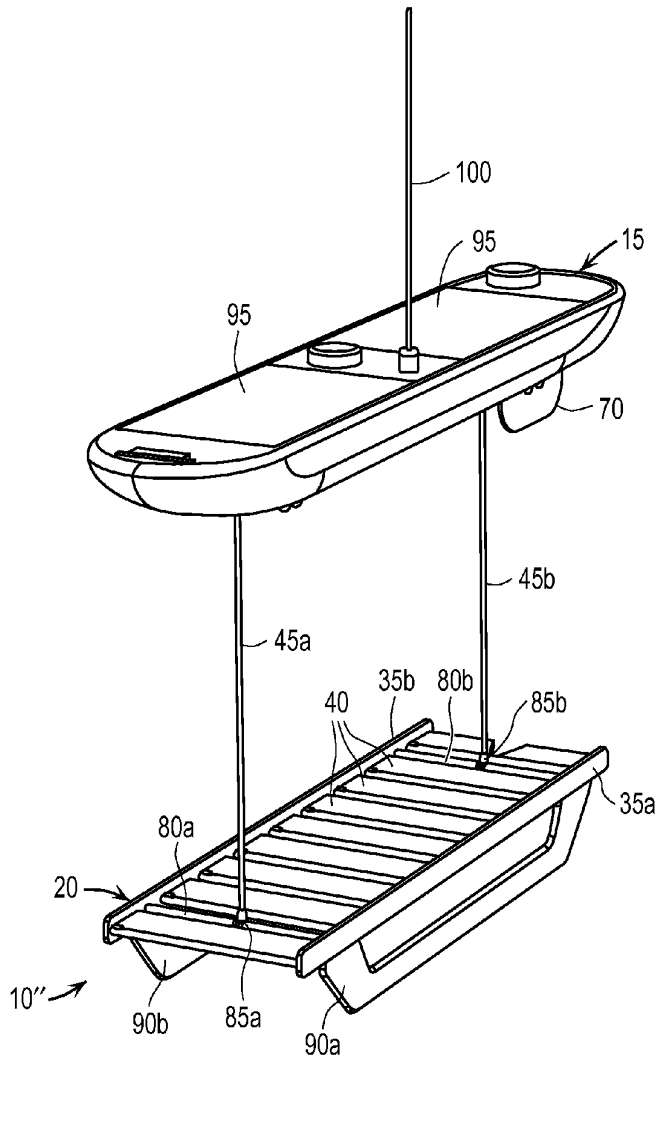
Publication Classification

(51) **Int. Cl.**
B63H 19/02 (2006.01)
B63B 35/44 (2006.01)
B63H 25/08 (2006.01)

(52) **U.S. Cl.** **440/9**; 701/21; 114/267; 414/800

(57) **ABSTRACT**

Many of the known wave-powered devices ("WPDs") comprise (1) a float, (2) a swimmer, and (3) a tether connecting the float and the swimmer. The swimmer generates thrust as the float moves up and down due to surface waves. A WPD is provided with a rigid tether that can be moved from (a) a first position ("adjacent position") in which at least a part of the tether is adjacent to the float to (b) a second position ("extended position") in which the tether (i) is extended below the float and (ii) is at least in part substantially rigid. The WPD can if desired be transported, stored, or launched while the tether is in the adjacent position, and the tether can be moved into the extended position after the device has been launched and remain in the extended position while the device is being operated.



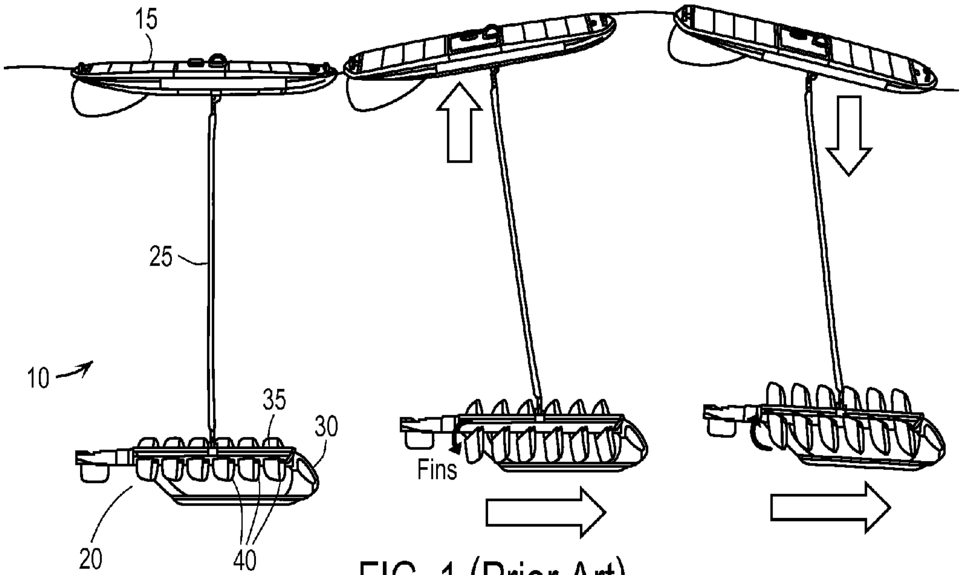


FIG. 1 (Prior Art)

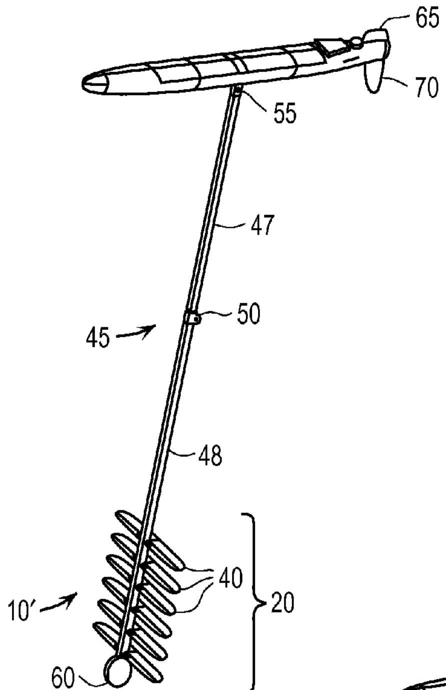


FIG. 2A

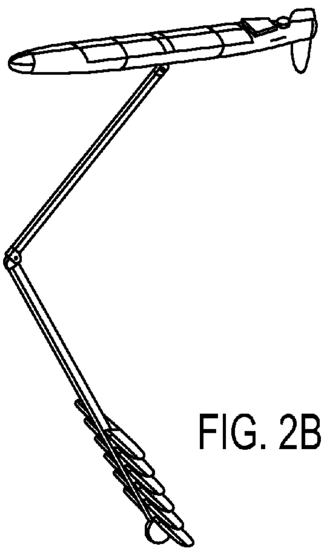


FIG. 2B

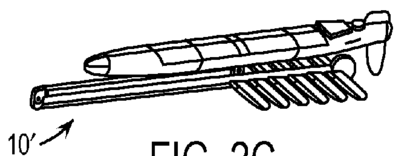


FIG. 2C

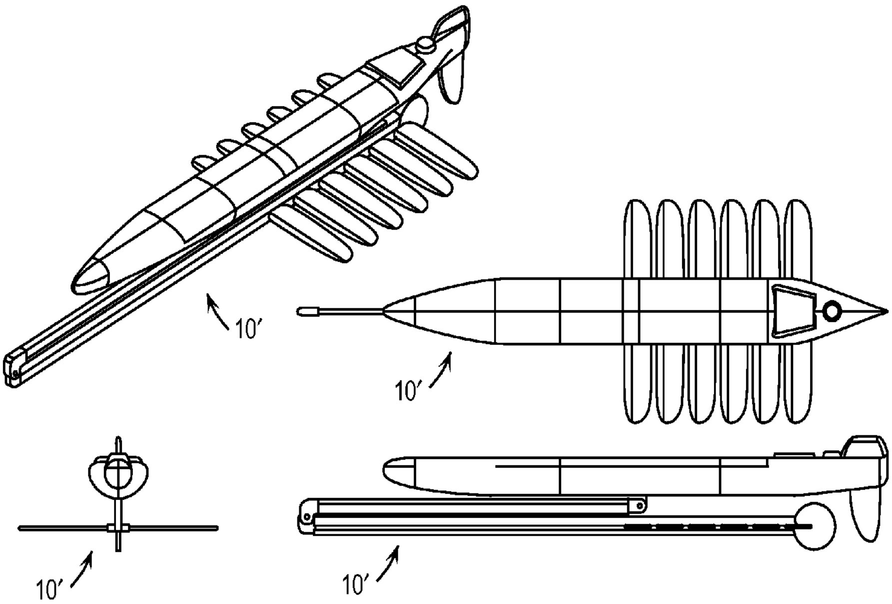


FIG. 3

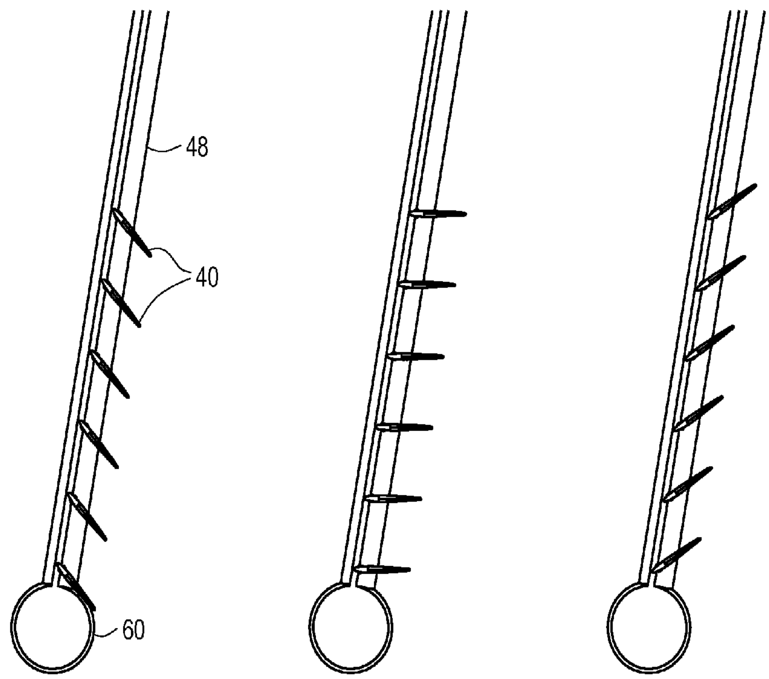


FIG. 4A FIG. 4B FIG. 4C

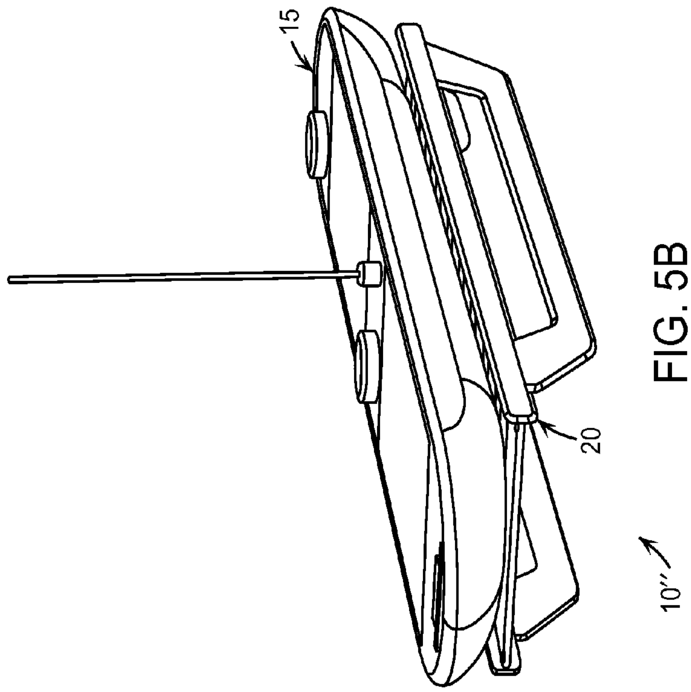

15
20
10''

FIG. 5B

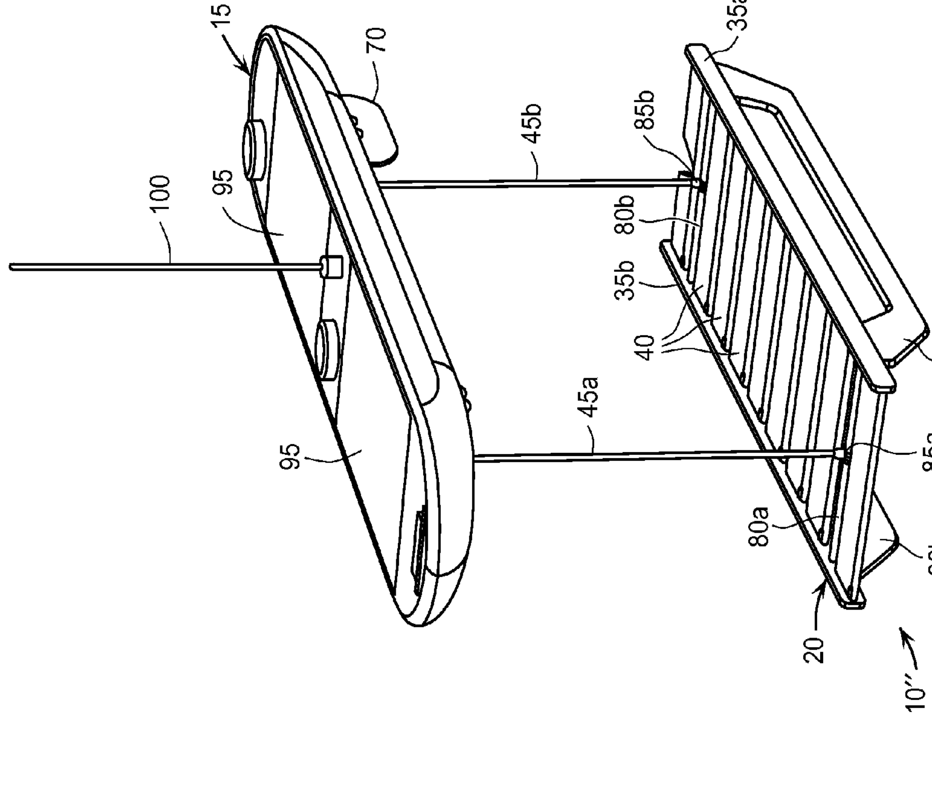

15
70
100
95
45b
85b
35a
80b
35b
40
90a
95
45a
85a
80a
90b
20
10''

FIG. 5A

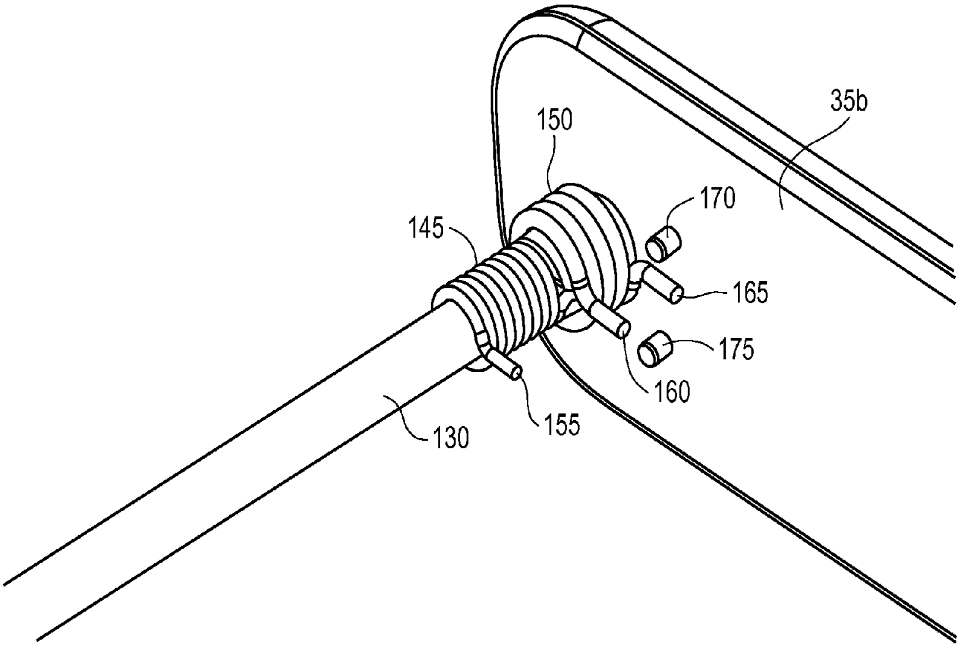


FIG. 6

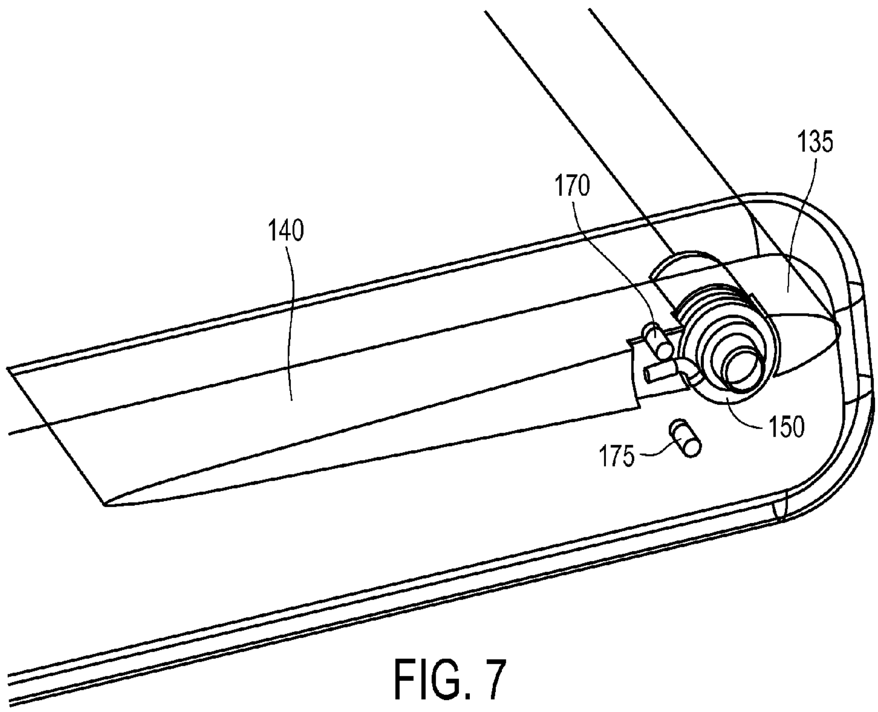


FIG. 7

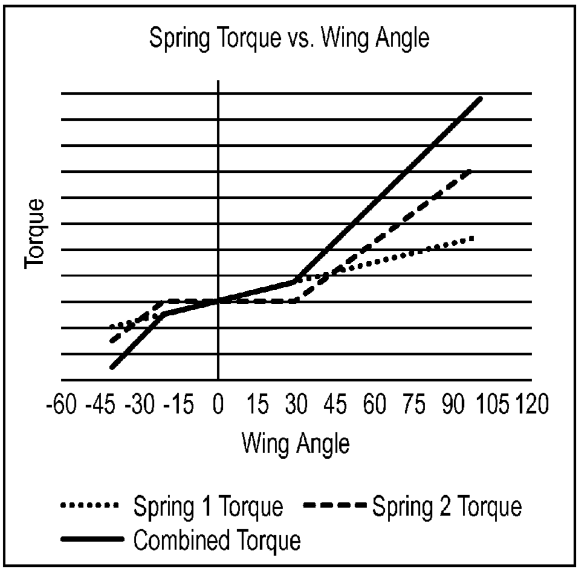


FIG. 8

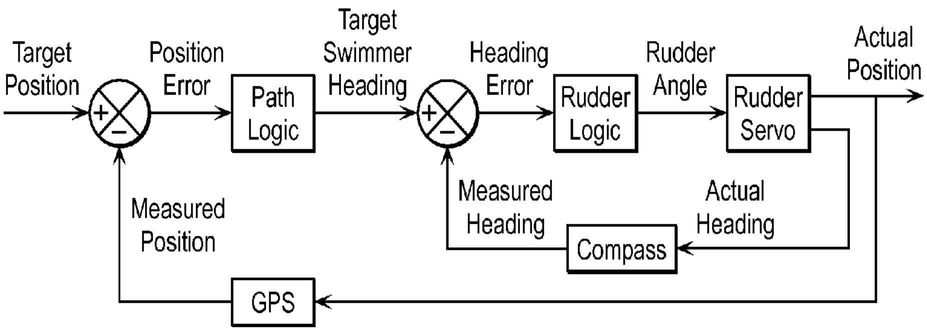


FIG. 9 (Prior Art)

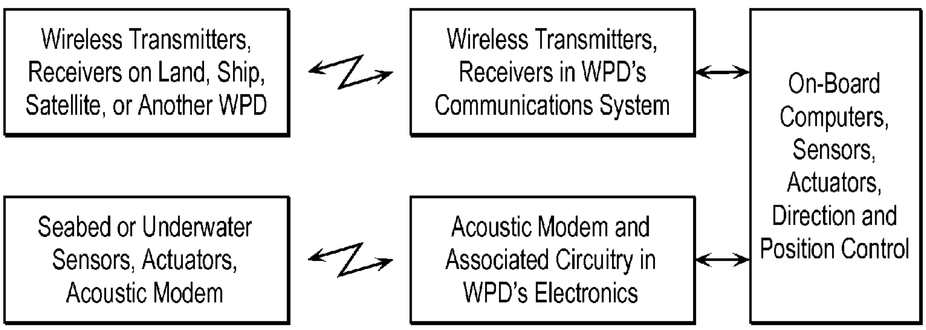


FIG. 10

WAVE-POWERED DEVICE WITH ONE OR MORE TETHERS HAVING ONE OR MORE RIGID SECTIONS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority from and the benefit of the following provisional patent applications:

[0002] U.S. Application No. 61/453,871, filed Mar. 17, 2011, for "Wave-Powered Vehicles (JUP 012)" (Roger G. Hine); and

[0003] U.S. Application No. 61/535,116, filed Sep. 15, 2011, for "Wave-Powered Vehicles (JUP 012-0)" (Roger G. Hine).

[0004] The following three applications (including this one) are being filed contemporaneously:

[0005] U.S. application Ser. No. ______, filed ______, for "Wave-Powered Device with One or More Tethers Having One or More Rigid Sections" (Roger G. Hine); and

[0006] U.S. application Ser. No. ______, filed ______, for "Wave-Powered Devices Configured for Nesting" (Roger G. Hine and Derek L. Hine); and

[0007] U.S. application Ser. No. ______, filed ______, for "Autonomous Wave Powered Substance Distribution Vessels for Fertilizing Plankton, Feeding Fish, and Sequestering Carbon From The Atmosphere" (Roger G. Hine).

[0008] This application is also related to the following U.S. and International patent applications:

[0009] U.S. application Ser. No. 11/436,447, filed May 18, 2006, now U.S. Pat. No. 7,371,136;

[0010] U.S. application Ser. No. 12/082,513, filed Apr. 11, 2008, now U.S. Pat. No. 7,641,524;

[0011] U.S. application Ser. No. 12/087,961, based on PCT/US 2007/001139, filed Jan. 18, 2007, now U.S. Pat. No. 8,043,133;

[0012] International Patent Application No. PCT/US 2007/01139, filed Jan. 18, 2007, published Aug. 2, 2007, as WO 2007/087197;

[0013] International Patent Application no. PCT/US 2008/002743, filed Feb. 29, 2008, published Sep. 12, 2008, as WO 2008/109002;

[0014] U.S. application Ser. No. 61/453,862, filed Mar. 17, 2011, for "Distribution of Substances and/or Articles into Wave-Bearing Water (JUP 013)" (Roger G. Hine);

[0015] U.S. application Ser. No. 61/502,279, filed Jun. 28, 2011, for "Energy-Harvesting Water Vehicle" (Roger G. Hine);

[0016] U.S. Application No. 61/585,229, filed Jan. 10, 2012, for "Retractable Nesting Wing Racks for Wave Powered Vehicle" (Roger G. Hine and Derek L. Hine); and

[0017] The U.S. and PCT applications filed on or about the same day as this application and claiming priority from one or more of U.S. Provisional Application Nos. 61/453,871, 61/453,862, and 61/535,116.

[0018] The entire disclosure of each of the above-referenced patents, applications, and publications is incorporated herein by reference for all purposes.

BACKGROUND OF THE INVENTION

[0019] This invention relates to devices that are subject to waves in the water, and that in some cases utilize the power of waves in water.

[0020] As a wave travels along the surface of water, it produces vertical motion, but no net horizontal motion, of water. The amplitude of the vertical motion decreases with depth; at a depth of about half the wavelength, there is little vertical motion. The speed of currents induced by wind also decreases sharply with depth. A number of proposals have been made to utilize wave power to do useful work. Reference may be made, for example, to U.S. Pat. Nos. 986,627, 1,315,267, 2,520,804, 3,312,186, 3,453,981, 3,508,516, 3,845,733, 3,872,819, 3,928,967, 4,332,571, 4,371,347, 4,389,843, 4,598,547, 4,684,350, 4,842,560, 4,968,273, 5,084,630, 5,577,942, 6,099,368 and 6,561,856, U.S. Publication Nos. 2003/0220027 and 2004/0102107, and International Publication Nos. WO 1987/04401 and WO 1994/10029. The entire disclosure of each of those patents and publications is incorporated herein by reference for all purposes.

[0021] Many of the known wave-powered devices ("WPDs") comprise (1) a float, (2) a swimmer, and (3) a tether connecting the float and the swimmer; the float, swimmer, and tether being such that when the vehicle is in still water, (i) the float is on or near the surface of the water, (ii) the swimmer is submerged below the float, and (iii) the tether is under tension, the swimmer comprising a fin or other wave-actuated component which, when the device is in wave-bearing water, interacts with the water to generate forces that can be used for a useful purpose, for example to move the swimmer in a direction having a horizontal component (hereinafter referred to simply as "horizontally" or "in a horizontal direction"). The terms "wing" and "fin" are used interchangeably in the art and in this application.

[0022] It is desirable to position sensors and equipment in the ocean or lakes for long periods of time without using fuel or relying on anchor lines which can be very large and difficult to maintain. In recent years, the WPDs developed by Liquid Robotics, Inc. and marketed under the registered trademark Wave Glider®, have demonstrated outstanding value, particularly because of their ability to operate autonomously. It is noted that Wave Glider® WPDs are often referred to as Wave Gliders as a shorthand terminology. It is also noted that WPDs are often referred to as wave-powered vehicles ("WPVs").

SUMMARY OF THE INVENTION

[0023] Until now, practical wave-powered devices have made use of flexible tethers. The possibility of using a rigid tether has been proposed, but has not been used in practice. A problem that arises when using a rigid tether is that it is difficult to transport, store, launch or recover a wave-powered device that has a rigid tether. Embodiments of the present invention provide a solution to this problem by making use of a tether that can be moved from (a) a first position ("adjacent position") in which at least a part of the tether is adjacent to the float to (b) a second position ("extended position") in which the tether (i) is extended below the float and (ii) is at least in part substantially rigid. The device can if desired be transported, stored, or launched while the tether is in the adjacent position, and the tether can be moved into the extended position after the device has been launched and remain in the extended position while the device is being operated. Preferably, the tether can also be moved from the extended position into the adjacent position, in which case, the device can be recovered, after a period of operation, after moving the tether into the adjacent position.

[0024] The Summary of the Invention and the Detailed Description below, and the accompanying drawings, disclose many novel features, each of which is inventive in its own right, and any one or more of which can be used in combination where this is physically possible. The different aspects of the invention identified below are no more than examples of the broad range of inventions disclosed herein.

[0025] In a first aspect of the invention, a device comprises: (1) a float; (2) a tether that is secured to the float, and that can assume multiple positions including at least (a) an adjacent position in which at least part of the tether is relatively close to the float, and (b) an extended position in which the tether (i) is extended below the float and (ii) is at least in part substantially rigid, wherein the tether can be moved from the adjacent position to the extended position; and (3) a wave-actuated component that is secured to the tether. The float, the tether, and the wave-actuated component are such that: (A) when the device is in still water and the tether is in the extended position, (i) the float is on or near the surface of the water, and (ii) the tether is submerged below the float, and (B) when the device is in wave-bearing water and the tether is in the extended position, (i) the float is on or near the surface of the water, (ii) the tether is submerged below the float, and (iii) the wave-actuated component interacts with the water to generate forces that are transmitted to the tether.

[0026] The term "substantially rigid" is used herein to denote a component which, when the tether is in the extended position and the WPD is in wave-bearing water, undergoes only elastic distortion, and preferably undergoes substantially no distortion. The invention will be described chiefly by reference to a device in which the whole of the tether, when it is in the extended position, is substantially rigid. However, the invention includes the possibility that the tether, when it is in the extended position, includes one or more parts that are not substantially rigid.

[0027] Preferably, the tether can also be moved from the extended position to the adjacent position. Preferably, the tether is substantially rigid when each is in the adjacent position; however, the invention includes the possibility that the tether become substantially rigid when it is moved from the adjacent position to the extended position.

[0028] The wave-actuated component is sometimes referred to herein as a "swimmer." It can comprise a fin system as disclosed in any of the documents incorporated herein by reference or any other mechanism that will interact with the water to generate forces that are transmitted to the tether, including the novel mechanisms disclosed in this application is.

[0029] In a first embodiment of the devices of the first aspect of the invention, the tether is in the extended position, and the device is a wave-powered device (hereinafter abbreviated to WPD). Embodiments of the invention will be described chiefly by reference to a WPD in which the forces generated by the interaction between the water and the wave-actuated component are transmitted through the tether to the float so that the float tends to move in a horizontal direction; such a device is sometimes referred to herein as a wave-powered vehicle or WPV. However, alternatively or additionally, the forces can produce some other effect on or in the tether and/or the float, e.g., the generation of electrical power.

[0030] With the tether is in the extended position, the device can become and operate as an autonomous wave-powered device (hereinafter abbreviated to WPD).

[0031] The tether can include a plurality of telescoping sections or a plurality of hinged sections. The wave-actuated component can be selected from one of the following two configurations: (A) the wave-actuated component has a single substantially rigid spine, with fins extending on each side of the rigid spine and the rigid spine, when the WPD is in still water and the tether is in the extended position, the rigid spine is at an angle of at most 40°, or at most 30° , or at most 15°, to the horizontal, e.g., substantially horizontal, and lies in a vertical plane that passes through the longitudinal axis of the float; or (B) the wave-actuated component has two substantially rigid spines, with fins extending between the rigid spines, and when the WPD is in still water and the tether is in the extended position, both the rigid spines lie in a plane at an angle of at most 40°, or at most 30°, or at most 15°, to the horizontal, e.g., substantially horizontal, and the rigid spines are equally spaced from a vertical plane that passes through the longitudinal axis of the float.

[0032] In at least some embodiments, the wave-actuated component comprises springs or other elastic components that return the fins to a neutral position. In a particular arrangement, the rotation of the fins, when the WPD is in wave-carrying water, is primarily controlled by a first spring when the rotation of the fins is within a first range about the neutral position and is primarily controlled by a second spring when the rotation of the fins is outside the first range, the second spring being stiffer than the first spring.

[0033] In at least some embodiments, there are at least two tethers that are secured to the same or different positions on the float, for example one secured to the fore section of the float and the other to the aft section of the float or both secured to the float in the same plane at right angles to the longitudinal axis of the float, at least one of the tethers being movable between a first position in which the remote end of the tether is relatively close to the float and a second position in which the remote end of the tether is relatively far from the float.

[0034] In a second embodiment of the first aspect of the devices of the invention, the tether is in the adjacent position, and the device is an assembly that can be converted into a wave-powered device by moving the tether from the adjacent position to the extended position. In the second embodiment, the assembly can for example have one or both of the following characteristics, (1) the tether is substantially parallel to the bottom of the float and/or in contact with the float over a substantial portion of the length of the tether, and (2) the wave-actuated component has a component that is substantially parallel to the bottom of the float and/or substantially parallel to the tether, and/or in contact with the tether over a substantial portion of the length of the tether. Preferably, the float, tether, and wave-actuated component are designed so that, in this embodiment, the tether and the wave-actuated component are nested closely to, and secured to, the float, thus making an assembly that remains a single unit until the time comes to launch the device on the water.

[0035] Assemblies of this type, in which the tether can be flexible or rigid when the device is in use, are described and claimed in detail in an application filed contemporaneously with this application and also claiming priority from U.S. Provisional Application Nos. 61/453,871 and 61/535,116, filed Sep. 15, 2011. Assemblies of this type provide a convenient way of transporting, storing, or launching a WPD. In some embodiments, the float includes one or more protective components, e.g., side rails, that extend downwards so that, when the tether is in the adjacent position, the tether and any wave-actuated component are above the components, thus making it possible to place the assembly on a surface with the tether and wave-actuated component separated from the surface. In other embodiments, the wave-actuated component includes one or more protective components, e.g., side rails, that extend downwards so that, when the tether is in the adjacent position, the tether and the wave-actuated component are above the protective components, thus making it possible to place the assembly on a surface with the tether and wave-actuated component separated from the surface.

[0036] In a second aspect of the invention, a method of placing a WPD as described above on water, comprises (A) placing the float of the WPD on or above the water, and (B) moving the tether from the adjacent position to the extended position either before or after the float has been placed on the water.

[0037] In a third aspect of the invention, a method of removing a WPD as described above from water in which it is floating, the WPD being a WPD which the tether can be moved from the extended position to the adjacent position, the method comprising (A) moving the tether from the extended position to the adjacent position, thus creating an assembly as described above, and (B) removing the assembly from the water.

[0038] In a fourth aspect of the invention, an assembly comprises a float and a tether, at least a part of which is substantially rigid and that is secured to the float by a connection that enables the tether to be moved from (a) a first adjacent position in which at least part of the tether is relatively close to the float to (b) a second extended position in which the tether is extended below the float.

[0039] In a fifth aspect of the invention, a float suitable for use in a WPD as described above comprises a connection to which a substantially rigid tether can be secured and that enables a substantially rigid tether secured to the connection to be moved between the adjacent and extended positions.

[0040] In a sixth aspect of the invention, an assembly comprises a substantially rigid tether and a wave-actuated component secured to one end of the tether, the wave-actuated component comprising a rigid spine having fins mounted at spaced intervals along the spine.

[0041] In a seventh aspect of invention, a wave-powered device that comprises (1) a float, and (2) a wave-actuated component, where the float and the wave-actuated component are such that, when the device is in still water, (i) the float is on or near the surface of the water, and (ii) the wave-actuated component is submerged below the float, wherein the wave-actuated component comprises an elongate rigid member that is directly connected to the float and extends downwards from the float.

[0042] In an eighth aspect of invention, a method of obtaining information comprises receiving signals from, or recorded by, a WPD as described above.

[0043] In an ninth aspect of invention, a method for controlling a function of a WPD as described above comprises sending signals to the WPD.

[0044] Embodiments of the wave-actuated component can use a fin control system wherein the angular movement of at least one fin is primarily controlled by a first spring or other means when the movement of the fins is within a first range about a neutral position and is primarily controlled by a second spring or other means when the movement of the fins is within a second range that is outside the first range. The second spring is stiffer than the first spring, thus making it more difficult for the fins to move within the first range, and the movement can be controlled solely by the first spring or by a combination of first spring and a second spring. Within the second range, the movement can be controlled solely by the second spring or by a combination of the first spring and a second spring.

[0045] The system can include a stop that prevents the first spring from moving beyond a first limit. The system can include a stop that prevents the second spring from moving beyond a second limit, and thus prevents the fin from moving outside a second range. Either or both of the springs can be replaced by an equivalent means that may be mechanical or electromechanical. When using such a system, when the waves in the wave bearing water are small, the rotation of the fins is controlled by the first spring and only a little fluid force is needed to rotate the fins to an angle within an effective range. As the waves become larger, the second spring comes into play and, by preventing the fins from "overrotating" maintains the fins at an angle within an effective range. Excessive water forces can rotate the fin so that it dumps the load, thus protecting the system from overload.

[0046] In a specific embodiment of the fin control system, a first spring is fixed on one end to the fin and on the other end to the side beam (rigid spine), via the first spring stop. As the fin rotates around the shaft, the first spring torques the fin back to a neutral position level with the side beam. A second spring is fixed on one end to the wing and on the other end rotates freely between an upper and lower stop. Only motion beyond the stop pin is resisted by the second spring. The combined result is a soft spring for motion around the neutral, level position, and stiff spring for motion beyond the stops. In light waves only a little fluid force applied the fins can rotate the wings to an effective angle of attack. As fluid force increases in rougher wave conditions, effective angle of attack is maintained. Very high fluid forces can rotate the fin to so that it dumps the load and is thus the system is protected from overload.

[0047] Many of the embodiments have on-board electronics, including (1) wireless communications equipment, (2) a computer system, (3) a satellite-referenced position sensor, (4) a sensor that senses direction in a horizontal plane, and (5) a steering actuator. The computer system (a) is linked to the communications equipment, the position sensor, the horizontal sensor and the steering actuator, and (b) contains, or is programmable to contain, instructions to control the steering actuator in response to signals received from the communications equipment, or from the position sensor and the horizontal sensor, or from signals received from another sensor on the vehicle.

[0048] A further understanding of the nature and advantages of the present invention may be realized by reference to the remaining portions of the specification and the drawings, which are intended to be exemplary and not limiting.

BRIEF DESCRIPTION OF THE DRAWINGS

[0049] FIG. **1** is a pictorial view showing the operation of a wave-powered device ("WPD") in still water (fins/wings in neutral position), when a wave lifts the float (up-stroke), and when the WPD sinks into the wave trough (down-stroke);

[0050] FIGS. **2**A, **2**B, and **2**C show a WPD with a rigid tether and a wave-actuated component having a rigid spine to which fins are attached at spaced apart-intervals, with FIG. **2**A showing the tether fully extended in a swimming position, FIG. **2**B showing the rigid tether partially retracted, and FIG.

2C showing the rigid tether fully refracted so that the WPD is in a bundle configuration suitable for launch or recovery;

[0051] FIG. **3** contains perspective, top, front, and side views of the WPD of FIGS. **2**A, **2**B, and **2**C in the bundled configuration;

[0052] FIGS. **4**A, **4**B, and **4**C respectively show the wings of the WPD of FIGS. **2**A, **2**B, and **2**C in an up-stroke position, in a neutral position, and in a down-stroke position as the WPD moves up and down in wave-bearing water;

[0053] FIG. **5**A is a perspective view of a WPD having two rigid tethers and a wave-actuated component having two horizontal rigid spines (side beams) and a fin system between the rigid spines, with the tethers in their extended positions;

[0054] FIG. **5**B is a perspective view of the WPD of FIG. **5**A with the rigid tethers in their retracted positions so that the WPD is in a bundle configuration with the float sitting atop the wave-actuated component;

[0055] FIG. **6** is a perspective view showing a two-spring arrangement for controlling the movement of a fin (not shown), which is part of a wave-actuated component such as that of the WPD of FIGS. **5**A and **5**B, viewed looking from between the spines (side beams);

[0056] FIG. **7** is a partially cutaway perspective view showing the two-spring arrangement with one end of each spring embedded in the fin, viewed looking from outside the spines (side beams);

[0057] FIG. **8** is a graph of spring torque as a function of fin (wing) angle;

[0058] FIG. **9** is a is a block diagram of a control system of the type that might be used in any of the WPDs discussed herein for directing the WPD along a desired path; and

[0059] FIG. **10** is a block diagram schematically showing some of the ways that a representative WPD communicates with outside entities.

DESCRIPTION OF SPECIFIC EMBODIMENTS

[0060] Overview

[0061] FIG. **1** is a pictorial view showing the operation of a wave-powered device ("WPD") **10**. This is an example of a prior art WPD developed by Liquid Robotics, Inc. and marketed under the registered trademark Wave Glider®. In short, WPD **10**, as additional embodiments described below, converts wave motion into forward thrust, and uses satellite location systems and radio to communicate data back to an operator and to receive navigation and other commands. It has on-board computers and sensors that allow it to navigate or hold position autonomously, without regular human interaction or control.

[0062] WPD **10** includes a float **15**, a submerged swimmer **20**, and a flexible tether **25**. The swimmer includes a frame **30** having a central rigid spine portion **35** to which a number of wings or fins **40** are pivotally mounted for rotation about respective normally horizontal axes. As waves lift and lower float **15** of the WPD, fins **40** on the submerged portion (swimmer **20**) passively rotate so as to convert the relative motion of the surrounding water into forward thrust. The azimuth of the thrust vector can be directed completely independently of the direction of the waves by a rudder at the back of the glider.

[0063] FIG. **1** contains three portions, from left to right showing the WPD in still water (fins/wings in neutral position), when a wave lifts the float (up-stroke), and when the WPD sinks into the wave trough (down-stroke). In still water (lefthand portion of FIG. **1**), the submerged swimmer hangs level directly below the float. As the wave lifts the float (middle portion of

[0064] FIG. **1**), the float pulls the swimmer upward through the water. Each fin is rotated so that as the glider moves up, the fins generate thrust. As the float sinks into the wave trough (righthand portion of FIG. **1**), the swimmer is lowered as well. The wings rotate so that the swimmer dives forward again. Both the up and down strokes generate forward thrust.

[0065] The swimmer is the component that generates forward thrust as the fins are pulled up and down by wave action. The fins are the actual elements that are actuated by the water, but it can be to view the swimmer as the wave-actuated component of the WPD. A significant use of the WPD is as a vehicle where the forces generated by the fins interacting with the wave-bearing water are used to move the swimmer in a direction having a horizontal component (hereinafter referred to simply as "horizontally" or "in a horizontal direction"). These forces, however, can be used for other purposes (e.g., power generation).

[0066] Single Rigid Tether Embodiment

[0067] FIGS. **2**A, **2**B, and **2**C show a WPD **10'** that differs from WPD **10** above in that the tether, represented by reference number **45**, is rigid rather than flexible. Despite the problems with rigid tethers discussed above, rigid tethers can provide advantages. For example, when the float descends, a rigid tether can push on the swimmer, rather than relying on the swimmer's weight to lower it to provide thrust (thus allowing the weight of the float to do useful work). Also, it eliminates the occurrence of slack in the tether, which can result in large snap loads when the slack is removed. Additionally, depending on the connection, a rigid tether can allow torque to be transmitted between the float and the swimmer such that steering alignment can be maintained, and tether twists are not possible.

[0068] While some rigid tether embodiments consist of a single rigid section without intermediate joints, in the illustrated embodiment, tether **45** has two rigid sections, upper and lower sections **47** and **48** connected at an intermediate joint **50**. Upper rigid section **47** is secured to the float through an upper joint **55** such that the upper rigid section can be in a first operating position ("extended position") in which the upper rigid section extends away from the float, or in a second folded position ("adjacent position") in which the rigid section is relatively close to the float, e.g., adjacent to the bottom of the float.

[0069] FIG. **2**A shows the tether fully extended in a swimming position. In this particular embodiment, swimmer **20** is rigidly attached to lower section **48** so that the swimmer rigid spine portion **35** remains generally vertical and fins **40** are disposed in a vertical array. This differs from the embodiment shown in FIG. **1** where the rigid spine is generally horizontal and the fins are disposed in a horizontal array. A weight **60** at the bottom of the tether/swimmer helps stabilize the tether, and the entire WPD in the vertical orientation.

[0070] When the WPD is floating in still water, and the rigid section is in the first operating position, the upper rigid section preferably lies (i) in a first plane that includes the longitudinal axis of the float and that is substantially vertical, and (ii) in a second plane that is orthogonal to the first plane and that is at an angle of at most 30°, or at most 15°, particularly at most **5**°, e.g., substantially 0°, to the vertical. In one embodiment, the upper rigid section is hinged at or near the point at which it is attached to the float so that the upper rigid section, when it is in the operating position, can pivot forward and backwards relative to the float when the WPD is in wave-bearing water, and/or so that it can move between the extended and adjacent positions. Upper joint **55**, which is between substantially rigid section **47** and the float, can be one that can be controlled, e.g., locked in the operating position and/or the folded position, for example manually or through a control mechanism, e.g., gears, operated remotely, e.g., by a winch or other mechanical or electromechanical mechanism mounted on the float.

[0071] Intermediate joint **50** is preferably configured so that it is possible for the sections to be in a first operating position in which the sections are substantially aligned, with both sections, preferably lying in a first plane and a second plane as described above, or in a second folded position in which both sections are relatively close to the float, e.g., adjacent to the bottom of the float. Joint **50**, which is between the two sections, can be one that can be controlled, e.g., locked in the operating position and/or the folded position, for example manually or through a control mechanism, e.g., gears, operated remotely, e.g., by a winch or other mechanical or electromechanical mechanism mounted on the float.

[0072] FIG. **2**B shows rigid tether **45** partially retracted with the two sections **47** and **48** partially folded toward each other at joint **50**. FIG. **2**C shows the rigid tether fully retracted, that is with tether sections **47** and **48** fully folded toward each other, and the upper section completely folded so that the WPD is in a bundle configuration suitable for launch or recovery. A lift eye **65** is provided on the top of the float at the aft end to facilitate recovery. Although not shown, the swimmer could also be provide with a lift section or pickup point, to which a line can be secured to enable the swimmer to be pulled upwards, so that the rigid section can be moved from the operating position to the folded position. The float and/or swimmer may also deploy a line with floats to enable easier recovery. A person on a recovery ship may throw a grapnel over the line and floats and then pull the bundle in.

[0073] FIG. **3** contains perspective, top, front, and side views of the WPD of FIGS. **2**A, **2**B, and **2**C in the bundled configuration.

[0074] The float can have solar panels and antennas (not explicitly shown), and a rudder **70** at the aft end that is actively steered. The folding mechanism for the rigid tether may be actuated by a cable and winch in the float, or by a worm gear drive, or by various other mechanisms. When in bundled position, the weight or rigid pole may latch into the float, to reduce stress on the folding mechanism during transport or handling. This latch may be automatically released for deployment.

[0075] FIGS. **4**A, **4**B, and **4**C respectively show show the WPD's fins at three different angles, in an up-stroke position, in a neutral position, and in a down-stroke position. The fins pivot along a pitch axis (an axis perpendicular to the vertical axis and perpendicular to the forward motion axis). Spring force may return the fin to a neutral position where it is roughly level. Alternatively, the fin may be balanced so that gravity returns it to this position. When moved up relative to the surrounding water, the fins rotate to the configuration of FIG. **4**A and generate thrust. When moved down relative to the surrounding water, the fins rotate to the configuration of FIG. **4**C, and generate thrust. Weight **60** at the bottom of the tether helps stabilize the pole, and the entire vehicle in the vertical orientation.

[0076] An alternative to the tether with folding rigid sections described above is to have telescoping rigid sections. Two or more substantially rigid sections are telescoped to each other so that the sections can be in a first operating position in which the sections are extended from each other, or in a second telescoped position in which the sections are nested together. Preferably, there is a control mechanism such that the sections can be locked, either manually or through a remote control, either in the operating position or the telescoped position. For example, the telescoping of the sections can be controlled by gears that can be operated by means of a winch or other control mechanism mounted on the float. It is contemplated that the sections would be telescoped together before the telescoped tether would be folded toward the bottom of the float.

[0077] The swimmer (wave-actuated component) embodiment illustrated above in connection with WPD **10'** had substantially rigid spine **35** rigidly mounted to lower tether section **48** and generally aligned with it. In this embodiment, the substantially rigid spine can be at an angle of at most 40°, or at most 30°, or at most 15°, to the vertical, e.g., substantially vertical; in this case, the fins can, for example, be mounted on the spine and lie one above the other in a substantially vertical plane, pivoting around a pitch axis (an axis perpendicular to the vertical axis and perpendicular to the forward motion axis).

[0078] Alternatively, the substantially rigid spine can be connected to a substantially rigid section of the tether through a connection that, when the WPD is operating in wave-bearing water, is substantially rigid, but generally extending away from the axis of the tether. The substantially rigid spine of the swimmer, when the WPD is operating in wave-bearing water, can be at an angle of at most 40°, or at most 30°, or at most 15°, to the horizontal, e.g., substantially horizontal; in this case, the fins can, for example, be mounted on the spine and lie side-by-side in a substantially horizontal plane. In either of these alternatives, the joint between the tether and the swimmer can be a fixed joint such that the spatial relationship between the tether and the swimmer is fixed or it can be a joint that permits the swimmer to move relative to the tether.

[0079] Multiple e.g., Dual Rigid Tether Embodiment

[0080] FIG. **5**A is a perspective view of a WPD **10"** having fore and aft rigid tethers **45*a*** and **45*b*** coupled between float **15** and swimmer **20**. The two rigid tethers are provided with folding or telescoping mechanisms similar to those described above in connection with the single-tether WPD **10'** shown in FIGS. **2**A, **2**B, **2**C, and **3**. In this view, the tethers are in their respective extended positions.

[0081] In this embodiment, the swimmer has two rigid spines **35*a*** and **35*b*** that define the side beams of a rectangular frame having fore and aft transverse crossbars **80*a*** and **80*b***. The fins **40** are mounted between the side beams, and the lower ends of the fore and aft tethers are attached to the crossbars by fore and aft connectors **85*a*** and **85*b***. The upper ends of the tethers are attached to float **10"** at fore and aft locations of the bottom of float by respective connectors (hidden from view). The frame also includes bottom runners **90*a*** and **90*b*** that extend below the fins and the side beams. Thus, when the swimmer is placed upon a horizontal surface, the runners separate the horizontal surface from any part of the swimmer that might otherwise be damaged by contact with the surface. This figure shows float **15** as having solar panels **95** and an antenna **100** between the solar panels. The floats of the other WPDs described above typically also include solar panels and one or more antennas, but those were omitted for clarity.

[0082] FIG. **5**B is a perspective view of the WPD of FIG. **5**A with the rigid tethers in their retracted (adjacent) positions so that the WPD is in a bundle configuration with the float sitting atop the swimmer. Again, the ability to fold or telescope the tethers and fold the retracted tethers against the bottom of the float addresses and solves the previously mentioned problems with rigid tethers. The use of multiple tethers can provide other advantages.

[0083] The use of dual tethers can reduce the likelihood that the tethers will become twisted; can enable a longer and narrower float shape (which reduces drag and increases speed); and by moving the connections and mechanisms associated with the tether to the fore and aft sections of the float, makes it possible to provide a larger central area of the float for payloads of all kinds, for example communications equipment and sensors and other scientific instruments. In addition, the use of two tethers can simplify recovery of a WPD. Recovering a WPD which has only a single tether can be difficult because pulling up on the single tether after lifting the float out of the water requires lifting the swimmer against the resistance of the fins to the water. When there are two tethers, pulling on only one of the tethers tilts the swimmer and the fins attached to it so that the resistance of the fins is reduced. This can be accomplished by tilting the float, or differentially retracting the rigid tethers so that the swimmer is no longer parallel to the float.

[0084] A WPD having a single tether generally has a tether termination assembly and load distribution structure at the center of the float, thus occupying the center of the float. The use of two spaced-apart tethers frees up the center of float, which for many purposes is the most valuable part of the float for desired components. For example, the best part of the float for tall antennas is the center, where they can cast a shadow on at most half of solar panels mounted on the upper surface of the float (shading just part of a solar panel can completely disable it if, as is often the case, the cells are wired in series and shut off like transistors when dark.) Also, tall antennas have no steering effect on the float due to wind if they are at the center. When the WPD has two tethers, the center area of the float may be free for payloads with integrated antennas, i.e., antennas which are integrated with a dry box, or kept entirely within a dry area, thus reducing the danger that routing wires to the antennas will be damaged by moisture. In addition, placing most or all of the payload at the center of float makes it easier to balance the float fore and aft, and thus reduces the danger that the float will nose in or nose up.

[0085] When the WPD has two tethers, the float preferably contains a means to steer the float, such as rudder **70** at the tail end of the float. The wave-actuated component (swimmer) provides thrust as it is lifted and lowered due to wave action. Torque from the float is transmitted to the wave-actuated component by the separation of the two tethers. The wave-actuated component thus points in the same direction as the float after a steering lag, caused by the inertia and fluid resistance to rotation of the wave-actuated component. In some applications, this can obviate the need for a rudder on the swimmer, possibly eliminating the need to run electrical wires down the inside of the tether.

[0086] The rigid tethers hold the swimmer parallel with the float. Particularly when the swimmer is held relatively level, a spring and stop system can control the angle of fins well, so that the fins operate at a favorable angle of attack during up and down motions with various speeds and amplitudes. The above-illustrated and described parallel bar structure with fin support shafts crossing between bars like ladder steps facilitates this. The position of the fins can, for example, be controlled by a spring assembly which maintains the fins at a desired neutral position, e.g., a level position, when the springs are not moving and which will resist upward and downward motion. The spring profile may be adjusted so that the wings tend to stop at an angle that is optimized for maximum lift.

[0087] While specific dimensions are not required to exploit the invention, examples will be given for completeness. For example:

- **[0088]** The horizontal distance between the front of the float and the fore tether connection location on the float can be at most 0.3 times, preferably at most 0.2 times, e.g., 0.05-0.15 times, the horizontal length of the float.
- **[0089]** The horizontal distance between the rear of the float and the aft tether connection location on the float can be at most 0.3 times, preferably at most 0.2 times, e.g., 0.05-0.15 times, the horizontal length of the float.
- **[0090]** The horizontal distance between the front of the swimmer and the fore tether connection location on the swimmer can be at most 0.3 times, preferably at most 0.2 times, e.g., 0.05-0.15 times, the horizontal length of the swimmer.
- **[0091]** The horizontal distance between the rear of the swimmer and the aft tether connection location on the swimmer can be at most 0.3 times, preferably at most 0.2 times, e.g., 0.05-0.15 times, the horizontal length of the swimmer.

[0092] Spring Arrangement for Controlling Wing Rotation with Gradations of Torque

[0093] FIG. **6** is a perspective view showing a two-spring arrangement for controlling the movement of a fin (not shown), which is part of a wave-actuated component such as that of the WPD of FIGS. **5**A and **5**B, viewed looking from between the spines (side beams). FIG. **7** is a partially cutaway perspective view showing the two-spring arrangement with one end of each spring embedded in the fin, viewed looking from outside the spines (side beams).

[0094] The spring arrangement constrains upward and downward rotation of the fins within two ranges requiring increasing torque. FIG. **6** is an upper perspective of the spring arrangement on the foremost fin to the right side beam **35***b* from behind on the inside, with the fin removed. FIG. **7** is an upper perspective of the same spring arrangement from behind on the outside, with the beam drawn transparently and showing a portion of the fin.

[0095] The fin is rotationally mounted to the side beam **35***b* by way of an axle **130** that passes transversely through the fin **40** just behind the leading edge **135** with the elevator portion of the fin **140** extending behind. The spring arrangement comprises first and second springs **145** and **150**. The first spring is wound around the axle **40** (shown in this example on the inside of the side beam **35***b*). The first spring **145** extends from the axle at one end **155** to form a hook portion disposed to provide a point of attachment for the fin. In this embodiment, the other end of the first spring, not shown, is fixed to the side beam.

[0096] The second spring **150** is also wound around the axle **130** in the same direction as the first spring **145**. In this example, the second spring is thicker, and therefore stiffer, than the first spring. The second spring **150** extends from the axle at one end **160** to form a hook portion disposed to provide a point of attachment for the fin. The second spring **150** extends from the axle at the other end **165** to form a hook portion disposed to travel between an upper stop **170** and a lower stop **175** mounted on the side beam **35***b*.

[0097] With this configuration, the first spring **145** is engaged to control the upward an downward rotational movement of the fin but the second spring is not—as long as the movement is within the range defined by the stops for the second spring. When the rotation of the fin goes beyond what is permitted by the stops, then the second spring **150** becomes engaged by encountering the upper or lower stop, depending on the direction of rotation. As a consequence, the torque required to rotate the fin is now determined by both the first spring and the engaged coil of the second spring. Thus more torque is required to rotate the fin further in the same direction.

[0098] FIG. **8** is a graph of spring torque as a function of fin (wing) angle. This is the torque required to alter the angle of a fin of the vehicle in either direction from a neutral position. The torque required to operate the fin within the inner range is determined by the first spring alone, beyond which the torque required to alter the angle in either direction is determined by the combined torque of both springs.

Specific Embodiments and Configurations

[0099] In one embodiment this invention provides a WPD that comprises a tether that will resist compression, and that also has at least one of the following features (i.e., which has one of the following features or a combination of any two or more of the following features):

[0100] When the substantially rigid spine is at an angle of most 40°, or at most 30°, or at most 15°, to the vertical, e.g., is substantially vertical, the substantially rigid spine of the swimmer and the substantially rigid section of the tether can optionally be a single monolithic component, with the substantially rigid spine and a substantially rigid section optionally being substantially aligned. In this case, the swimmer can comprise an additional weight, which helps to maintain the swimmer in a desired, e.g., substantially vertical, orientation.

[0101] In one embodiment, the tether can for example consist essentially of a single substantially rigid section having one end secured to the substantially rigid spine of the swimmer and the other end secured to the float, for example through a joint as described in (1) above. In another embodiment, the tether can for example consist essentially of first and second substantially rigid sections; the first substantially rigid section having one end secured to the substantially rigid spine of the swimmer and the other end secured to the second substantially rigid section, for example through a joint as described in (1) above; and the second substantially rigid section having one end secured to the first substantially rigid section, and the other end secured to the float, for example through a joint as described in (1) above.

[0102] The wave-actuated component (swimmer) comprises a substantially rigid spine having fins secured thereto, and the substantially rigid spine is connected to a substantially rigid section of the tether through a connection which, when the WPD is operating in wave-bearing water, is substantially rigid. The substantially rigid spine of the swimmer, when the WPD is operating in wave-bearing water, can be at an angle of at most 40°, or at most 30°, or at most 15°, to the horizontal, e.g., substantially horizontal; in this case, the fins can for example be mounted on the spine and lie side-by-side in a substantially horizontal plane. Alternatively, the substantially rigid spine can be at an angle of at most 40°, or at most 30°, or at most 15°, to the vertical, e.g., substantially vertical; in this case, the fins can for example be mounted on the spine and lie one above the other in a substantially vertical plane, pivoting around a pitch axis (an axis perpendicular to the vertical axis and perpendicular to the forward motion axis). The swimmer may comprise springs or other elastic components which return the fins to a desired neutral position.

[0103] When the substantially rigid spine is at an angle of most 40°, or at most 30°, or at most 15°, to the vertical, e.g., is substantially vertical, the substantially rigid spine of the swimmer and the substantially rigid section of the tether can optionally be a single monolithic component, with the substantially rigid spine and a substantially rigid section optionally being substantially aligned. In this case, the swimmer can comprise an additional weight, which helps to maintain the swimmer in a desired, e.g., substantially vertical, orientation.

[0104] In one embodiment, the tether can for example consist essentially of a single substantially rigid section having one end secured to the substantially rigid spine of the swimmer and the other end secured to the float, for example through a joint as described in (1) above. In another embodiment, the tether can for example consist essentially of first and second substantially rigid sections; the first substantially rigid section having one end secured to the substantially rigid spine of the swimmer and the other end secured to the second substantially rigid section, for example through a joint as described in (1) above; and the second substantially rigid section having one end secured to the first substantially rigid section, and the other end secured to the float, for example through a joint as described in (1) above.

[0105] The swimmer can comprise a substantially rigid spine having fins secured thereto, and the substantially rigid spine is connected to a substantially rigid section of the tether through a joint, for example a joint that makes it possible for the substantially rigid spine and the substantially rigid section of the tether to be (i) in a first operating position in which the fins secured to the spine generate desired forces when the WPD is in operation in wave-bearing water, or (ii) in a second folded position. The operating position and the folded position, and the joint between the rigid section and the rigid spine can for example be as described above.

[0106] Communications and Control

[0107] FIG. **9** is a is a block diagram of a control system of the type that might be used in any of the WPDs discussed herein for directing the WPD along a desired path. This figure duplicates FIG. **5** in the above-referenced U.S. Pat. No. 7,371,136.

[0108] FIG. **10** is a block diagram schematically showing a representative WPD's on-board electronics and some of the ways that the representative WPD communicates with outside entities. As mentioned above, the WPD uses satellite location systems and radio to communicate data back to an operator and to receive navigation and other commands, and has on-board computers and sensors that allow it to navigate or hold position autonomously, without regular human interaction or control.

[0109] The float contains core electronics including: satellite position sensor (GPS), radio communications (preferably sat-comm such as Iridium), an orientation sensing means such as a magnetic compass, batteries, navigation controller that uses information from the GPS and compass to control the rudder and steer the vehicle. The float may also include solar panels and various payload electronics such as environmental sensors or observation equipment such as radio monitors, cameras, hydrophones. All core electronics may be housed in the same enclosure, preferably at the tail end of the float. By keeping all the core electronics together, there is no need for wet connectors or cables in the core system. This is great reliability benefit. (solar panels and winches will connect with wet connectors—solar can be redundant so one connector can fail without taking the system down and winches are not necessary for basic functionality.) Since the GPS and sat-comm antennas are short, they will not shade the solar panels. Also the tail end is the least frequently submerged part of the float. (Submersion obscures the antennas.) however, as discussed above, with dual-tether embodiments, it is possible to house electronics and the like at the center of the float because the tether connections are near the end.

[0110] Terminology

[0111] The term "comprises" and grammatical equivalents (e.g., "includes" or "has") thereof are used herein to mean that other elements (i.e., components, ingredients, steps, etc.) are optionally present. For example, a water vehicle " comprising" (or "that comprises") components A, B, and C can contain only components A, B, and C, or can contain not only components A, B, and C but also one or more other components. The term "consisting essentially of" and grammatical equivalents thereof is used herein to mean that other elements may be present that do not materially alter the claimed invention. The term "at least" followed by a number is used herein to denote the start of a range beginning with that number (which may be a range having an upper limit or no upper limit, depending on the variable being defined). For example "at least 1" means 1 or more than 1, and "at least 80%" means 80% or more than 80%. The term "at most" followed by a number is used herein to denote the end of a range ending with that number (which may be a range having 1 or 0 as its lower limit, or a range having no lower limit, depending upon the variable being defined). For example, "at most 4" means 4 or less than 4, and "at most 40%" means 40% or less than 40%. When, in this specification, a range is given as "(a first number) to (a second number)" or "(a first number)–(a second number)," this means a range whose lower limit is the first number and whose upper limit is the second number. For example, "from 5 to 15 feet" or "5-15 feet" means a range whose lower limit is 5 feet and whose upper limit is 15 feet. The terms "plural," "multiple," "plurality," and "multiplicity" are used herein to denote two or more than two items.

[0112] Where reference is made herein to a method comprising two or more defined steps, the defined steps can be carried out in any order or simultaneously (except where the context excludes that possibility), and the method can optionally include one or more other steps that are carried out before any of the defined steps, between two of the defined steps, or after all the defined steps (except where the context excludes that possibility). Where reference is made herein to "first" and "second" elements, this is generally done for identification purposes; unless the context requires otherwise, the first and second elements can be the same or different, and reference to a first element does not mean that a second element is necessarily present (though it may be present). Where reference is made herein to "a" or "an" element, this does not exclude the possibility that there are two or more such elements (except where the context excludes that possibility). Where reference is made herein to two or more elements, this does not exclude the possibility that the two or more elements are replaced by a lesser number or greater number of elements providing the same function (except where the context excludes that possibility). The numbers given herein should be construed with the latitude appropriate to their context and expression; for example, each number is subject to variation that depends on the accuracy with which it can be measured by methods conventionally used by those skilled in the art.

[0113] Unless otherwise noted, the references to the positioning and shape of a component of the vehicle refer to that positioning and shape when the vehicle is in still water. The terms listed below are used in this specification in accordance with the definitions given below.

[0114] "Leading edge" (or leading end) and "trailing edge" (or trailing end) denote the front and rear surfaces respectively of a fin or other component as wave power causes the vehicle to move forward.

[0115] "Fore" and "aft" denote locations relatively near the leading and trailing edges (or ends) respectively.

[0116] "Aligned" denotes a direction that lies generally in a vertical plane that is parallel to the vertical plane that includes the axial centerline of the swimmer. "Axially aligned" denotes a direction that lies generally in the vertical plane that includes the axial centerline of the swimmer.

[0117] "Transverse" denotes a direction that lies generally in a vertical plane orthogonal to the vertical plane that includes the axial centerline of the swimmer.

[0118] Where reference is made herein to a feature that "generally" complies with a particular definition, for example "generally in a vertical plane," "generally laminar," or "generally horizontal," it is to be understood that the feature need not comply strictly with that particular definition, but rather can depart from that strict definition by an amount that permits effective operation in accordance with the principles of the invention.

CONCLUSION

[0119] In conclusion, it can be seen that the use of rigid tethers in embodiments of the present invention can address and overcome the problems and can provide advantages.

[0120] In the Summary of the Invention and the Description of Specific Embodiments above, and the accompanying drawings, reference is made to particular features of the invention. It is to be understood that the disclosure of the invention in this specification includes all possible combinations of such particular features. For example, where a particular feature is disclosed in the context of a particular aspect, a particular embodiment, or a particular figure, that feature can also be used, to the extent appropriate, in the context of other particular aspects, embodiments, and figures, and in the invention generally. It is also to be understood that this invention includes all novel features disclosed herein and is not limited to the specific aspects or embodiments of the invention set out above.

[0121] While the above is a complete description of specific embodiments of the invention, the above description should not be taken as limiting the scope of the invention as defined by the claims.

1. A device comprising:

(1) a float;

(2) a tether that is secured to the float, and that can assume multiple positions including at least

(a) an adjacent position in which at least part of the tether is relatively close to the float, and

(b) an extended position in which the tether (i) is extended below the float and (ii) is at least in part substantially rigid, wherein the tether can be moved from the adjacent position to the extended position; and

(3) a wave-actuated component that is secured to the tether;

the float, the tether, and the wave-actuated component being such that:

(A) when the device is in still water and the tether is in the extended position, (i) the float is on or near the surface of the water, and (ii) the tether is submerged below the float, and

(B) when the device is in wave-bearing water and the tether is in the extended position, (i) the float is on or near the surface of the water, (ii) the tether is submerged below the float, and (iii) the wave-actuated component interacts with the water to generate forces that are transmitted to the tether.

2. The device of claim **1** wherein:

the tether is in the extended position; and

the device is an autonomous wave-powered device (hereinafter abbreviated to WPD).

3. (canceled)

4. The device of claim **1** wherein the tether can be moved from the extended position to the adjacent position.

5. (canceled)

6. The device of claim **1** wherein the tether is secured to the float through a joint such that the tether can be rotated between the extended position and the adjacent position.

7. The device of claim **1** wherein the tether comprises sections that can slide relative to each other to enable the tether to be moved from the adjacent position to the extended position.

8-15. (canceled)

16. The device of claim **1** wherein the tether consists essentially of a single rigid section.

17. The device of claim **1** wherein:

(1) the tether comprises a first rigid section having first and second ends, and a second rigid section having first and second ends;

(2) the first and second rigid sections are secured to each other through a joint at their respective first ends;

(3) the first rigid section, at its second end, is secured to the float;

(4) the second rigid section, at its second end, is secured to the wave-actuated component;

(5) the wave-actuated component comprises an elongate rigid member that is connected to the second end of the second rigid section in a manner that in use the elongate rigid member and the second rigid section are substantially collinear; and

(6) the wave-actuated component comprises a plurality of fins disposed along the elongate rigid member.

18. The device of claim **1** wherein:

the tether comprises two substantially rigid sections that are secured to each other through a joint that makes it possible for the sections to be in

(a) an operating position in which the sections are substantially aligned, with both sections preferably lying in a first plane that is substantially vertical and includes the longitudinal axis of the float, and a second plane that is orthogonal to the first plane and is at an angle of at most 30° to the vertical, or

(b) a second folded position in which both sections are relatively close to the float; and

the joint between the two sections is one that can be controlled.

19. The device of claim **1** wherein the wave-actuated component comprises a plurality of fins that extend from the tether.

20. The device of claim **1** wherein the wave-actuated component comprises at least one substantially rigid spine having fins secured thereto, and the substantially rigid spine is connected directly or indirectly to the tether.

21. (canceled)

22. The device of claim **20** wherein the wave-actuated component is selected from one of the following two configurations:

(A) the wave-actuated component has a single substantially rigid spine, with fins extending on each side of the rigid spine and the rigid spine, when the WPD is in still water and the tether is in the extended position, the rigid spine is at an angle of at most 40°, or at most 30°, or at most 15°, to the horizontal, and lies in a vertical plane that passes through the longitudinal axis of the float; or

(B) the wave-actuated component has two substantially rigid spines, with fins extending between the rigid spines, and when the WPD is in still water and the tether is in the extended position, both the rigid spines lie in a plane at an angle of at most 40°, or at most 30°, or at most 15°, to the horizontal, and the rigid spines are equally spaced from a vertical plane that passes through the longitudinal axis of the float.

23. The device of claim **22** wherein, when the WPD is in still water, the fins lie side-by-side in a plane that is at an angle of at most 30° or at most 15°, to the horizontal.

24. The device of claim **20** wherein, when the WPD is in still water, the substantially rigid spine spine is at an angle of at most 40°, or at most 30°, or at most 15°, to the vertical.

25. The device of claim **24** wherein the fins are mounted on the spine, and when the WPD is in still water and the tether is in the extended position, lie one above the other, with each of the fins lying in a plane that is at an angle of at most 60°, or at most 15-45°, to the horizontal.

26-30. (canceled)

31. A fin system for use in a wave-powered device, the fin system having (a) at least one fin that rotates about an axis and that has a neutral position, and (b) a control system for controlling the rotation of the fin, the control system comprising:

a first means that controls the rotation of the fin within a first range about the neutral position; and

a second means that controls the rotation of the fin when the movement of the fins is outside the first range.

32. The device of claim **31** wherein the second means makes it more difficult for the fin to rotate within the second range than it is for the fin to rotate within the first range.

33. The device of claim **31** wherein the rotation within the first range is controlled solely by the first means.

34. The device of claim **31** wherein the rotation within the first range is controlled both by the first means and by the second means.

35. The device of claim **31** wherein the rotation within the first range is controlled solely by the first means.

36. The device of claim **31** wherein the rotation within the second range is controlled both by the first means and by the second means.

37-38. (canceled)

39. The device of claim **1** comprising two tethers that are secured to the same or different positions on the float, at least one of the tethers being movable between a first position in which the remote end of the tether is relatively close to the float and a second position in which the remote end of the tether is relatively far from the float.

40. The device of claim **39** wherein:

(a) one of the two tethers is secured to the fore section of the float and the other to the aft section of the float;

(b) the wave-actuated component comprises a substantially rigid spine having fins attached thereto;

(c) one of the tethers is secured to the wave-actuated component close to one end of the wave-actuated component, and the other tether is secured to the wave-actuated component close to the opposite end of the wave-actuated component; and

(d) when both the tethers are in the extended position and the WPD is in still water, the substantially rigid spine (i) lies in a vertical plane that includes the longitudinal axis of the float, and (ii) is at an angle of at most 40°, or at most 30°, or at most 15°, to the horizontal.

41-45. (canceled)

46. The device of claim **1** wherein the tether, or at least one of the tethers when there are multiple tethers, has at least one of the following characteristics:

(1) it has a streamlined cross-section;

(2) it is constructed of one or more materials selected from carbon-fiber-reinforced polymeric composites, fiberglass-reinforced polymeric composites, titanium, aluminum, stainless steel, or steel treated with a corrosion inhibitor;

(3) it includes a channel that extends from one end of the tether to the other and that contains electrical and/or communication cables that connect components in the float and the wave-actuated component;

(4) it comprises a single rigid section having a length of 3-30 feet or 4-12 feet, or 6-10 feet (1-10 m or 1.2-3.7 m, or 1.8-3.0 m), or two or more rigid sections that can be folded together, and which together have a length of 3-30 feet or 4-12 feet, e.g., 6 10 feet (1-10 m or 1.2-3.7 m, or 1.8-3.0 m).

47-48. (canceled)

49. The device of claim **1**, and further comprising:

(1) wireless communications equipment;

(2) a computer system;

(3) a satellite-referenced position sensor

(4) a horizontal direction sensor that senses direction in a horizontal plane; and

(5) a steering actuator;

the computer system

(a) being linked to the communications equipment, the position sensor, the horizontal sensor and the steering actuator, and

(b) containing, or being programmable to contain, instructions to control the steering actuator in response to signals received from the communications equipment, or from the position sensor and the horizontal direction sensor, or from signals received from another sensor on the vehicle.

50. (canceled)

51. A method of placing a device in water, the method comprising:

(A) placing in the water the float of the device of claim **1** through **50** in which the tether is in the adjacent position, and

(B) moving the tether from the adjacent position to the extended position while the float is above the water or after the float has been placed in the water.

52. A method of removing a device from water in which it is floating, the WPD being the device of claim **1** in which the tether is in the extended position and can be moved from the extended position to the adjacent position, the method comprising

(A) moving the tether from the extended position to the adjacent position, and

(B) removing the assembly from the water.

53. An assembly comprising a float and a tether, at least a part of which is substantially rigid, the tether being secured to the float by a connection that enables the tether to be moved from (a) an adjacent position in which at least part of the tether is relatively close to the float to (b) an extended position in which the tether is extended below the float.

54-57. (canceled)

58. A method of obtaining information, the method comprising receiving signals from, or recorded by, the device of claim **1**.

59. A method for controlling a function of the device of claim **1**, the method comprising sending signals to the device.

60. The fin system of claim **31** wherein:

the first means includes a first spring;

a second means includes a second spring;

the angular movement of the fin is primarily controlled by the first spring when the movement of the fin is within a first range about the neutral position; and

the angular movement of the fin is primarily controlled by the second spring when the movement of the fins is within a second range that is outside the first range, the second spring being stiffer than the first spring, thus making it more difficult for the fins to move within the second range.

59. A method for controlling a function of the device of any of claims **1** through **50**, the method comprising sending signals to the device.

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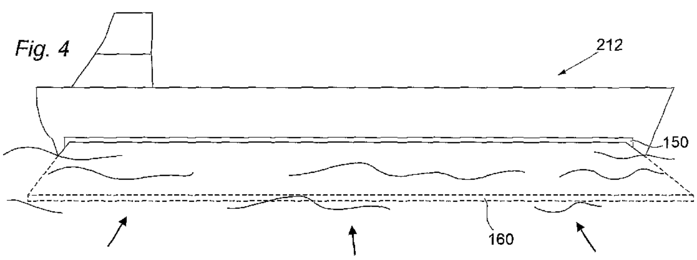
Fig. 4



(57) Abstract: A method of generating power from renewable energy, the method comprising the steps: locating a vessel offshore in waves or a tidal stream; using the energy in the waves or a tidal stream to generate heat; storing the heat in a heat store on the vessel; transporting the heat store to an onshore facility; using the heat to generate power onshore. Embodiments of the invention do not require a cable to be run from an offshore device to the onshore station and so may be used at more remote locations where the wave energy is greater. Moreover since the vessel may be directed to the most energetic waves, the vessels of the present invention operate in the most optimum conditions whereas, known fixed devices extract much less, on average, because of localised vagaries in weather and wave conditions. In preferred embodiments the energy extracted from the waves is stored as heat and in especially preferred embodiments the energy is converted directly to heat, obviating the inefficient step of conversion to electricity at source.

WO 2010/064041 A2

Improvements in or relating to Renewable Energy

The present invention relates to a method and apparatus for harnessing renewable energy and in particular, though not exclusively, to a wave energy extraction method.

There is now great interest in systems to harness the energy from tidal and/or wave power. Such systems typically operate by mounting turbines/propellers or fins on a device fixed to the seabed or floating platform. The tidal/wave power is used to turn the fins and by rotation of the shaft the kinetic energy is converted to electricity by known methods. A major disadvantage of these systems is that an electrical cable must be run from the device to the shore, so that the electricity generated can be supplied to the National Grid. Laying cables is a difficult process, is costly and cables must be regularly inspected to ensure they remain free from damage. Yet further the location of the fixed unit is limited by the length of the cable required to transport intermittent electricity to shore because of resistance losses.

Tidal and near shore fixed wave power are both also subject to variations in the energy available and have low energy densities. For example, spring and neap tides vary the energy available over a period of half a lunar month as do the flow and ebb tides themselves. Other natural renewable energy sources have similar variations e.g. solar, based on daylight hours and wind, based on speed and direction. Such fluctuations mean that electricity generated is random and uploaded to the National Grid in real time subject to the vagaries of the weather and tides. Accordingly, as consumer electricity demand on the National Grid fluctuates also at different times so that these renewable energy systems cannot match supply to demand.

It is therefore an object of the present invention to provide a method and apparatus for generating more continuous electrical power from intermittent renewable energy sources.

It is a further object of the present invention to provide a method and apparatus for generating power from renewable energy which does not require cables to be run from a vessel to onshore.

It is a yet further object of at least one embodiment of the present invention to provide a method and apparatus for generating power from renewable energy and to provide desalinated water as a by-product from a thermal generation process.

According to a first aspect of the present invention there is provided a method of generating power from renewable energy, the method comprising the steps:

(a) locating a vessel offshore in waves or a tidal stream;
(b) using the energy in the waves or a tidal stream to generate heat;
(c) storing the heat in a heat store on the vessel;
(d) transporting the heat store to be transferred at an onshore facility;
(e) using the transferred the heat to generate power onshore.

Step (b) preferably includes converting the energy in the waves or a tidal stream into heat.

Step (d) preferably includes transferring the heat to a larger thermal store located at an onshore generating facility.

Step (e) preferably includes converting the transferred heat to generate power onshore.

By storing the energy in a heat store onboard the vessel and transferring it onshore, as heat, there is no requirement to run cables over the seabed. The power can be generated thermally onshore at any time, as a heat store can also exist onshore. In this way the electrical power supply is non-intermittent as it is not dependent on the ‘real time’ availability of waves. The vessel will typically remain offshore until sufficient heat has been generated either directly or indirectly from the waves and stored. Supply of heat to the on-shore thermal store need not be constant because the onshore generating plant can typically operate at full rating for a period of time, for example over 6 days, without thermal ‘top ups’ from the wave energy converter stations

One apparatus for capturing wave power is described in WO02/25107 which is hereby incorporated by reference in its entirety.
A ramp is preferably provided from an aperture in the vessel. Preferably it is extended to a depth below the waves having an average height h, to a depth at least h below the average trough of the waves.

Preferably the kinetic energy in the wave/tidal steam is used to directly generate heat, that is there is preferably no intermediate stage where the energy is converted into electricity. The kinetic energy may be used to rotate a shaft, whereby rotation of the shaft within a heat transfer fluid increases the temperature of the fluid preferably when it is forced through a restriction. In this way the heat transfer fluid acts as a thermal accumulator. By retaining the heat transfer fluid in an insulated container we have a heat store. The heat transfer fluid may be any suitable fluid - water is preferred.

Typically the heat transfer fluid is maintained under pressure – for certain embodiments the temperature of the heat transfer fluid may be up to 400 ºC or more. Thus when water is used as the heat transfer fluid a pressurised heat store is preferred since it is preferred to largely maintain the heat transfer fluid as a liquid.

Alternatively the energy may be transferred to heat by directing pressurised hydraulic oil to a hydraulic motor that rotates a shaft that forces a continuous flow of the heat store’s fluid through a restriction by means of suitable device such as an immersed Archimedes’ screw connected directly or indirectly to the main power take-off shaft thus causing the temperature to rise in direct proportion to the dynamic shaft power.

Thus generating heat directly from the energy received is normally a more efficient process than converting it into electricity first and then into heat.

Nevertheless in an alternative embodiment, a shaft receiving the energy may power a DC generator and preferably a so-called ‘wild DC’ generator which in turn heats the heat transfer fluid, optionally via one or more bank, preferably banks, of DC immersion heaters in direct proportion to the dynamic shaft power. Thus for such an embodiment, whilst the energy is first converted to ‘wild DC’ electricity it is thereafter converted to heat in direct proportion to the applied shaft power, and subsequently transferred to the shore, as heat. The inventor of the present invention has noted that the conversion to wild DC and then to heat is much more effective than the conversion of shaft power into truncated and regulated AC and then to heat.

For certain embodiments, the potential and kinetic energy may be stored as heat in a solid heat storage media, such as magnesium hydride as described in “High Temperature Metal Hydrides as Heat Storage Materials for Solar and Related Applications” (Int J Mol Sci. 2009 January; 10(1): 325–344) the disclosure of which is incorporated herein by reference in its entirety.

Thus storage of heat energy according to the present invention includes storage of energy in solid media or form.

Preferably a portion of the heat generated and stored on the vessel is used to power the vessel by means of steam turbines.

Preferably the heat is transferred through a heat exchanger as is known in the art. More preferably, the transferred heat is used to drive a steam turbine. Advantageously electricity is generated from the shaft of the steam turbine as is known in the art. The electricity may be fed to the National Grid or may be used in a private supply. In this way the power generated can be continuous base load, peak shaving or load following.

Advantageously the vessel may include further renewable energy gathering means to directly generate heat. These may include one or more solar panels and/or wind turbines.

In the case of wind turbines, preferably a vertical axis turbine is used. They are particularly suitable for use in relatively hot climates where strong winds are present at the coast during daybreak and nightfall. Moreover in any situation the wind turbine may be used whilst the ship is in harbour and provide additional power to the vessel’s thermal stores.

The heat store may comprise a plurality of separate containers. For example in one embodiment four containers are provided and heat may be exchanged with suitable facilitates onshore.

In an embodiment of the present invention the transferred heat is used to desalinate sea water. Advantageously the desalination treatment is conducted in the same process as operating the steam turbine. In this way, desalination can be considered as a by product of the method. Additionally, power generated onshore can be used to pump the desalinated water inland to provide irrigation for food production. Advantageously, excess heat in the pure water produced following desalination can be extracted to provide space heating for domestic, commercial, agricultural or horticultural use including hydroponics

According to a second aspect of the present invention there is provided apparatus for generating power from renewable energy comprising a vessel containing a plurality of fins or Archimedes' screw upon a shaft; the shaft being located to rotate in a heat transfer fluid when tidal or wave power acts upon the fins or the screw; the heat transfer fluid being contained in a heat store.

Preferably an aperture is provided in a hull of the vessel to receive waves therein, wherein the aperture is typically at least 1m height, preferably at least 2m in height, optionally more than 3m in height.

Normally the aperture is at least 2m width, preferably at least 5m width, and may be more than 15m width.

Preferably the aperture extends along at least 75%, more preferably at least 95% of the length of the vessel.

Preferably a ramp is provided extending from the aperture. The ramp may be retractable.

The average height and the average trough of the waves is taken over a timeline of 5 minutes.

Typically waves travel into the aperture and contact the energy capture device.

Preferably the heat transfer fluid is forced through a restriction also contained in a heat store to release the dynamic shaft power as heat in direct proportion to the applied shaft power.

By storing heat upon the vessel, the vessel does not require to have any physical connections onshore. In particular, an electrical cable is not required to transfer converted energy to shore

The vessel may include a heat exchanger. Alternatively and/or additionally a heat exchanger may be located at an onshore facility. Preferably the onshore facility includes a thermal store. Preferably the onshore facility includes a steam turbine rotating a drive shaft to generate electricity.

Preferably the vessel includes a steam turbine. The steam turbine may have a drive shaft rotatable to generate electricity such as a propeller drive shaft. In this way, the vessel can be self propelled.

Thus embodiments of the invention provide a non-intermittent supply of electricity from a renewable energy system which collects renewable energy offshore to generate heat, stores the heat in a thermal accumulator, which is then transported ashore to a heat store. The heat can then be used to generate electricity. Ceramic plate power modules may also be used to convert heat into DC electricity. The DC electricity can be transmitted as HVDC or inverted locally to Grid Quality AC electricity.

Preferably the onshore facility includes a desalination plant. More preferably the plant includes a flash evaporator and a condenser as are known in the art.

An alternative aspect of the present invention is provided where it is impossible to use ships to bring off-shore renewable energy ashore as heat. For such embodiments, fixed location marine renewable energy systems could benefit from generating Varying High Voltage Direct Current (VHVDC). The electrical power so generated would be in direct proportion to the prime mover's dynamic shaft power and the varying voltage subject to the multiple pole Direct Current Generator's shaft velocity. The VHVDC electrical power is fed to arrays of immersion heaters fitted to a large thermal store ashore that will be charged up with heat. Electricity is generated from thermal storage in line with the utility grid's demands using known in the art thermodynamic processes. Advantageously, the electrical current, in amperes, flowing through the sub-sea cable can be reduced from shore by increasing the resistance of the immersion heating load allowing the voltage to rise in direct proportion to the increased resistance. This allows the off-shore renewable energy ‘farm’ to expand without having to lay a new cable with a larger cross sectional area of the subsea conductors.

The inventor of the present invention has also noted that the area of a sin wave above the x-axis is (2 x wavelength x height) / π.

An embodiment of the present invention will now be described, by way of example only, with reference to the following drawing of which:

Fig. 1 is a schematic illustration of apparatus for generating power from renewable energy according to an embodiment of the present invention;

Fig. 2 is a flow diagram showing the processing of heat recovered from a vessel in accordance with the present invention;

Fig. 3 is a side view of a second embodiment of a vessel in accordance with the present invention;

Fig. 4 is a side view of a third embodiment of a vessel in accordance with the present invention;

Fig. 5 is a perspective side view of the Fig. 4 vessel;

Fig. 6 is a sectional end view of the Fig. 4 vessel with the energy capture device removed for clarity; and,

Fig. 7A and 7B are one example of an energy capture device used in accordance with the method of the present invention.

Reference is made to Figure 1 of the drawings which illustrates an apparatus, generally indicated by reference numeral 10, for generating power from renewable energy according to an embodiment of the present invention.

Apparatus 10 comprises a vessel 12 that is positioned in the most energetic of pelagic waves within the vessel's prospect area. In the hull 14 there are located two ducts or channels having one or more shafts 18 located perpendicularly thereto within the fluid pathway. Each shaft has a plurality of fins, typically 5 to 7, mounted thereon which can be turned on the kinetic energy of a wave or tidal stream. The shaft 18 is mounted to a gear box which via the rotation causes the shaft to rotate with a heat transfer fluid 20. As by known physics principles, the rotating shaft will heat up the fluid, raising its temperature. The more the shaft rotates in the waves or tidal stream, the increase in temperature that will be experienced by the fluid 20 will be in direct proportion to the shaft power derived from the extractable kinetic and potential energy of the wave. The fluid 20 is contained in a heat store 22 which can be considered as a thermal accumulator.

The apparatus also includes an onshore facility 30. The facility 30 has a thermal store 32 wherein the heat from the fluid 20 is transferred. The thermal store 32 will contain a further heat transfer fluid 34 so that the heat collected offshore can be stored at the facility 30. Heat is transferred between the fluids 20 and 34 via a heat exchanger. Thus the vessel 12 can dock at a harbour 36 and transfer heat from its store 20 to the thermal store 32. In the embodiment shown, sea water 38 is pumped through a line 40 to a heat exchanger 42. Here the sea water is heated by location against a condenser 44. The sea water 42 is further heated by passing through the thermal store 32 and then passes into a flash evaporator 46. The flash evaporator separates the salt from the pure water. The waste liquid 48, being a saturated solution of salt, is drawn off and can be used for other purposes.

Meanwhile the heated water is used to run a steam turbine 50. The steam turbine 50 is used to generate electricity 52 by known methods, typically through a drive shaft of the turbine. The resultant water is then passed through the condenser 44 to provide pure water 54 which will have an elevated temperature. This heat in the water 54 may be extracted for use in domestic or horticultural applications, such as heating greenhouses.

Further features which may be included are a solar panel 60 and/or a wind turbine 62 upon the vessel 12. Each of these will be used to further heat the fluid 20. Additionally, a steam turbine 66 can be located on the vessel

12, such that the stored renewable heat on board can be used to power the vessel in order to move it freely to varying offshore locations and the harbour 36.

It will be apparent that additional vessels can be used, each transferring their heat store to the onshore facility 30. Likewise multiple facilities could be located around the coast to provide electricity or desalinated water where it is most needed. Each vessel can then be directed to unload renewable heat at the most appropriate facility.

In this way, shaft power is transferred to heat which in turn is transferred back to shaft power, according to an embodiment of the present invention. This is in contrast to the prior art systems which do not provide the heat conversion. It is through the heat conversion, that wave energy can be stored for transport to shore, stored, and converted to ‘firm’ electricity from storage subject to demand.

By storing heat at the facility, electricity can be supplied to the National Grid on a continuous base load mode, a peak shaving mode or a load following mode. In this way the most effective transfer of electricity to the National Grid is achieved. Yet further, because electricity is generated from heat storage and can do so for over 6 days without any thermal input from the vessels it is not subject to the fluctuations and the availability of wave energy. The vessel is nomadic and seeks out and captures energy from the waves at any location in its prospect area regardless of availability and the time of day making the harvesting process effective also.

It is a principle advantage of the present invention to provide a method and apparatus for generating power from renewable energy which is firm and secure.

It is a further advantage of the present invention to provide a method and apparatus for generating power from renewable energy which does not require cables to be run from a vessel to onshore.
It is a yet further advantage of at least one embodiment of the present invention to provide a method and apparatus for generating power from renewable energy and to provide desalinated water as a by-product.

A further embodiment is shown in Fig. 3 comprising a vessel 112 with a wave energy extraction device 114 and a heat store 116.

A larger vessel 212 is shown in Fig. 4 and Fig. 5 which has an aperture or 150 extending almost the full length of the vessel 212. From the aperture 150, a ramp 160 is extended into the water. The ramp is at a slight angle – preferably a maximum of 7 degrees to the horizontal to minimise reflective losses. The ramp 160 and aperture 150 thus provide an “artificial beach”. Fig. 6 shows the artificial beach in the bow of the vessel. The beach is split into a plurality or seawater pathways each a single shaft and paddle mounted thereto within each seawater pathway. Each shaft has a single paddle with a rubberised skirt attached to its toe and is rotated through 75 degrees or thereby as the oncoming wave strikes the paddle which operates a crank on the paddle’s shaft. The wave, having passed under the paddle at the end of the first stroke, returns by means of a parabolic reflector at the top of artificial beach to return the paddle to its start position. Kinetic and potential energy extracted from the wave during both strokes and converted to heat by direct or indirect methods by known principles of physics.

In use, the vessel 112 is positioned to receive the most energetic waves in the artificial beach. Any suitable wave energy capture device, such as that described in WO02/25107 may be used in the vessel 112 to extract energy from the waves.

In particular as shown in Fig. 6, the ramp 160 is extended to a position much deeper than the waves 162. The inventor of the present invention has recognised that the water below the troughs of a wave 162 also has recoverable energy and rather than extracting energy merely from the visible surface sinusoid of the wave, having the ramp 160 extend lower than the straight line between troughs will recover energy in the ‘wave stream’ moving at the same velocity as the dispersant wave velocity immediately below the wave’s surface profile.

One suitable wave energy device 301 is shown in Figs. 7A and 7B and described in more detail in WO 0225107.

A wave 328 travels over a flexible skirt 324 of a paddle 302 and impinges upon a lower portion of a forwardly directed wave engagement face 304, transferring at least some of the momentum of the wave 28 to the lower portion of the paddle 302 which subsequently rotates rearwardly through around 75 degrees of arc about a pivot 310. As shown in Fig. 7A, as the paddle 302 rotates from a more forwardly position, a flexible skirt 324 is also pushed rearwardly by the wave 328 so that a proximal portion 330 thereof, located adjacent the lowermost edge 322 of the paddle 302 passes thereunder thereby drawing a distal end 330 rearwardly thereafter. The wave 328 thereafter passes underneath the flexible skirt 324 and exits at the distal end 330 thereof and travels upwardly along the forwardly directed concave reflecting surface 320 of the reflector wall 318. As shown in Fig. 7B, the direction of travel of the wave is reversed as indicated by arrow B as a result of the wave being directed forwardly by the reflecting surface 320 so that the wave is now a reflected wave 332. The reflected wave 332 is directed forwardly by the reflecting surface 320 and the base 315 which is sloped forwardly at an angle of approximately 8 onto the rearwardly directed wave engagement face 306 of the paddle 302. The reflected wave 332 imparts at least portion of its momentum to the lowermost edge 322 of the paddle 302 and to the rearwardly directed wave engagement face 306 to rotate the paddle 302 back towards the original position. The reflected wave 332 acts to push the proximal end of the skirt 324 forwardly of the device 301 and under the lowermost edge 322 (see Fig. 7B), wherein when the paddle 302 passes through the neutral position. The lowermost edge 322 of the paddle 302 is raised as the paddle 302 moves to the first position, the reflected wave 332 continues to act upon and push the skirt 324 forwardly thereby drawing the distal end 320 of the skirt 324 forwardly thereafter whereupon when the skirt 324 again reverts leaving the device 301 in the (starting) position. In this way energy may be extracted from the waves.

The normal practice in the art of energy generation is to avoid heat loss wherever possible. This is because the energy is normally derived from finite resources which must be mined such as coal. Thus there is presently a mindset in the industry against the use of thermal storage because of the inevitable heat loss.

The inventor of the present has gone against this mindset and recognised that whilst thermal loses should be minimised, the generation of the heat is received from the abundant and renewable wave, tidal or wind power and so such losses are not as critical as they would be for energy generation by more traditional combustion means. For example, predicted heat losses of 5% can be attenuated by storing 105% of the target heat store capacity from an infinite resource.

A further benefit of the present invention is the harvesting of wave power in the pelagic sea rather than closer to the shore. This results in a benefit because waves will lose much of their energy as the water shallows approaching the shore. Wave extraction devices close to shore can only recover energy from these energy depleted waves

Moreover many existing offshore wave energy devices extract energy from the surface of the waves. In contrast preferred embodiments of the present invention also extract energy from the wave stream present below the wave surface. Indeed the inventor has recognised that the energy available is a function of the overall 'effective height' of the wave. The effective height is determined by adding the height of the wave and the depth of the toe of the artificial beach together. Further, conventional wave turbines are situated 3 – 4 miles offshore since the cable connecting them to the onshore facility cannot be longer due to resistance losses. However at this distance the sea is typically shallow so that energy is lost from the waves and the availability of waves in a fixed location is low. Thus the present invention benefits by seeking out and harvesting wave energy in different locations, thereby increasing the availability of waves within areas of the sea which are much deeper and so have much larger waves.

Indeed comparing wind and fixed near shore wave power –near shore waves are 25-fold more energy dense than wind. Comparing fixed near shore wave power with nomadic pelagic wave power – the latter is 200-fold more energy dense than the former.

A fixed location conventional wave energy extraction device can receive around 5kW/m of wave front averaged over a year. This figure is low because the waves, when available, have to come to the device. Flat calm periods in this one location may amount to over 60% of the year. However, the ship is nomadic and can seek out the most energetic waves wherever they are in the prospect area on a day to day basis. The almost omnipresent waves which provide energy to the present invention raise the energy density to around 1MW/m because almost all the 'no wave' or flat calm periods in hours are all but eliminated from the denominator of the fraction.

Another aspect of this invention is that existing fossil fuel thermal power stations can be converted by providing an alternative wave derived heat source (store). The existing grid connected steam turbine generators can then use 'green' steam instead.

It will be appreciated by those skilled in the art that various modifications may be made to the invention herein described without departing from the scope thereof. For example, any renewable energy power collection means may be used on the vessel to heat the fluid. The entire heat store may be transferred onshore and a replacement heat store be located on the vessel.

Claims

1. A method of generating power from renewable energy, the method comprising the steps:
(a) locating a vessel offshore in waves or a tidal stream;
(b) using the energy in the waves or a tidal stream to generate heat;
(c) storing the heat in a heat store on the vessel;
(d) transporting the heat store to an onshore facility;
(e) using the heat to generate power onshore.

2. A method as claimed in any preceding claim, wherein the heat transfer fluid comprises water.

3. Apparatus as claimed in claim 1 or claim 2, wherein a ramp is extended from an aperture in the vessel into water having waves, said waves having an average height h, and wherein the ramp is extended to a depth at least h below the average trough of the waves.

4. The energy in the wave/tidal steam is used to directly generate heat.

5. A method as claimed in claim 4, wherein step (b) includes using the energy in the waves to rotate a shaft in a heat transfer fluid to generate heat.

6. A method as claimed in claim 4 or claim 5, wherein step (b) includes the step of using the energy in the waves to direct pressurised hydraulic oil to a hydraulic motor that rotates a shaft that forces a continuous flow of the heat store's fluid through a restriction by means of suitable device such as an Archimedes' screw.

7. A method as claimed in any one of claims 1 to 3, wherein step (b) includes the step of using the energy in the waves to rotate a shaft to power a DC generator, especially a wild DC generator, which in turn heats the heat transfer fluid via at least one immersion heater.

8. A method as claimed in any preceding claim, wherein a portion of the energy recovered from the waves, preferably a portion of the heat generated and stored on the vessel, is used to power the vessel.

9. A method as claimed in any preceding claim, wherein in step (e) the transferred heat is used to drive a steam turbine and to desalinate sea water.

10. Apparatus for generating power from renewable energy comprising a vessel containing a wave energy capture device comprising a shaft having a plurality of fins, or Archimedes' screw; the shaft being located to rotate in a heat transfer fluid when tidal or wave power acts upon the fins or screw; the heat transfer fluid being contained in a heat store.

11. Apparatus as claimed in claim 10, wherein an aperture is provided in a hull of the vessel to receive waves therein, wherein the aperture is at least 1m height x 2m width, preferably at least 1m height x 5m width, and may be more than 2m height x 15m width; such that in use, waves travel into the aperture and contact the energy capture device.

12. Apparatus as claimed in any one of claims 10 to 11, wherein the ramp is provided at an angle less than 10 degrees to the horizontal, preferably at most 7 degrees.

13. Apparatus as claimed in any one of claims 10 to 12, wherein the vessel includes a steam turbine with a propeller drive shaft.

14. An onshore facility for receiving energy from a vessel, the onshore facility comprising a thermal store and a steam turbine rotating a drive shaft to generate electricity.

15. An onshore facility as claimed in claim 14, wherein which includes a desalination plant.

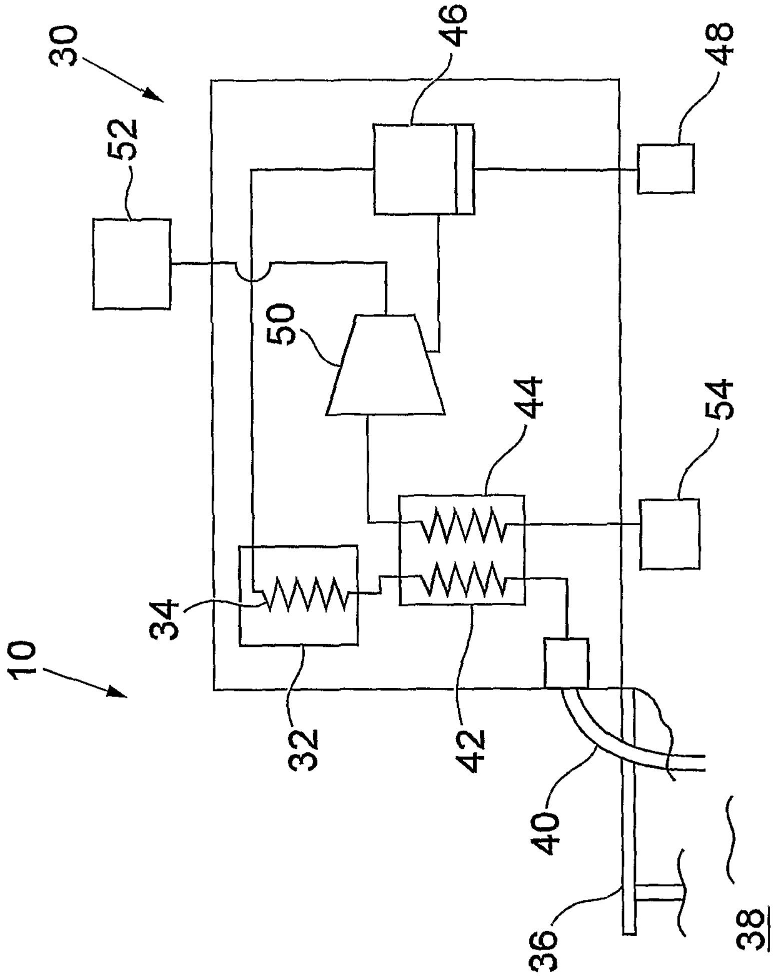


Fig. 2

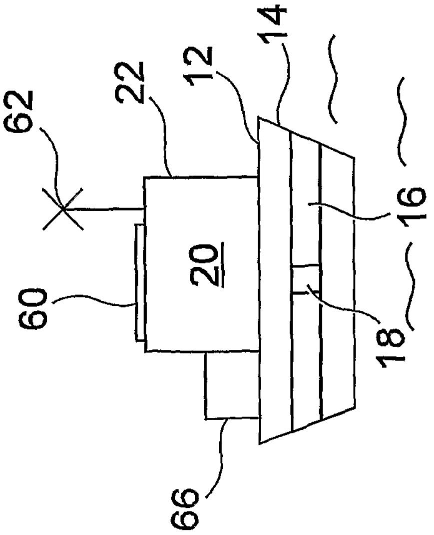


Fig. 1

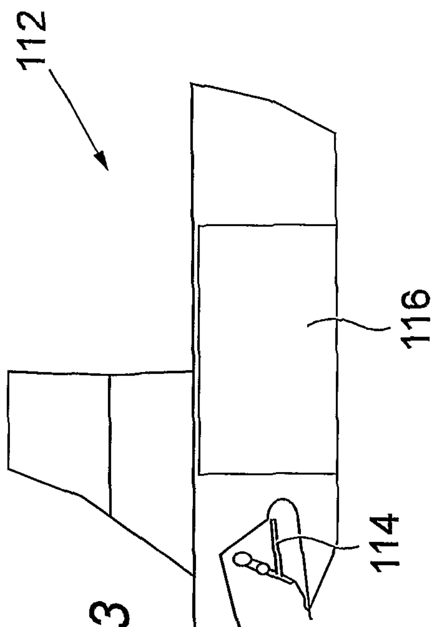


Fig. 3

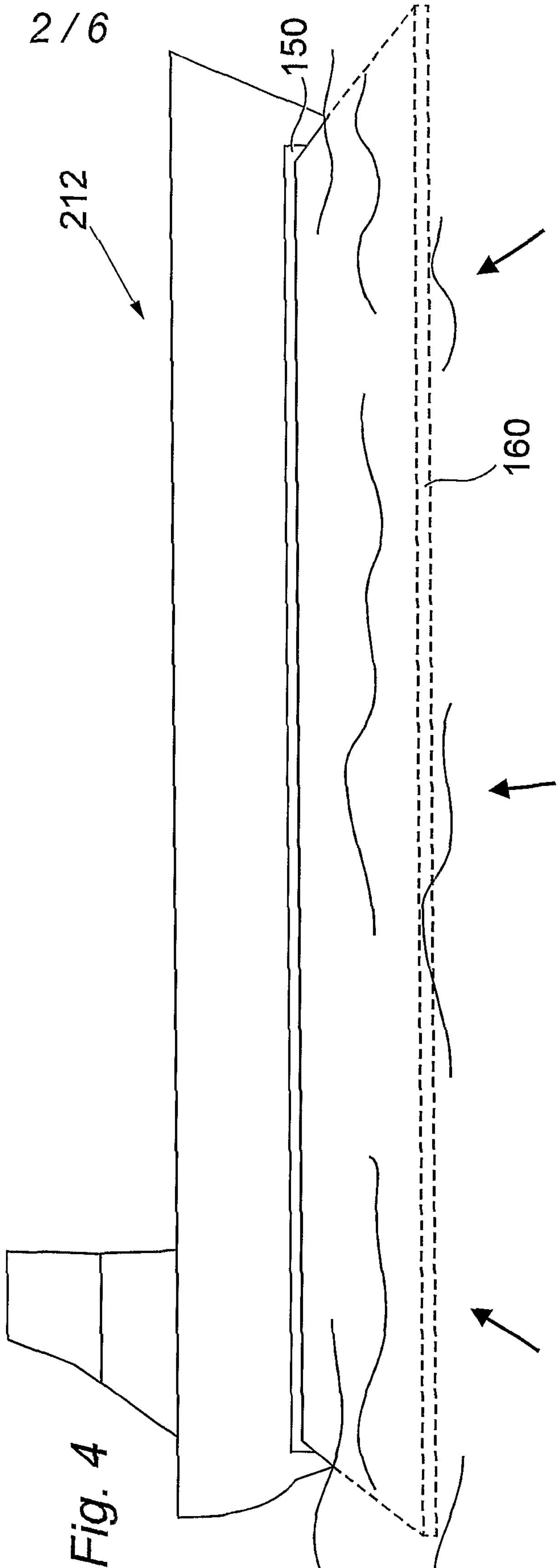


Fig. 4

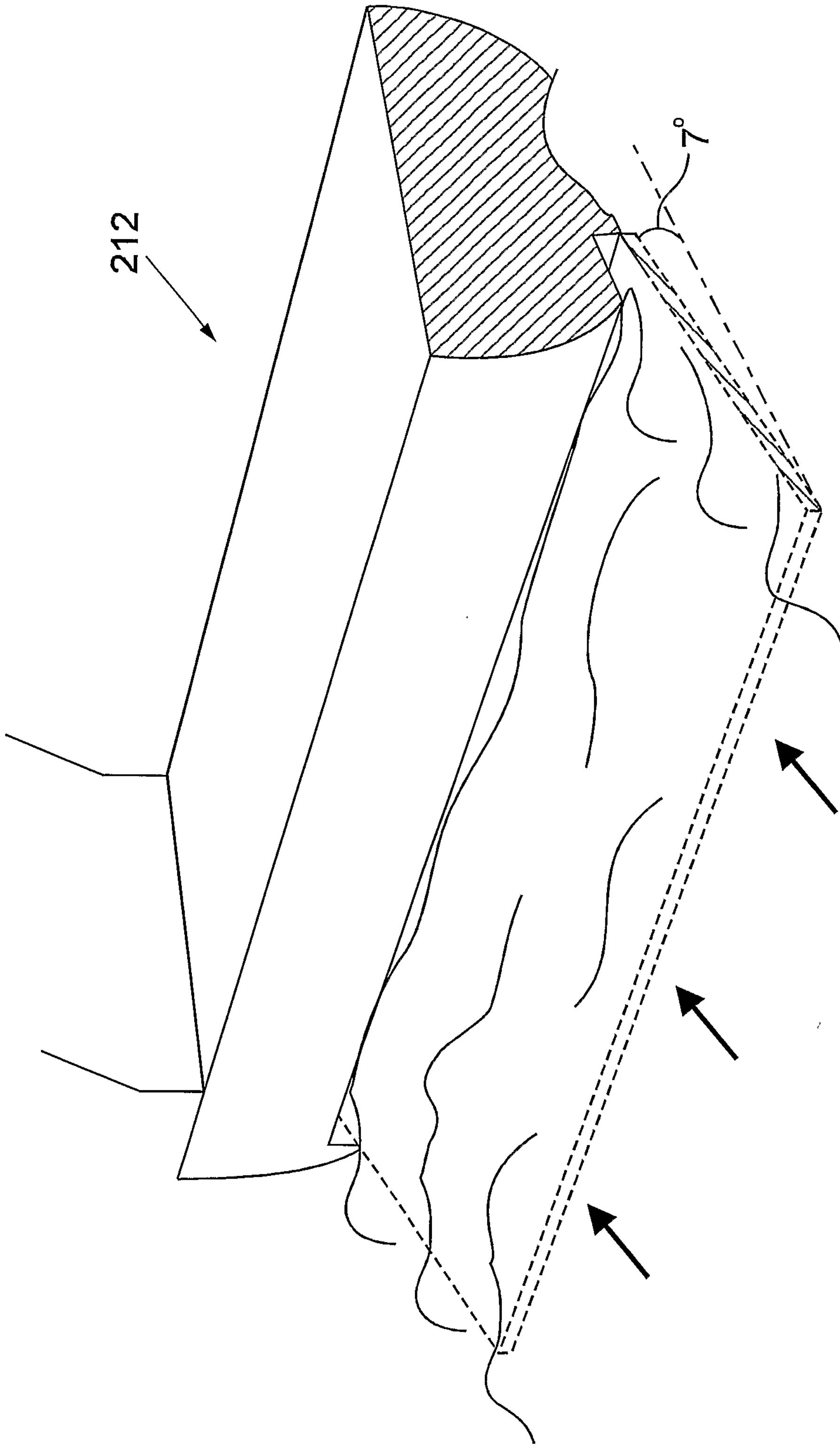


Fig. 5

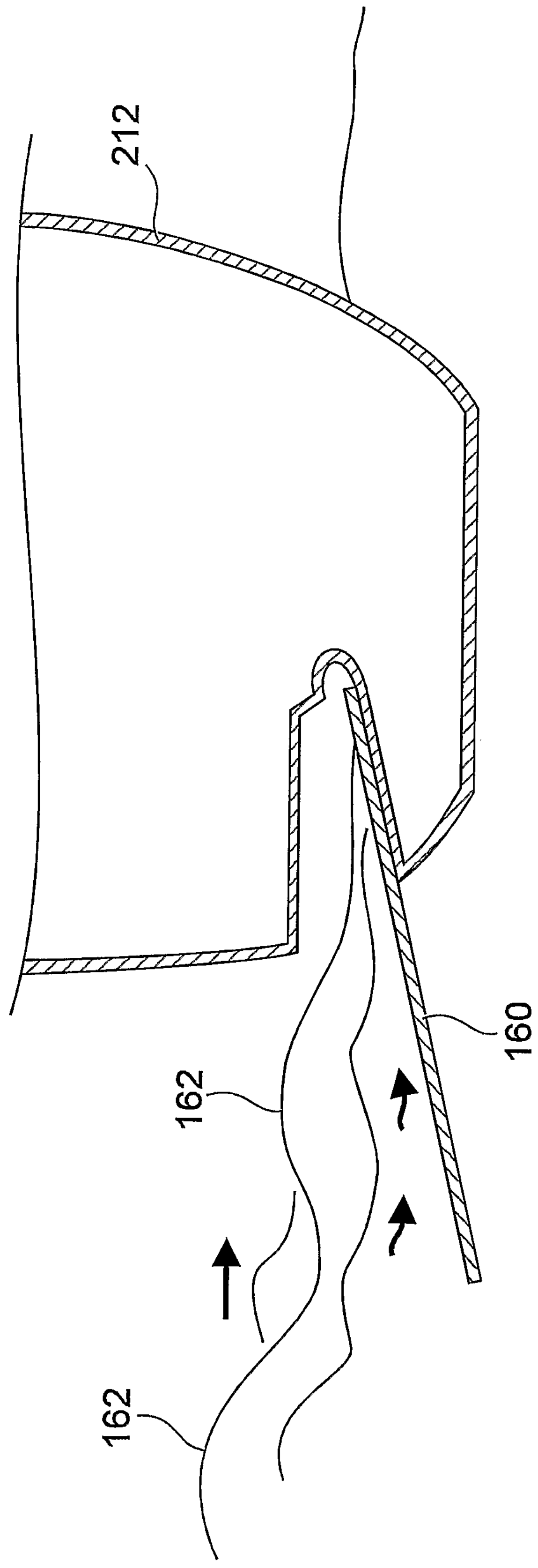


Fig. 6

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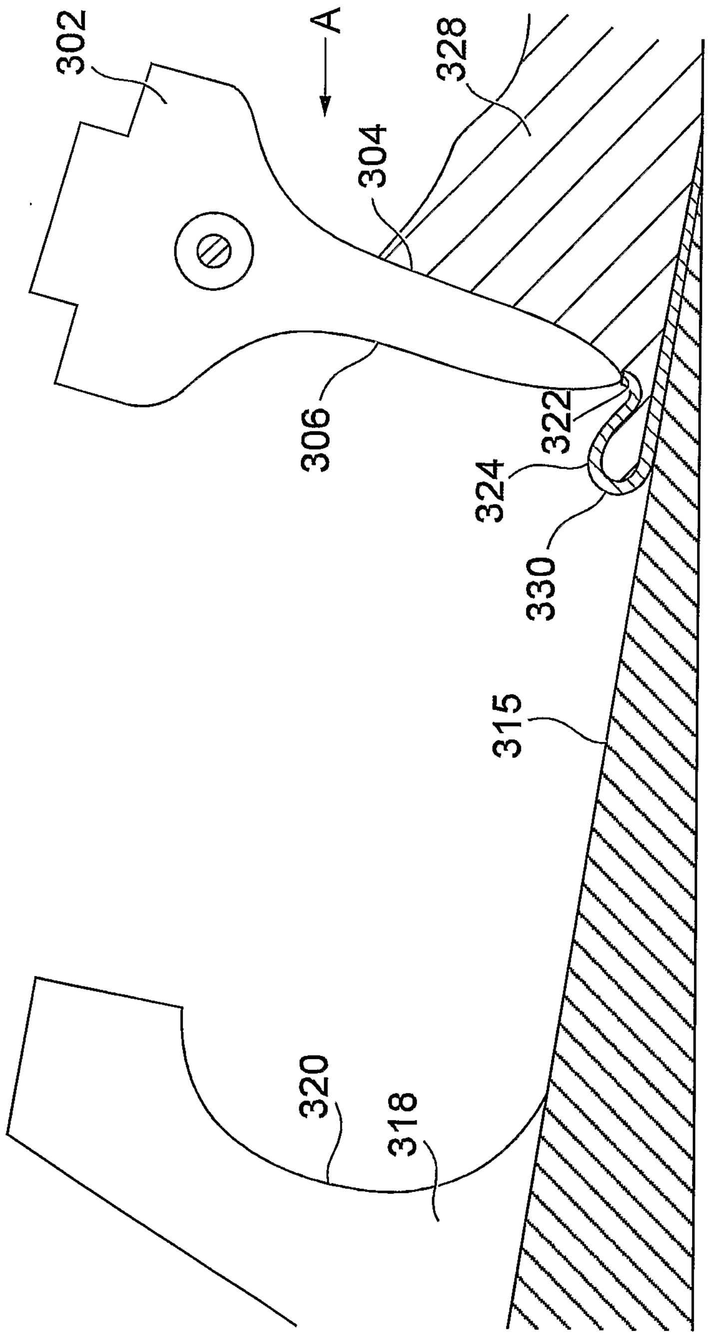

Fig. 7A

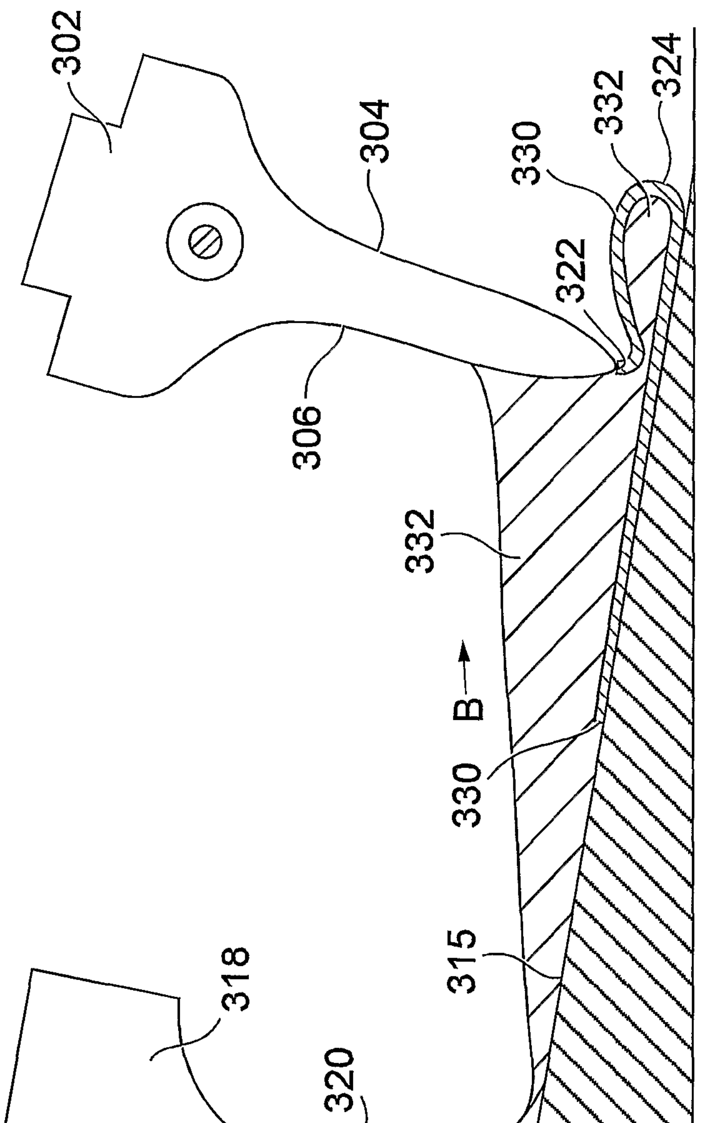

Fig. 7B

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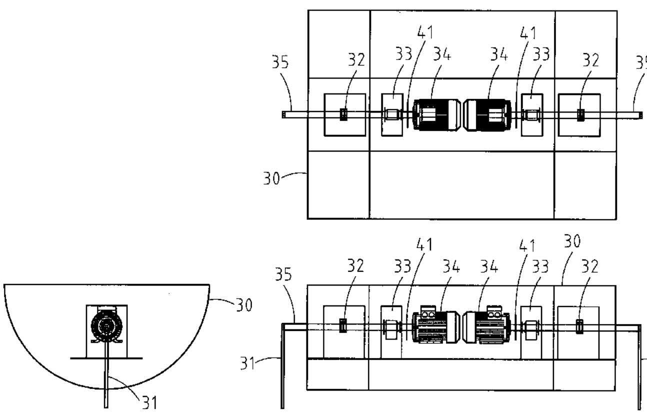

Fig. 7

(57) **Abstract:** A system of converting wind and wave energy into movement of a drive train comprising a vessel, having a substantially cylindrical shaped hull, or another shape designed to the give the vessel optimal roll characteristics, adapted to roll freely on water in response to the wind and/or water wave energy; and a mooring system, suitable for connecting the vessel with an anchor, the mooring system adapted to capture the relative movement between the vessel and the anchor in response to the rolling, pitching and/or vertical motion of the vessel on water, and convert the relative movement into movement of a drive train to generate electricity. The wind capture system is adapted to amplify the hulls rolling motion by increasing the wind heeling load on the hull at a forward point of roll and decreasing the wind heeling load on the hull at an aft point of roll. The wind capture system comprises a system of shutters or vanes in which wind heeling load on the hull is varied by opening and closing the shutters or moving the vanes.

WO 2009/080361 A2

A POWER GENERATION SYSTEM

Introduction

The invention relates to a power generation system suitable for converting wave and/or wind energy into movement of a drive train. In particular, the invention relates to a power generation vessel suitable for converting wave and/or wind energy into movement of a drive train.

Energy is produced from a variety of sources such as fossil fuels, nuclear energy, solar energy, and water movement. Nowadays, fossil fuels and carbon represent the base of energy resources in terms of dependency. However, depletion and pollution are the biggest financial and environmental concerns for society.

The use of tidal and/or wave movement from the sea provides an energy source that is abundant and does not produce waste products that present pollution problems. Wave energy is a viable environmentally acceptable option since it comes indirectly from the sun via the wind. Wave energy is concentrated at the sea surface and decreases with depth below the surface. Near the surface, there is vigorous movement of water up and down and horizontally, and the pressure of water cyclically increases and decreases as waves move over a location.

Numerous prior art systems have been developed to harness the power of wave and/or wind energy. For example, German patent publication number DE 38 035 70 A1, ZELCK GERD, discloses a system that combines wind and wave driven generators in the same floating structure/device, but with no functional interaction between wind and wave devices. An encircling and connected array of wave overtopping devices is used to create a lagoon. Floating in the lee or shelter of the overtopping devices are a number of standard type horizontal axis wind turbines. However this German system does not generate power by vessel vertical and oscillatory motion.

US Patent Number US 4,993,348 discloses a conceptual design of a vessel for transport and sustainable living at sea. Much of the concept appears to be of doubtful efficacy, particularly the hydro-foil type mechanism. The vessel also incorporates some type of vertical axis wind vane and it appears that it can be used both for propulsion as a sail and as a power generation system. A wave stream turbine is used to capture wave energy as the vessel moves. The design is not a stationary or moored hull and does not generate power from the vessel's vertical and oscillatory motion as induced by the action of the waves and the wind. It does not make the power generated on the vessel available to systems and end-users external to the vessel

US Patent Publication Number US 2006/261597 discloses a combination of submersible current generators mounted on redundant gas and oil platforms and oscillating buoys with some form of direct drive to submerged generators. It is not a stationary or moored hull, and it does not generate power from a vessel's vertical and oscillatory motion as induced by wave and wind forces on the hull.

PCT patent publication number WO 2007/142338 discloses a design of a catamaran type vessel using a wind energy converter to drive a propeller. Polar diagram are provided to indicate the effectiveness of the drive system. It appears in one embodiment that vertical axis wind turbines can be set, depending on the apparent wind angle to the vessel, either as sails, or allowed to spin and thereby indirectly drive a propeller type propulsion system. In an embodiment a venturi type opening is shown in the vessel's superstructure with the apparent intention of accelerating airflow through the superstructure whose energy can be captured and used. Another embodiment appears to use horizontal axis wind turbines on a catamaran type vessel to either generate power or provide propulsion. Another vessel places horizontal axis wind turbines on a float structure for power generation. While it appears that this design can generate power while stationary, it is not a single integral hull, and it does not generate power by vessel vertical and oscillatory motion as induced by wave and/or wind forces on the hull.

The elusive goal of designing an optimal wave energy capture device continues but with minimal success. Thus, a need still exists for a practical and economical system that will effectively accommodate variations in the wave energy source to provide an efficient wave energy conversion means to supply electrical power.

Statements of Invention

According to the invention, as set out in the appended claims, there is provided system of converting wave and/or wind energy into movement of a drive train comprising:

a vessel, having a hull, for example a substantially cylindrical shaped hull, adapted to roll on water in response to wave and/or wind energy; and

a mooring system, suitable for connecting the vessel with an anchor, the mooring system adapted to capture the relative movement between the vessel and the anchor in response to the rolling, pitching and/or vertical motion of the vessel on water, and convert the relative movement into movement of a drive train to generate electricity.

The advantage of the invention is that the vessel makes use of the oscillatory wave motion of water to capture the wave power by means of a vessel having a mechanical drive train. In addition the invention can make use of wind as a roll enhancing/amplifying energy input to maximise the rolling or oscillatory motion of the vessel, thereby generating energy by virtue of the rolling of the vessel. The shape of the hull is designed to give the vessel optimal roll characteristics in response to wave and/or wind energy.

Ideally, the vessel may additionally comprise a wind capture system capable of controllably presenting a variable wind heeling load to amplify the hulls rolling motion. In this manner, the hull rolling motion is amplified so as to amplify the relative motion between the vessel and the anchor, which increases the movement of the drive train.

Suitably, the wind capture system is adapted to amplify the hulls rolling motion by increasing the wind heeling load on the hull at a forward point of roll and decreasing the wind heeling load on the hull at an aft point of roll. The term “forward point of roll” should be understood to mean that position when the vessel is heeling to windward. The term “aft point of roll” should be understood to mean that position when the vessel is heeling to leeward. Generally, the variation of the wind loading on the hull is synchronised with the rolling of the hull. Thus, in one embodiment, the wind capture system is operatively connected to the mooring system or the drive train such that the variation in captured wind heeling load on the hull is synchronised with the rolling of the hull.

In one embodiment, the wind capture system comprises a system of shutters or vanes in which wind heeling load on the hull is varied by opening and closing the shutters or moving the vanes potentially using a system of mechanical linkages or actuators or drives. Typically, the system of shutters/vanes is mounted on a mast(s) or structure(s). Ideally, the vessel comprises a plurality of such shutter/vane systems, each suitably mounted on a separate mast. As such, when a system of shutters or vanes mounted on a mast is employed, the mast (including the shutter/vane system) may be rotatable with respect to the vessel, or the system of shutters may be rotatable on the mast. In either case the shutter or vane can be controllably moved to present either it's full surface to the wind or just it's edge thereby altering the wind heeling load. Either way, the system of shutters may be rotated into a favourable orientation with respect to the wind direction. It will be appreciated that the shutter can be rotated.

In a preferred embodiment, the mooring system includes tensioning means for maintaining a tension on the mooring system as the vessel rises and falls in the water.

In one embodiment, the mooring system comprises a cable system comprising at least one cable operatively connected to the vessel and adapted for being fixed at least one end to the anchor, whereby the motion of the hull with respect to the cable actuates the drive train. Generally, the motion captured will be rolling and vertical movement, however other motion such as pitching will also be captured.

Suitably, at least one cable is directly connected to the vessel and is adapted to be restrained at each end by the anchor. Thus, in this manner the cable loops over the vessel and interacts directly with the drive train. In another embodiment, at least one cable is indirectly connected to the vessel through an intermediate connecting mechanism connecting at least one cable and the drive train. Various types of intermediate connecting mechanisms can be used, for example, a lever linkage and/or a four-bar linkage.

Ideally, the cable system is operatively connected to a cable tensioning means to maintain tension on the pulley as the vessel rises and falls.

In one embodiment, the cable tensioning means comprises a pulley whose axis of rotation is movable and which is biased to take up tension in the cable as a vessel falls, the pulley mounting assembly typically being operatively connected to an energy capture and transmission means to capture and transfer energy released as the pulley mounting assembly moves. Various types of energy capture and transfer means due to the linear movement of the pulley mounting assembly can be used, for example, a hydraulic cylinder, a pneumatic cylinder, a mechanical linear drive mechanism and/or the potential energy of masses incorporated in the pulley assembly from which energy can be an output and be used to drive a generator.

In one embodiment, the energy capture and storage means is operatively connected to a drive train, typically the main drive train of the system.

Suitably, the cable tensioning pulley is biased by virtue of a weight or spring system or pressure settings in a pneumatic or hydraulic system.

In a preferred embodiment, the mooring system comprises at least two cable systems. Suitably, the drive train is mounted in the vessel intermediate at least two cable systems.

In a preferred embodiment of the invention, the system comprises an anchor which is suitably fixed with respect to the vessel. Typically, the anchor comprises a riser fixed to the sea bed and optionally fixed to the mooring system through a swivel adapted to swivel in response to orientation of the vessel in the water. Ideally, the mooring system tethers the vessel to the anchor at four corners of the vessel.

In one embodiment, the mooring system is adapted to bias the hull of the vessel into an orientation where it is beam-on to the wind.

Ideally, a section of a part of the hull intended to be underwater is semi-circular. However, other designs of hull which minimise resistance to rolling and/or which optimises vessel roll characteristics can be used. Suitably, the profile of the hull is substantially half-cylindrical.

In one embodiment of the invention, the mooring system and/or the drive train comprise overload protection means to prevent an overload of power being transmitted between or along the mooring system and the drive train. Various types of spring or hydraulic dampening systems can be employed to provide power overload protection.

In a particularly preferred embodiment, the invention relates to a system for converting wind and wave energy into electricity comprising a system according to the invention, and further comprising an electricity generator operatively connected to the drive train.

Typically, the system includes electrical power transmission means for transmitting electrical power from the vessel. Suitably, the electrical power transmission means comprises a cable and electrical slip ring assembly.

The invention also relates to a vessel suitable for forming part of the power generation system of the invention and comprising a vessel having a hull shaped to roll freely in response to the action of the wind and waves, and a wind capture system capable of controllably presenting a variable wind heeling load to amplify the hulls rolling motion.

Ideally, the wind capture system comprises wind heeling load variation means to amplify the hulls rolling motion by increasing wind heeling load on the hull at a forward point of roll and decreasing wind heeling load on the hull at a leeward point of roll.

Typically, the wind capture system is operatively connected to the mooring system or the drive train such that the changes in wind heeling load on the hull are synchronised with the rolling of the hull.

In one embodiment, the wind capture system comprises a system of shutters/vanes in which wind heeling load on the hull is varied by opening and closing the shutters/vanes. Suitably, system of shutters or vanes is mounted on a mast, wherein the vessel ideally comprises a plurality of shutter or vane systems, each mounted on a mast or structure.

In one embodiment, the wind capture system is rotatable with respect to the vessel.

Suitably, the vessel further includes a mooring system adapted for connecting the vessel with a fixed anchor, the mooring system adapted to capture the relative movement between the vessel and the anchor in response to the rolling, pitching and/or vertical motion of the vessel in the water and convert the relative movement into movement of a drive train.

In a further embodiment there is provided a drive train comprising a mechanical drive or a hydraulic system to capture the rolling motion of said vessel. In a further embodiment a hydraulic system can additionally be provided to also capture the vertical motion, with respect to the mooring system of said vessel. All mooring loads are transmitted to the vessel via a hinged frame restrained by a hydraulic or mechanical system. The frame is retained but free to pivot about the hinge such that as the vessel rises and falls vertically due to wave action mooring load variation is transmitted via the hinged frame to provide a reciprocating pumping type action to the hydraulic and/or mechanical system.

The invention also relates to a method of generating electricity comprising a step of positioning an electricity generation system according to the invention in a body of water exposed to wind and wave motion, and converting the wind and wave energy into electricity.

Brief Description of the Figures

The invention will be more clearly understood from the following description of some embodiment thereof, given by way of example only, with reference to the accompanying figures in which:

FIG. 1 illustrates an isometric projection of a power generation system according to a first embodiment of the invention;

FIG. 2 illustrates an isometric projection of the power generation system of Figure 1;

FIG. 3 illustrates a simplified two-view projection the power generation system of Figure 1;

FIG. 4 illustrates a longitudinal axis cut down section-view of the power generation system of Figure 1;

FIG. 5 illustrates an isometric projection of a power generation system according to an alternative embodiment of the invention;

FIG. 6 illustrates a simplified three-view projection of the power generation system of Figure 5;

FIG. 7 illustrates a power generation system according to another embodiment of the invention;

FIG. 8 illustrates another power generation system of Figure 7;

FIG. 9 illustrates a power generation system according to a further embodiment of the invention;

FIG. 10 illustrates another power generation system of Figure 9; and

FIG. 11 illustrates a further embodiment of the power generation system of Figure 10.

Detailed Description of the Invention

A system for the conversion of wave and wind energy to electrical power is now described according to the invention. According to a first aspect in Fig 1, the system comprises a vessel having a hull (1) of shape optimised for rolling motion under wave action. Optionally mounted on this hull are one or more masts or structures (2) on which in turn is mounted a rotational wind capture element or sail (3) capable of rotating about the vertical axis on the mast (2), or is mounted on the mast a wind capture device consisting of multiple slats, shutters or vanes (mounted either horizontally or vertically) capable of being opened or closed (4) so as to enable or impede air flow (as in Fig. 2, Fig 3 and Fig. 4).

In operation the vessel floats on water such that the hull is designed to lie abeam of the sea and at right angles to the prevailing direction of the wind. The vessel is designed such that internal and external masses (5) act as: ballast to ensure the vessel does not invert; to provide a righting moment when the vessel rolls, to act as counterweights to the rigs heeling influence in the event of a wind capture system being mounted on the hull as described. The wind capture system is optionally used to maximise the hulls rolling motion by maximising wind heeling load at the forward or windward point of roll of the vessel (into the wind/waves) and maintaining that wind loading as the vessel rolls away from the wind. The wind capture system minimises wind heeling load at the leeward or aft point of roll (vessel is rolled away from the wind) and maintains that minimised wind loading as the vessel rolls to windward.

By operating the wind capture system in phase with rolling motion caused by wave action on the hull of the vessel, the vessel's angle of roll is thereby amplified by the dual action of wave energy and wind energy. The energy released by the waves, and potentially wind also, causing the rolling motion of the vessel and also its vertical motion, rise and fall, are captured by the vessel's mooring system and an associated onboard drive train. The anchoring system comprises a single riser (6) running from a seabed anchor to a swivel (7) above which point a system of multiple cables (8) runs up towards the vessel.

A first embodiment of the present invention is shown in Fig 1, two cables are looped and held at the swivel (7) but in other embodiments more than two cables may be used. The cables (8) come inboard by running first over an outboard pulley (9) at each corner of the vessel and then over an inboard pulley (10) before looping under a pulley (11) attached via bearings to a weight (12) that can slide vertically in a linear slide (13) under the influence of varying cable tension. In the embodiment shown the cables motion relative to the vessels as it rolls, rises and falls causes the inboard pulleys (10) to rotate and the weight (12) to move. The rotational motion of the pulleys (10) is used to drive a generator via a drive train consisting of shafts, clutches, flywheels, gearboxes, and bearings (not shown). In the embodiment shown this drive train is shown schematically in its most basic form and additional complexity could be included in additional embodiments.

The inboard pulleys (10) are integral with and provide a torque to the upper drive shafts (14). Clutches, sprag clutches or ratchet elements (15) split the drive shaft (14) so as to convert intermittent reciprocating rotary motion at the inboard pulleys (10) to unidirectional, but intermittent rotational motion at the upper drive shaft gears (16). In the embodiment depicted the upper shaft gears and lower shaft gear (17) combine to form a simple gear train driving the lower or main drive shaft (18) which in turn drives a flywheel (19) and generator (20).

Additional power is captured from the moving weight system (11) and is transferred to the main drive shaft (18) for transmission to the generator by means of a hydraulic system. In Figs 1 to 6 the variation in cable tension caused by the vessels rise and fall is taken up by a moving weight (12) as it slides in the linear slide system (13). As the vessels drops into a trough between the waves cable tension is reduced and the weight is lowered. As the vessel rises on a wave the cable tension is increased and the weight rises. The energy released by the movement of the weight is captured by a hydraulic cylinder (21). The cylinder is connected to a hydraulic motor (22) via a hydraulic pressure storage and hydraulic power transmission system. The hydraulic motor (22) is used to drive the main shaft (18) as required. A ratchet or clutch mechanism (23) between hydraulic motor (22) and shaft (18) is used to engage/disengage the hydraulic drive as required.

Electrical power is fed from the vessel via a heavy duty electrical slip ring with the electrical cable running through the centre of the swivel (7) as per existing rotary unions used in offshore oil sector technology.

Figs 5 and 6 illustrate another embodiment of the vessel according to the present invention. The mooring system cables are not brought on board via roller drive system but instead the cables are connected to linkage elements (24) and the motion of the vessel is transmitted to the power generation drive trains via these linkages. Suitable linkages such as lever type or four-bar linkages can be used to connect each cable to the onboard drive train and thence to convert vessel roll, rise and fall to rotational motion in the generator drive shaft. In the embodiment shown in Fig. 5 a lever type linkage (24) is used eliminate the requirement to bring the cables onboard as in shown in Figs 1 to 4. The lever is integral with the upper shaft (25) and causes it to rotate in a reciprocal manner as the upper shaft (14) in Embodiment 1. The drive train is similar to the previous embodiment in that clutches, sprag clutches or ratchet elements (15) in the drive shaft (25) convert intermittent reciprocating rotary to unidirectional but intermittent rotational motion. A chain or belt drive (28) is used to connect the external shaft (25) with the inner upper shaft (26) (see Fig. 6). The inner upper shaft gears are similar to gears (16) described above and combine with each other and lower shaft gear (17) to form a simple gear train driving the lower or main drive shaft (18) which in turn drives a flywheel (19) and generator (20). As described above the inboard end of the lever element is connected to a chain or cable (27) that is used to raise or lower the weight (12) and thereby transfer power via the hydraulic system to the generator.

Fig. 7 shows another embodiment of the present invention. A vessel comprises a hull (30) of substantially cylindrical shape, or another suitable shape, designed to give the vessel optimal roll characteristics. Rigid mooring elements (31) at both ends of the vessel connect to the vessel anchor chain and combine to hold the vessel beam on to the waves. Part of the anchor chain or cable is rigid and acts as a lever to increase torque and conversion of relative movement into movement of the drive train to generate electricity. The reciprocating rotational motion of the hull generates a torsional load in the main shaft (35). This reciprocating torque and rotational motion is transmitted from the mooring element via the main shaft (35) to a uni-directional rotational coupling (32). The resultant cyclical but uni-directional rotation and associated torque is transmitted from the coupling (32) to a gearbox (33) and hence to a flywheel and generator (34) as the hull rolls in response to the wave action. Shaft supports including bearings and mountings, gearbox and generator mounting frames, known in the art, are not shown in the functional schematic Fig 7. The shaft (35) and its mounting system are designed to be of adequate strength to hold the vessel and simultaneously transmit the design output torque the hull generates as it rolls. One of the main advantages of this embodiment is the simplicity in the design as very few moving parts are required, thus increasing the robustness of the design, especially in harsh sea environments. This embodiment can be used with or without a wind energy capture system as described above.

Figure 8 illustrates a further embodiment of Figure 7 having a single generator (34). The twin upper shafts (35) are connected to a lower shaft (35a) via the gearboxes 33 and hence to the unidirectional couplings (32). The unidirectional shafts (35a) drive the generator (34) via a further gearbox (33a) and flywheel (41). The advantage of this system is that a single generator can be used. Bearings (36) are shown on the main shaft (35).

Figure 9 illustrates a further aspect of the invention wherein the drive system shown in the embodiment in Fig 7 is mounted on a hinged frame (37), that is retained but free to pivot about a hinge (38), as shown. As the vessel rises and falls vertically due to wave action the mooring load variation on the main drive shaft (35) is transmitted via the frame (37) to provide a reciprocating pumping type action to the hydraulic piston (36). The main shaft (35) can be seen to be able to move in the slot in the hull in response to vessel vertical motion. This enables the device convert the vertical motion of the vessel into a hydraulic pressure and flow. The energy of the rolling motion of the vessel is converted to electrical energy as described above. As the vessel (30) rises and falls the hydraulic piston (36) translates the vertical movement into electrical energy via a hydraulic motor (42), flywheel (41a), and generator (34). In addition the apparatus of the invention is placed on a moving floor or base (37) that can pivot about a point (38) in response to the vertical motion. It will be appreciated the mooring loads will vary under different sea and wind conditions. Hydraulic circuit operational pressures can be adjusted to the mooring system mean load and amplitude to ensure optimal use of the mooring load differential in generating maximum displacement of the piston (36) and thereby optimal power generation. Springs, dampers, linear bearings and other restraining elements can be incorporated in the design as necessary to ensure the drive and mooring system is adequately stiff and robust to survive sea and wind conditions.

Figure 10 illustrates yet a further aspect of the invention wherein the vessel rolling motion is transmitted via the main shaft (35) for capture by a hydraulic pump (39) in combination with bearings (40). A hydraulic piston (36) captures the energy of the vessel moving in a vertical direction with respect to the water as in Fig. 9. Both hydraulic systems (39) and (36) feed via hydraulic circuits featuring reservoirs, unidirectional valves, pressure relief valves, accumulators and flow control valves to a hydraulic motor (42). The mechanical output from the hydraulic motor feeds drives the generator (34) via a flywheel to generate electricity. The embodiment shown in Fig. 11 shows a hydraulic system (39) to only capture energy of the rolling motion of the vessel, as described above. It will be appreciated that the wind capture system used to increase the rolling motion of the vessel described with respect to Figures 1 to 6 can be incorporated in the vessel shown in Figures 7 to 11.

In other embodiments of the invention a rack and pinion, power screw, ballscrew, or some other form of linear drive may be used to convert linear movement of weights directly to rotational motion and thence provide rotational drive to an electrical generator without using a hydraulic system of power transmission.

In other embodiments springs are used in conjunction with weights, or on their own, as the energy storage medium for vertical displacement of the vessel. A spring and hydraulic system and/or spring and linear drive system are used in place of, or in conjunction with, a system of weights to capture energy associated with rise and fall motion of the hull.

Other embodiments may use multiple generators with the power captured from vessel vertical motion being used to drive generators other than the generator(s) used to capture power from the vessel's rolling motion.

Item	**No.**
Hull	1
Mast	2
Vertical Axis Rotational Wind Capture Element	3
Horizontal Axis Rotational Wind Capture Element	4
External counterweight/keel	5
Single riser mooring component	6
Mooring System Swivel	7
Cables above swivel	8
Outboard pulley	9
Inboard pulley	10
Weight pulley	11
Weight	12
Weight linear slide	13
Upper drive shaft	14

Upper drive shaft clutch, sprag clutch or ratchet mechanism	15
Upper drive shaft gears	16
Lower drive shaft gear	17
Lower/main drive shaft	18
Flywheel	19
Generator	20
Hydraulic cylinder for weight movement energy capture	21
Hydraulic motor	22
Ratchet/clutch between hydraulic motor & main shaft	23
Lever linkage 2nd embodiment	24
Upper outer shaft 2nd embodiment	25
Upper inner shaft 2nd embodiment	26
Weight cable or chain 2nd embodiment	27
Chain/belt drive connecting outer to inner upper shafts 2nd embodiment	28
Vessel	30
Mooring elements	31
Coupling	32
Gearbox	33 & 33a
First Flywheel	34
Shaft	35 & 35a
Hydraulic piston	36
Pivoting Frame/floor	37
Pivot point	38
Hydraulic pumping system	39
Bearings	40
Second Flywheel	41 & 41a
Hydraulic motor	42

The invention is not limited to the embodiments hereinbefore described which may be varied in construction and detail without departing from the spirit of the invention.

Claims

1. A system of converting wave and/or wind energy into movement of a drive train comprising:

   a vessel, having a hull, for example a substantially cylindrical shaped hull, adapted to roll on water in response to wave and/or wind energy; and

   a mooring system, suitable for connecting the vessel with an anchor, the mooring system adapted to capture the relative movement between the vessel and the anchor in response to the rolling, pitching and/or vertical motion of the vessel on water, and convert the relative movement into movement of a drive train to generate electricity.

2. A system as claimed in Claim 1 wherein the mooring system comprises a cable system comprising at least one cable operatively connected to the vessel and adapted for being fixed to at least one end to the anchor, whereby rolling, pitching and/or vertical motion of the hull with respect to the cable actuates the drive train.

3. A system as claimed in Claim 2 wherein the cable system is operatively connected to a cable tensioning means to maintain tension on the cable as the vessel rises and falls, and wherein part of the cable is rigid and acts as a lever to increase torque and conversion of relative movement into movement of the drive train to generate electricity.

4. The system of claim 3 wherein the cable tensioning means comprises a cable flywheel which is movable and biased to take up tension in a pulley as a vessel falls, the flywheel being operatively connected to an energy capture and storage means to capture and store energy released as the flywheel moves.

5. A system as claimed in any preceding claim further comprising an electricity generator, for example a fly wheel generator, operatively connected to the drive train.

6. A system as claimed in any preceding claim wherein said anchor is fixed with respect to the vessel, said anchor comprising a riser fixed to the sea bed and optionally fixed to the mooring system through a swivel adapted to swivel in response to orientation of the vessel in the water.

7. A system of claim 6 wherein the mooring system tethers the vessel to the anchor at four corners of the vessel.

8. A system as claimed in any preceding claim comprising at least one cable indirectly connected to the vessel through a rigid intermediate connecting mechanism, connecting the at least one cable and the drive train to provide increased torque.

9. A system as claimed in any preceding claim wherein the vessel comprises a wind capture system capable of controllably presenting a variable wind heeling load to amplify the hulls rolling motion.

10. A system as claimed in claim 9 wherein the wind capture system is adapted to amplify the hulls rolling motion by increasing the wind heeling load on the hull at a forward point of roll and decreasing the wind heeling load on the hull at an aft point of roll.

11. A system as claimed in claims 9 or 10 in which the wind capture system is operatively connected to the mooring system or the drive train such that the variation in captured wind heeling load on the hull is synchronised with the rolling of the hull.

12. A system as claimed in any of claims 9 to 11 in which wind capture system comprises a system of shutters in which wind heeling load on the hull is varied by opening and closing the shutters.

13. A system as claimed in claims 9 to 12 in which the wind capture system comprises wind heeling load variation means to amplify the hulls rolling

motion by increasing wind heeling load on the hull at a forward point of roll and decreasing wind heeling load on the hull at an aft point of roll.

14. The system as claimed in any preceding claim wherein the mooring system and/or the drive train comprises overload protection means to prevent an overload of power being transmitted between or along the mooring system and the drive train.

15. The system as claimed in claim 1 wherein the drive train comprises a hydraulic system and/or mechanical system to capture the rolling motion of said vessel.

16. The system as claimed in claim 15 wherein the hydraulic system and/or mechanical system is provided to capture the vertical motion, with respect to the mooring system of said vessel.

17. The system as claimed in claim 16 comprising a hinged frame, that is retained but free to pivot about a hinge such that as the vessel rises and falls vertically due to wave action a load variation on the drive train is transmitted via the frame to provide a reciprocating pumping type action to the hydraulic system and/or mechanical system.

18. A sea or ocean vessel comprising the system as claimed in any preceding claim.

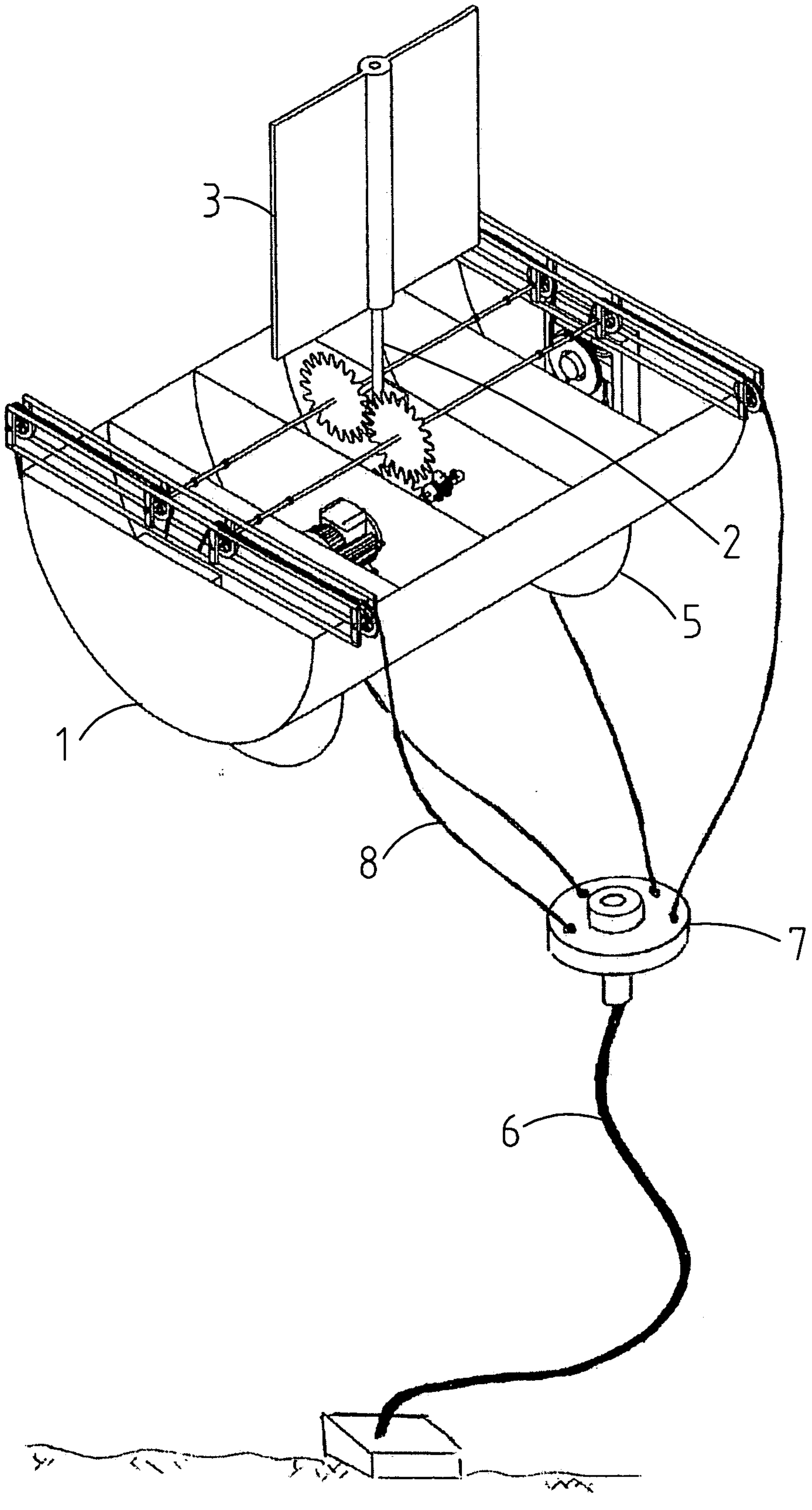

Fig. 1

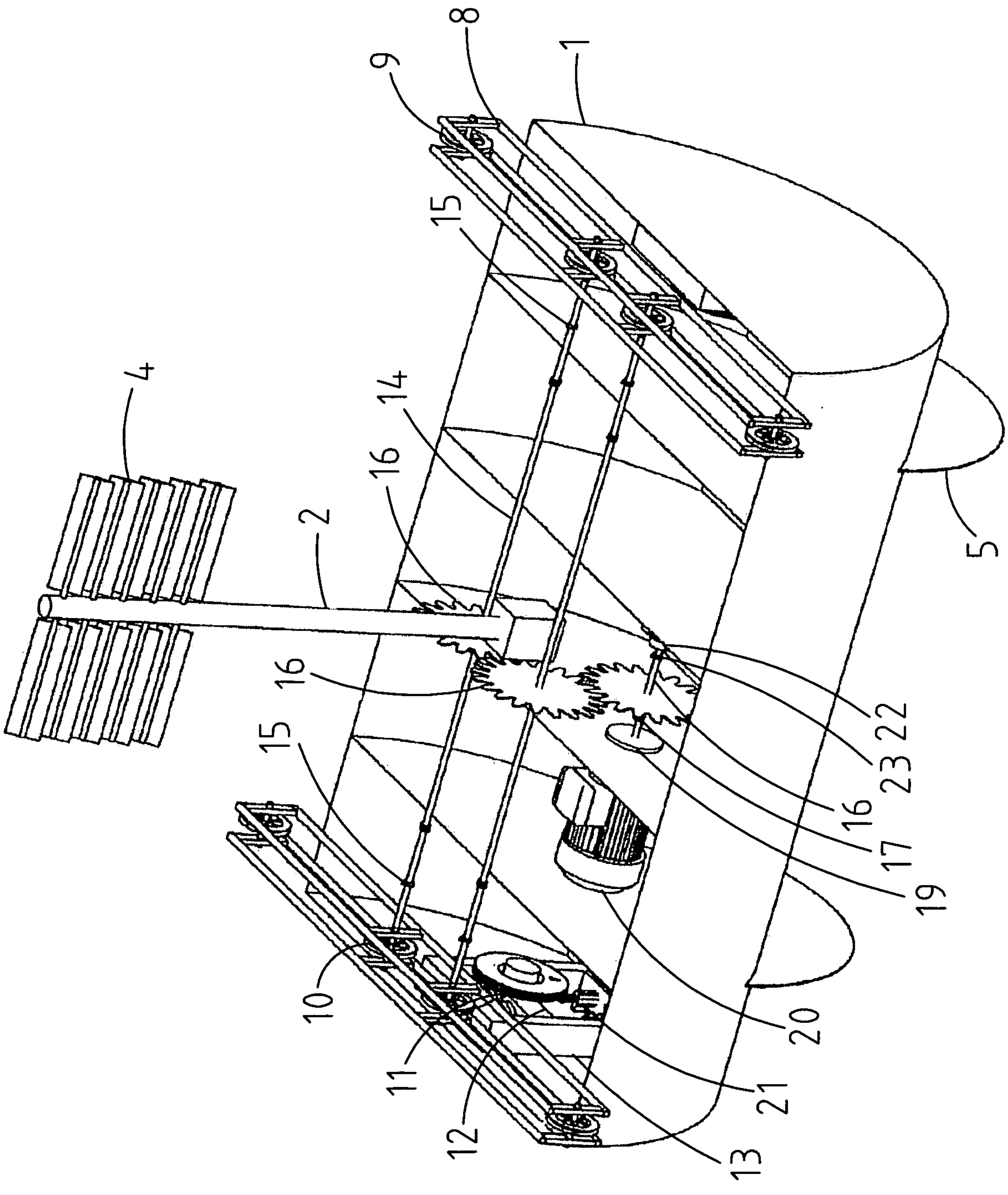

Fig. 2

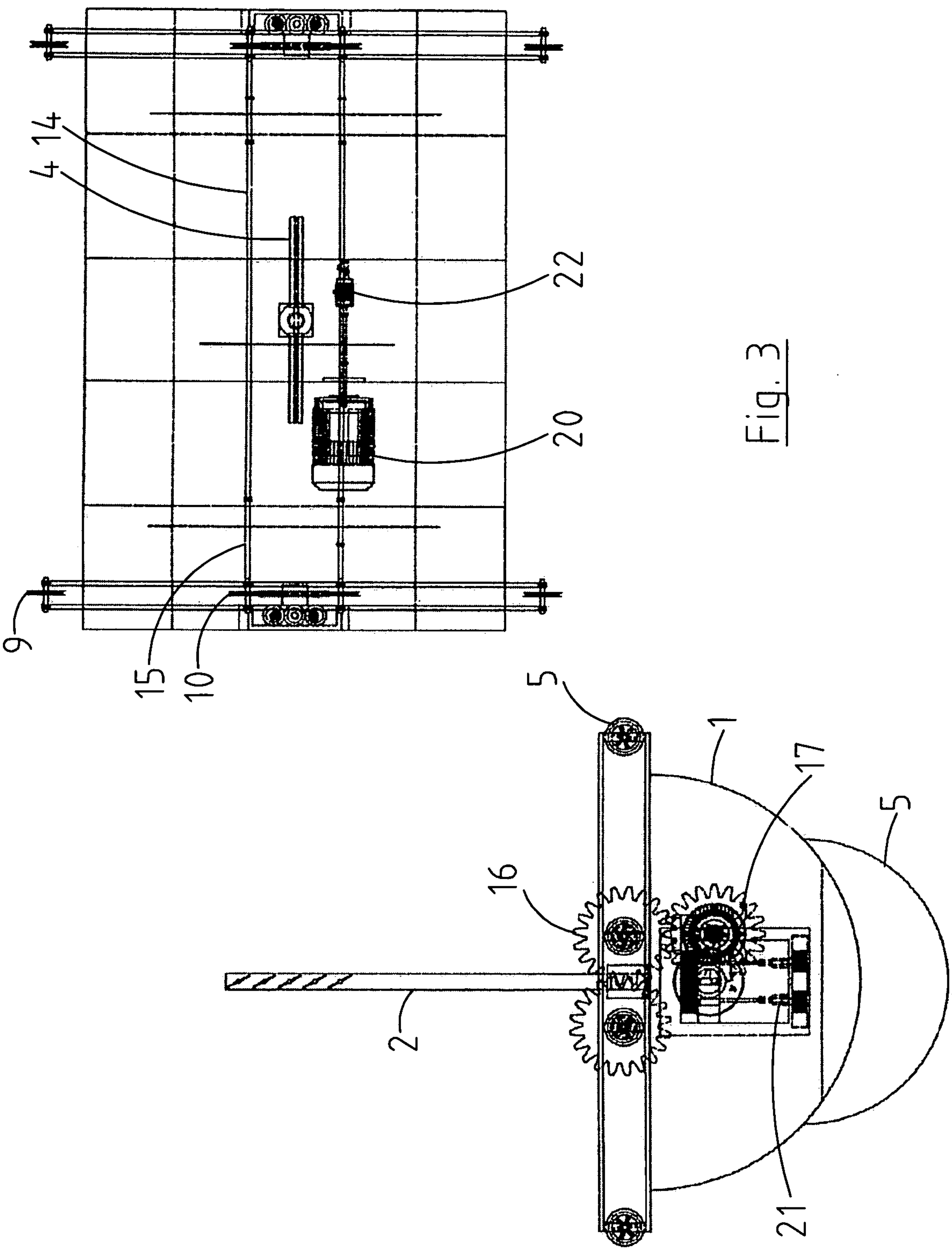

Fig. 3

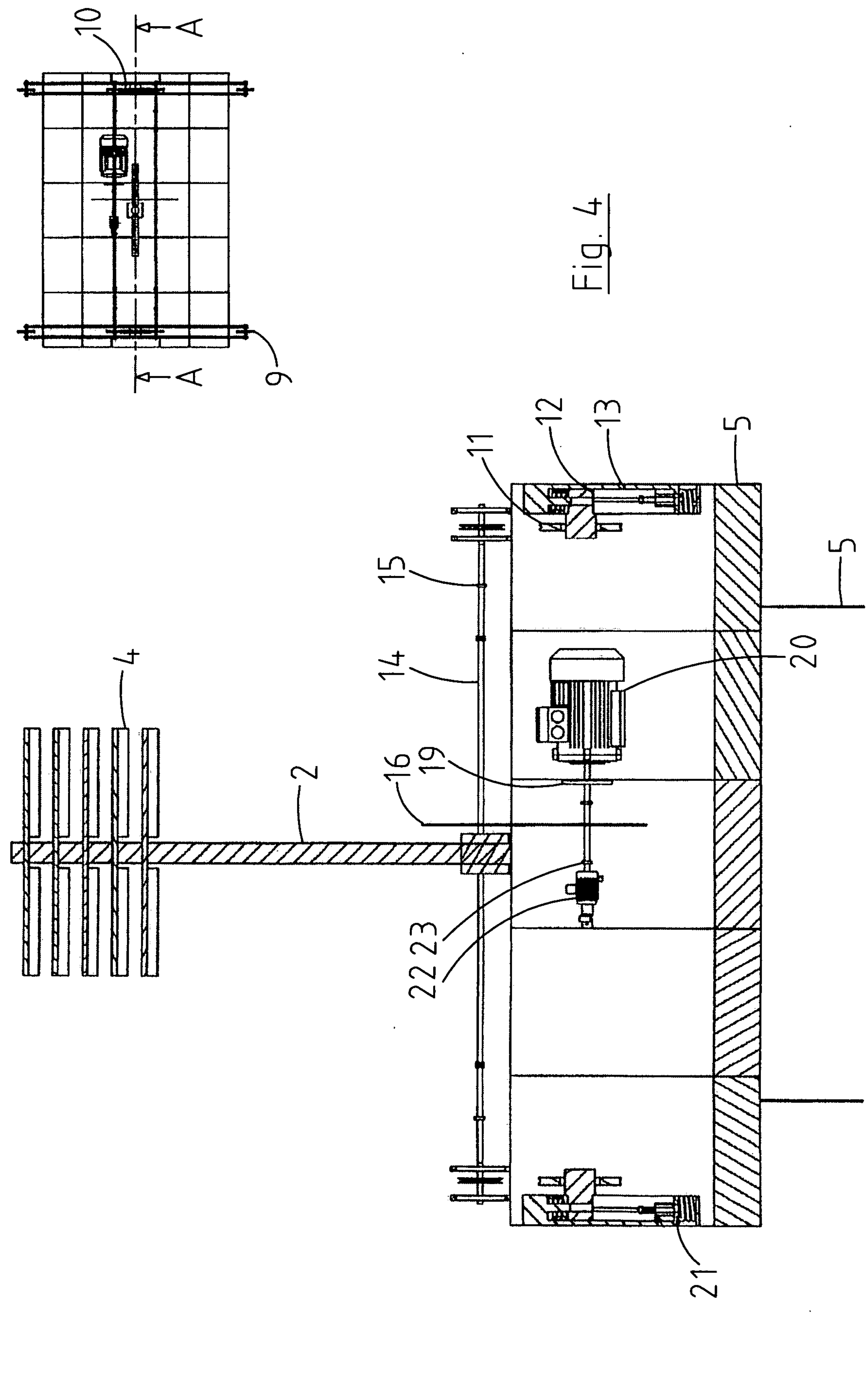

Fig. 4

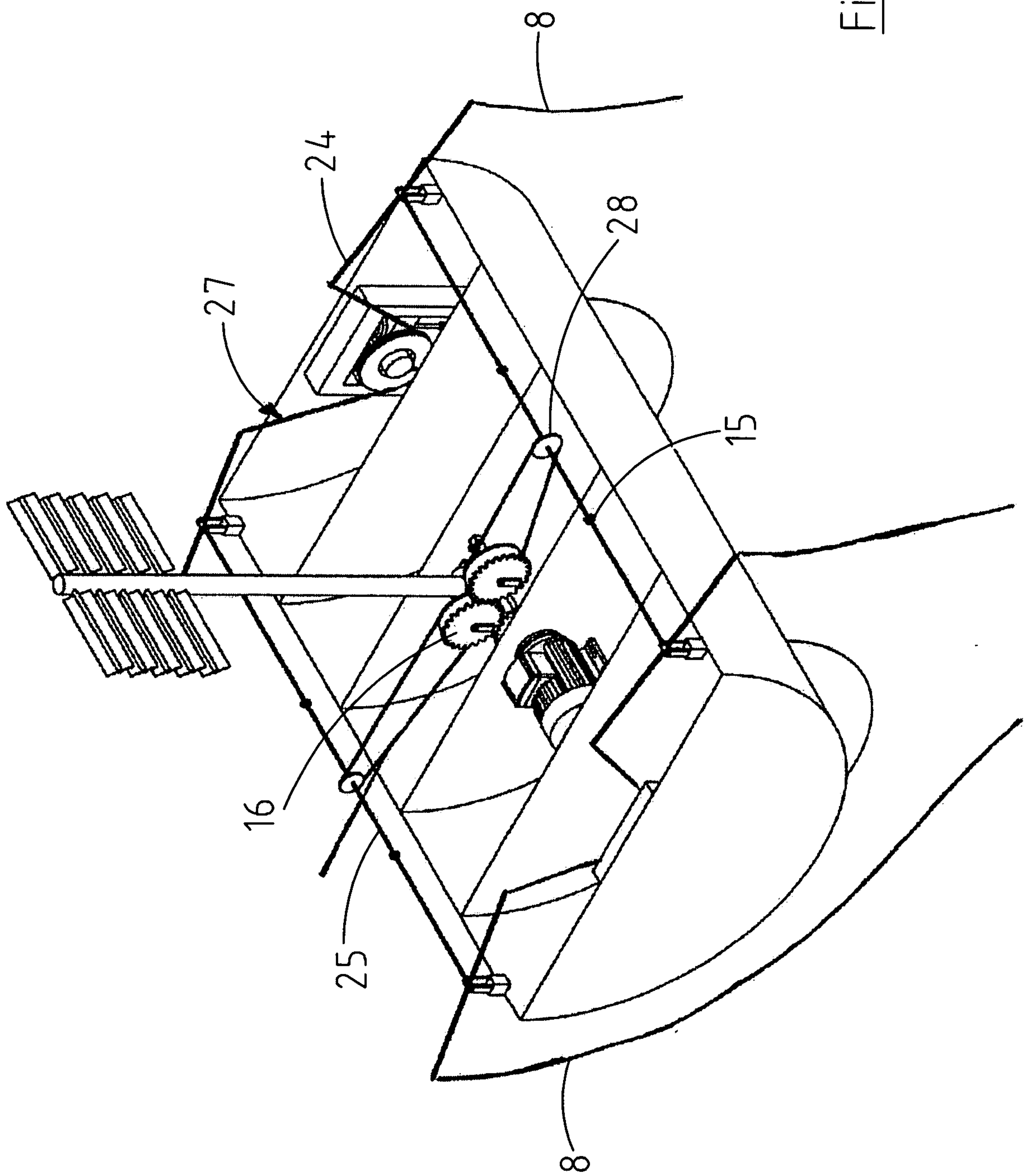

Fig. 5

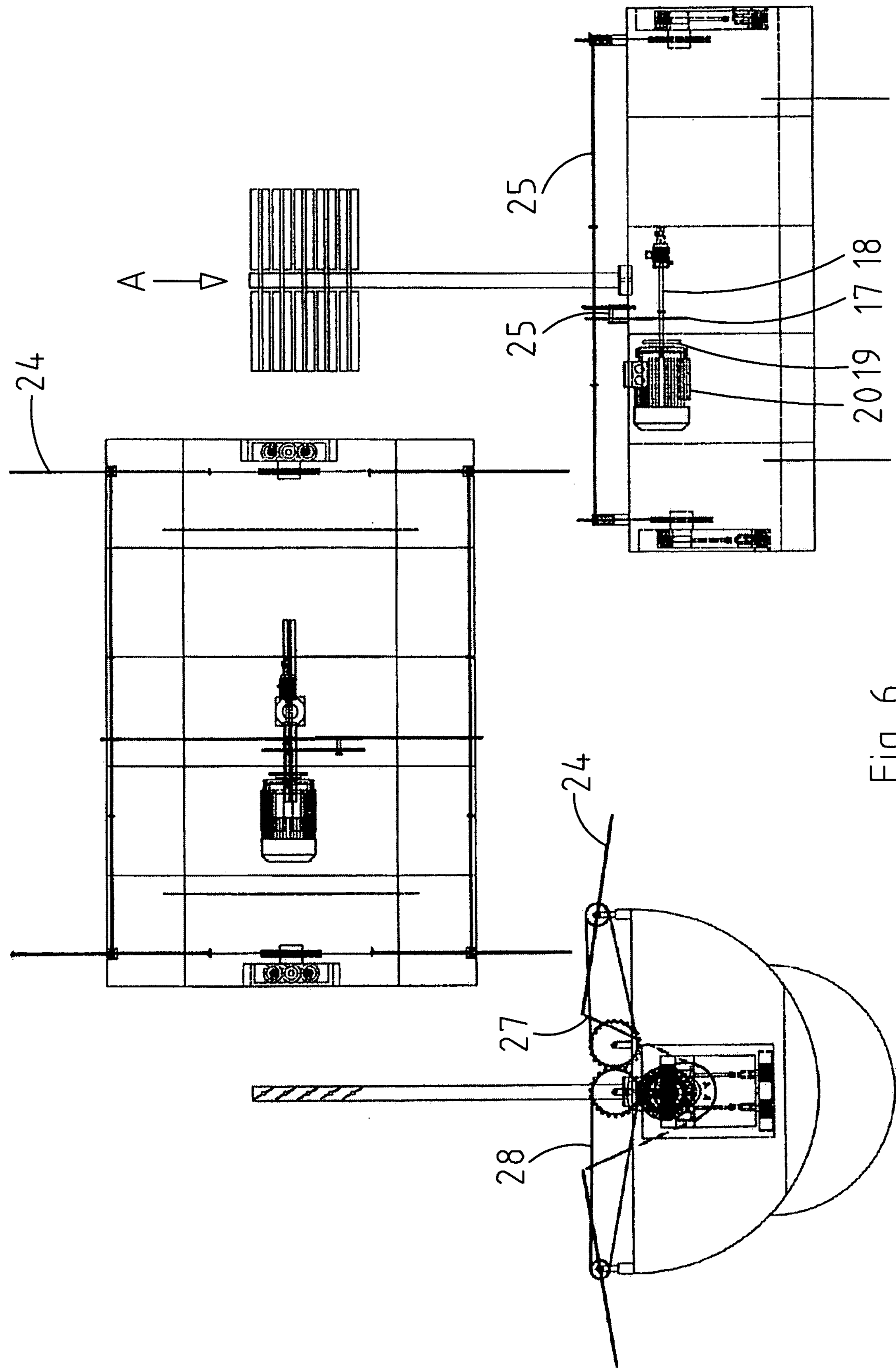

Fig. 6

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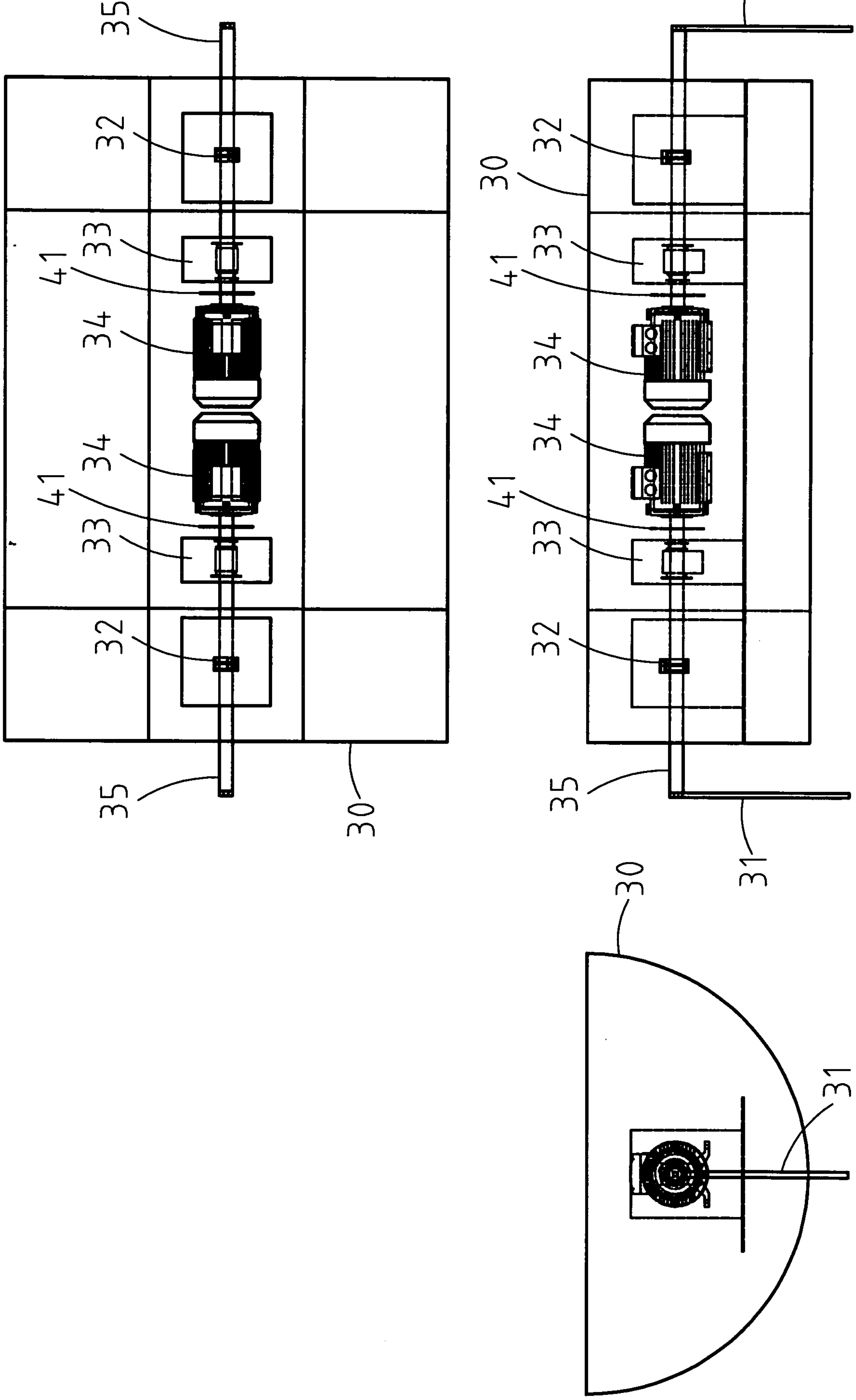
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Fig. 7

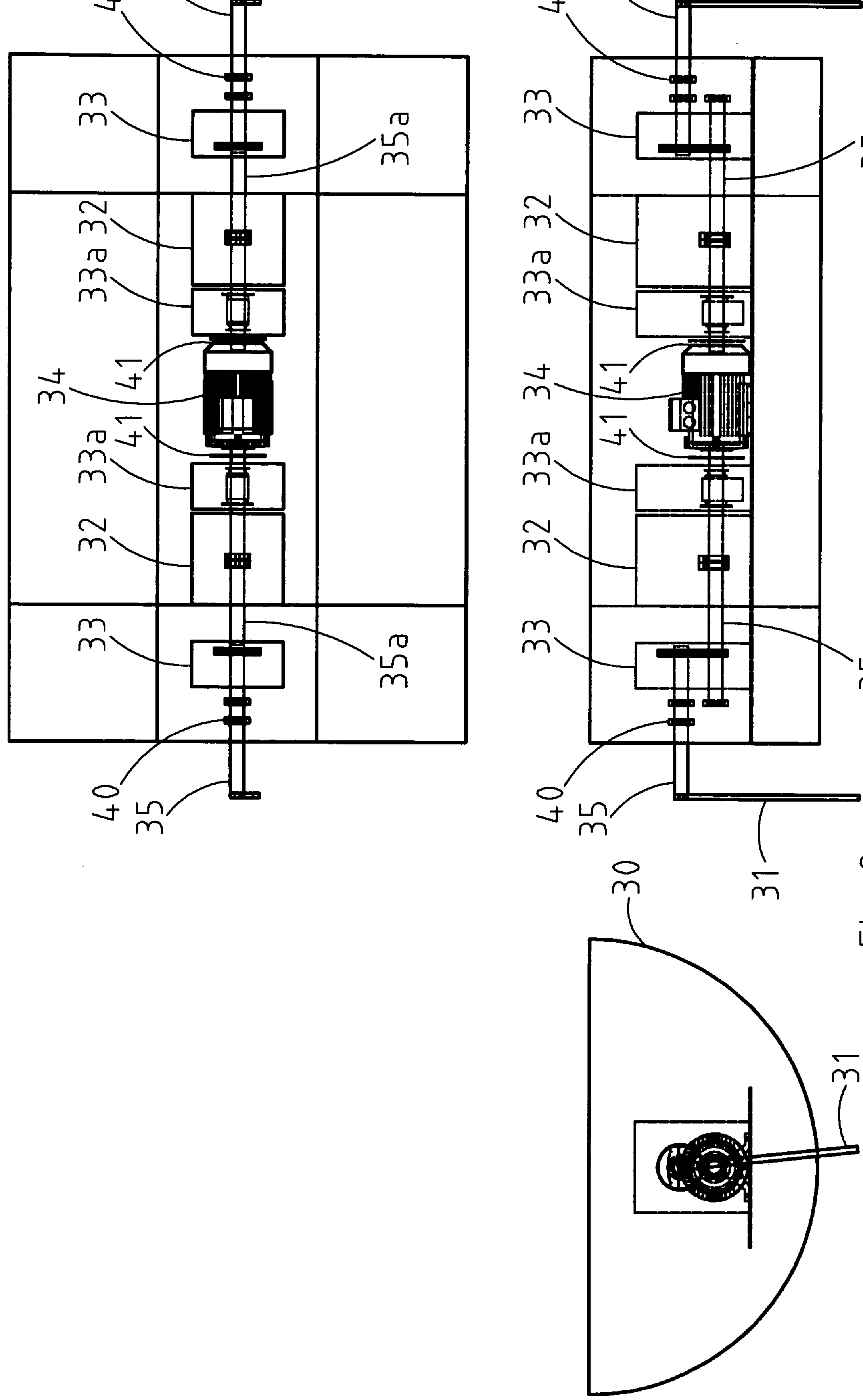

Fig. 8

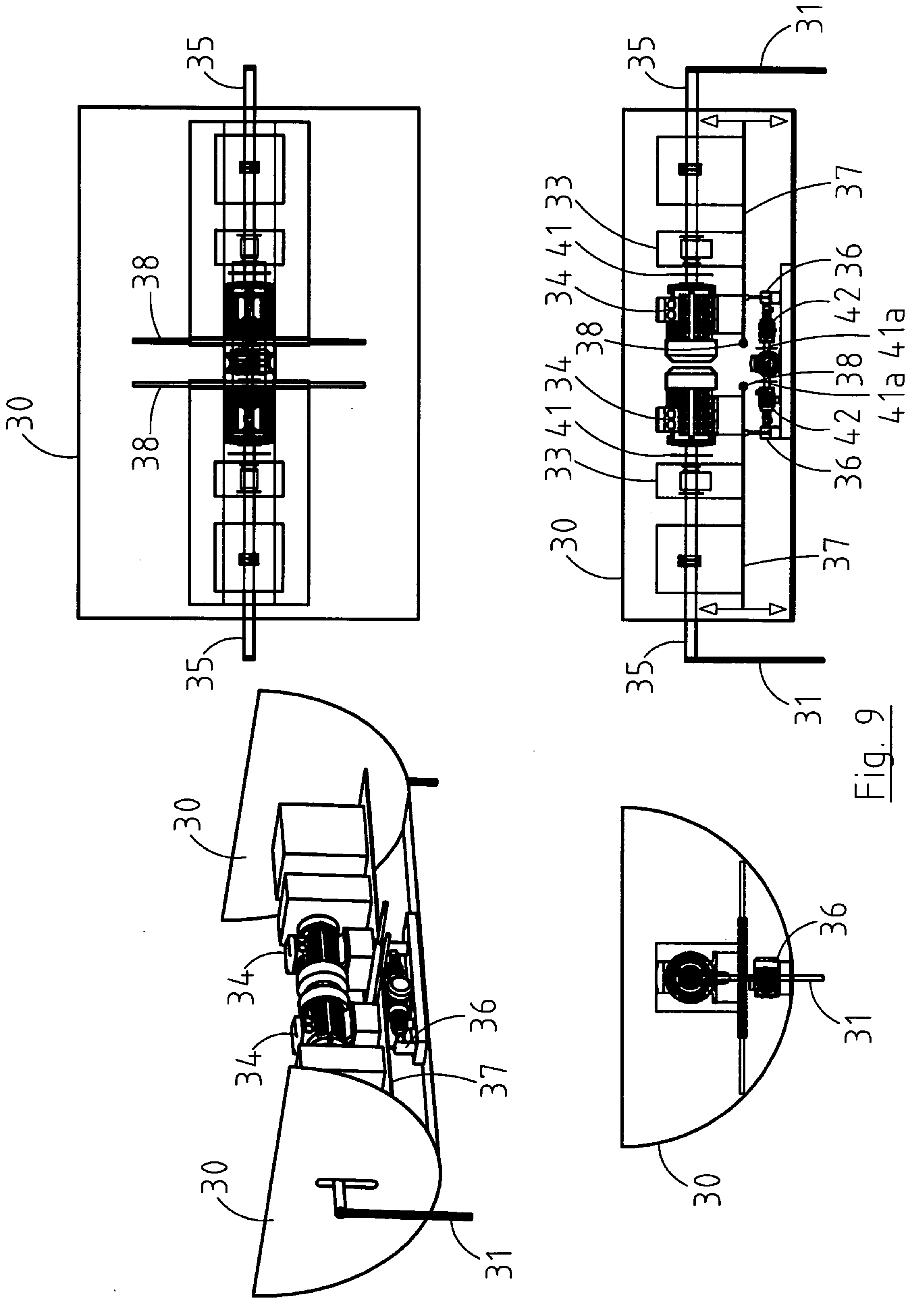

Fig. 9

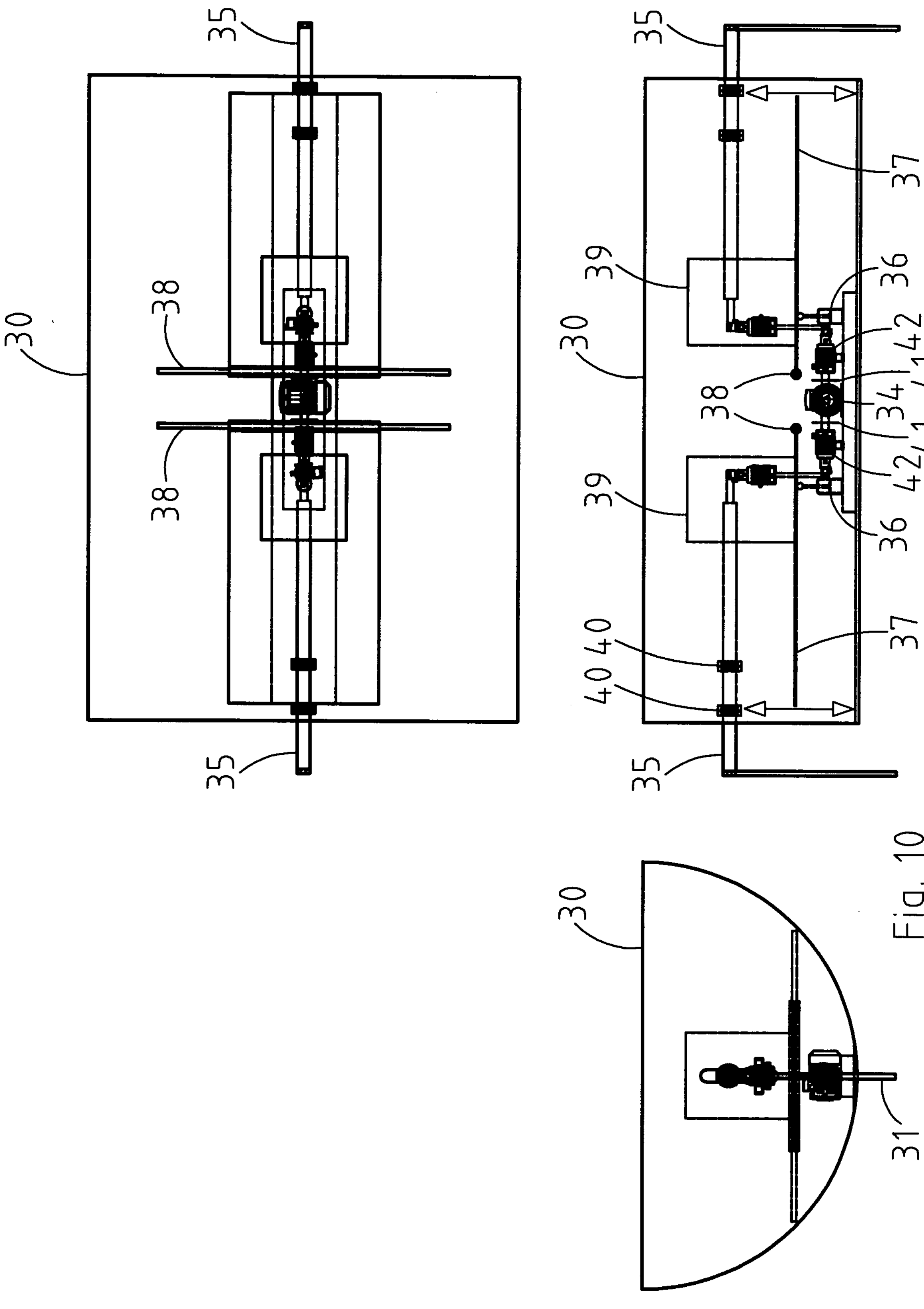

Fig. 10

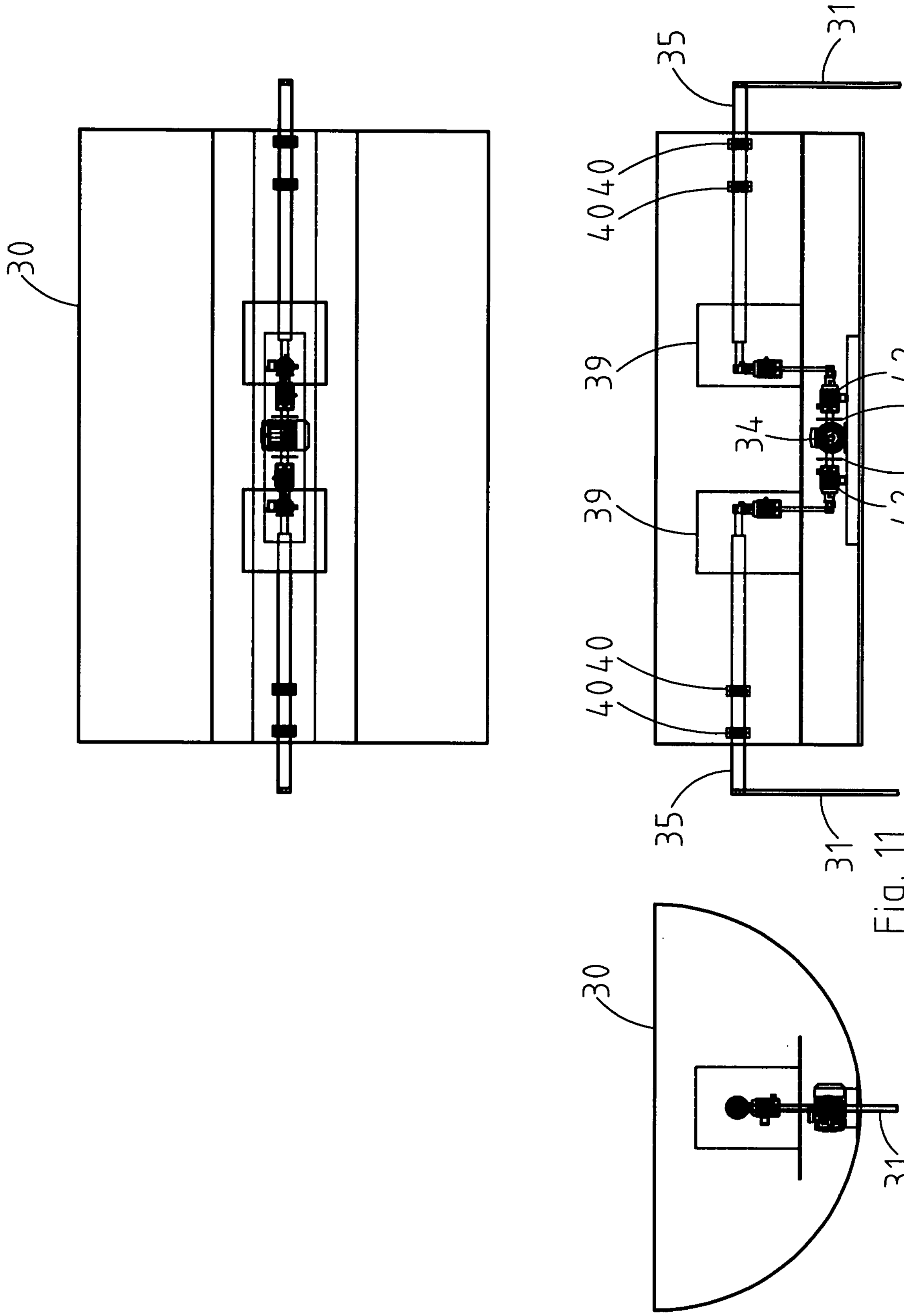

Fig. 11

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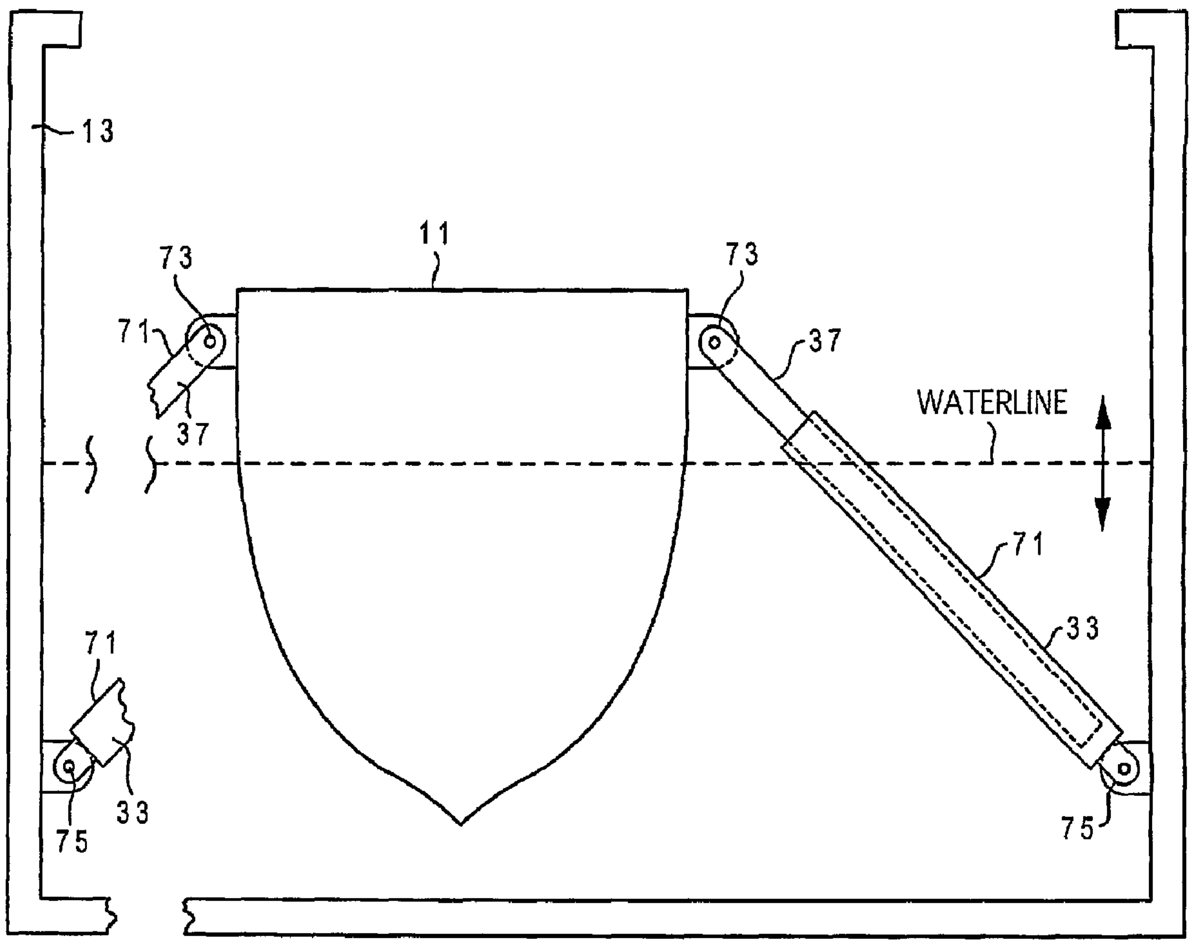

(57) Abrégé/Abstract:
A tidal power generator has a floating vessel hull (11) that is subject to rising and falling water levels (22) so that the hull moves vertically up and down. Linear-to-rotary converters (31) are coupled between the vessel hull and a fixed object (38). The converters

(57) Abrégé(suite)/Abstract(continued):
allow the hull to move vertically while constraining the horizontal movement of the hull. The converters convert the vertical movement of the hull into rotary movement, which is then used to drive an electrical generator (61). A harborage (13) is provided to protect the hull and the converters and to regulate the water level for the vessel hull as well as become a fixed object relative to the vessel from which a change in relative position causes power to be developed. If the hull is subject to tidal variations, vertical movement of the hull can be desynchronized from the tidal variations so as to store energy during slack tides.

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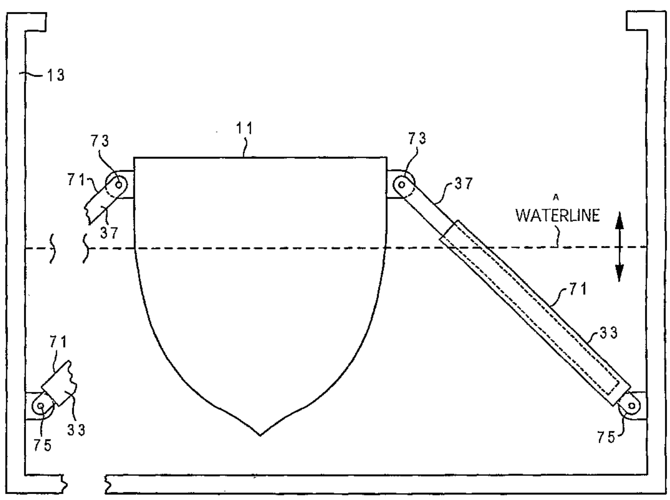


(57) Abstract: A tidal power generator has a floating vessel hull (11) that is subject to rising and falling water levels (22) so that the hull moves vertically up and down. Linear-to-rotary converters (31) are coupled between the vessel hull and a fixed object (38). The converters allow the hull to move vertically while constraining the horizontal movement of the hull. The converters convert the vertical movement of the hull into rotary movement, which is then used to drive an electrical generator (61). A harborage (13) is provided to protect the hull and the converters and to regulate the water level for the vessel hull as well as become a fixed object relative to the vessel from which a change in relative position causes power to be developed. If the hull is subject to tidal variations, vertical movement of the hull can be desynchronized from the tidal variations so as to store energy during slack tides.

WO 2007/142647 A1

SPECIFICATION

TO ALL WHOM IT MAY CONCERN

BE IT KNOWN that we, Robert B. Lomerson, Sr. and Robert B. Lomerson, Jr., currently residing in Texas, have invented new and useful improvements in

TIDAL POWER GENERATION

of which the following is a specification:

TIDAL POWER GENERATION

SPECIFICATION

Field of the Invention

The present invention relates to extracting energy from tides on water bodies.

Background of the Invention

Most of the electricity generated in the United States requires hydrocarbon-based fuel sources such as coal, oil or natural gas. The burning of such fuels produces harmful emissions that are both difficult and expensive to either contain, or remove, from the exhaust gasses. Also, the transport of these fuels from point of origin, to point of processing (such as refining crude oil), to point of use not only requires the expenditure of additional energy, but is inefficient, costly, potentially hazardous and creates further harmful emissions. In addition, most sources of liquid hydrocarbon-based fuels used in the United States are located outside of the United States. The political environments of many producing areas, such as the Middle East, Venezuela, Russia and Nigeria have been unstable in recent history.

Nuclear power plants pose an alternative generating source to hydrocarbon fuels. However, nuclear power plants are expensive to build and pose security problems. Also, the disposal and storage of spent nuclear fuel is an expensive and a highly contentious problem. Public perception of nuclear power plants is largely negative.

Solar panels are still another alternative. At present, solar panels are high in cost, very low in efficiency and are unusable at night and on cloudy or stormy days. Wind power, while available, is also dependent on the weather as well as being inefficient and relatively expensive.

In contrast to solar and wind, the tides are highly regular, cycling once or twice each twenty-four hour period. Although the height of tides vary due to factors such as coastline geography, the lunar cycle, and to a lesser degree, the direction and velocity of the wind, tides are remarkably constant and continuously changing. In some areas of the world, the water level range may be as much as forty-four feet between high and low tide.

In the prior art, tides have been harnessed by opening and closing flood gates to impound a head of water. The impounded water drives turbines. Such schemes have been planned, if not actually used, in Passamaquoddy Bay between Maine and New Brunswick, Canada. The continuous opening and closing of the flood gates creates problems. Also, the efficiency is somewhat low because only part of the tidal rise and fall can be used. Marine life is adversely impacted as well.

Summary of the Invention

The present invention provides a method of generating power. A harborage is provided with an interior and an exterior, with the exterior being subject to tidal variations. A vessel hull is floated in the interior of the harborage. Water is allowed to flow between the interior and the exterior of the harborage so as to vary the water level in the harborage interior and to move the vessel hull vertically. The vertical movement of the vessel hull is desynchronized from the tidal variations. Power is generated from the vertical movement of the vessel hull.

In accordance with one aspect of the present invention the vertical movement of the vessel hull is desynchronized from tidal variations by retarding the vertical movement of the vessel hull so as to vary the displacement of the vessel hull within the harborage.

In accordance with still another aspect of the present invention, the vertical movement of the vessel hull is desynchronized from the tidal variations by regulating the flow of water between the interior and the exterior of the harborage so as to lag the tidal variations.

In accordance with still another aspect of the present invention, the step of floating a vessel hull in the interior of the harborage further comprises floating a vessel hull with a displacement. The vessel hull displacement is varied so that the vessel hull has a first displacement on a rising water level and a second displacement on a falling water level, with the second displacement being greater than the first displacement.

In accordance with one aspect of the present invention, the step of varying the displacement of the vessel hull further comprises taking on water and discharging water from the vessel hull.

In accordance with still another aspect of the present invention, the step of taking on and discharging water from the vessel hull further comprises providing a port in the vessel hull that allows water to flow out of the vessel hull. A buoyant cover is provided for the port. The cover is allowed to move between open and closed positions relative to the port, wherein on a rising water level, the cover is in the closed position and on a falling water level, the cover moves to the open position.

In accordance with still another aspect of the present invention, the step of generating power from the vertical movement of the vessel hull further comprises producing pressurized fluid from the vertical movement of the vessel hull. The pressurized fluid is used to rotate a turbine.

In accordance with still another aspect of the present invention, the step of allowing water to flow between the interior and the exterior of the harborage so as to vary the water level in the harborage interior and move the vessel hull vertically further comprises the step of generating power from the flow of water between the interior and the exterior of the harborage.

The present invention also provides a power generator that comprises a body of water that has a top level that fluctuates. A vessel hull is buoyantly located on the water body, the hull being free to move vertically as the top level fluctuates. A piston-cylinder arrangement is coupled between the vessel hull and the fixed object. The cylinder has an output for pressurized fluid when the vessel moves vertically. The piston-cylinder arrangement constrains horizontal movement of the vessel hull. A turbine has an input which is connected to the cylinder output. The pressurized fluid from the cylinder rotates the turbine.

In accordance with one aspect of the present invention, the body of water is contained within a harborage that is subject to tidal activity.

In accordance with another aspect of the present invention, the body of water is contained within a lock. The lock comprises an input of water with a head relative to the lock and an output of water that is below the head.

In accordance with still another aspect of the present invention, the vessel hull has a high displacement-to-perimeter ratio.

In accordance with still another aspect of the present invention, the piston-cylinder arrangement has two ends, one end of which is fixed to the hull and the other end being fixed to the fixed object.

In accordance with still another aspect of the present invention, the piston-cylinder arrangement has two ends that are each respectively pivotally coupled to the hull and the fixed object.

The present invention also provides a method of generating power, wherein a vessel hull that has a displacement is provided. The vessel hull is floated on a varying water level, wherein the vessel hull moves vertically. The displacement of the vessel hull is varied so that the vessel hull has a first displacement on a rising water level and a second displacement on a falling water level, with the second displacement being greater than the first displacement. Power is generated from the vertical movement of the vessel hull.

In accordance with one aspect of the present invention, the step of varying the displacement of the vessel hull further comprises taking on water and discharging water from the vessel hull.

In accordance with still another aspect of the present invention, the step of taking on water and discharging water from the vessel hull further comprises providing a port in the vessel hull that allows water to flow out of the vessel hull. A buoyant cover is provided for the port. The cover is allowed to move between open and closed positions relative to the port, wherein on a rising water level, the cover is in the closed position, and on a falling water level, the cover moves to the open position.

The present invention provides an apparatus for producing power. A floating vessel hull has an interior for containing water. The vessel hull is located on a body of water that has a rising and falling water level. The vessel hull moves vertically between a top position, wherein the vessel hull takes on water into its interior, and a bottom position, wherein the vessel hull discharges water from its interior. A generator converts the vertical movement of the vessel hull into electricity.

In accordance with one aspect of the present invention, the vessel hull has side walls and a base that move vertically along guides. The base opens and closes a first port to the vessel hull interior. The vessel hull has a second port to the interior. The second port communicates with the water body when the vessel hull is at the top position. When the vessel hull is at the bottom position, the base separates from the vessel hull to open the first port. The base is more buoyant than the side wall.

The present invention also provides a system for generating electrical power from water flowing in a channel. A conduit has intake and discharge ends. The intake end communicates with the water in the channel and is located at a first elevation. The discharge end is located at a lower elevation than the first elevation. A turbine is located in the conduit. A generator is operatively connected to the turbine. The conduit allows water to flow in the channel as well as inside the conduit.

In accordance with one aspect of the present invention, the conduit is located outside of the channel.

In accordance with another aspect of the present invention, the conduit is located inside of the channel.

In accordance with still another aspect of the present invention, the conduit is a pipeline.

In accordance with another aspect of the present invention, one of the intake or discharge ends is connected to a harborage, which harborage has a rising and falling water level.

In accordance with still another aspect of the present invention, the harborage comprises a lock that allows vessels to pass therethrough.

In accordance with still another aspect of the present invention, a vessel is located in the harborage. A linear-to-rotary converter is coupled between the vessel and a fixed object. The converter converts the vertical movement of the vessel into rotational movement.

The present invention provides a tidal power generator that comprises a harborage. The harborage is located so as to be subject to fluctuating water levels. The harborage has at least one port for allowing water to ingress and egress. A vessel hull is located in the harborage, with the hull being free to move vertically as the water level inside of the harborage rises and falls. A linear-to-rotary converter, at least part of which is coupled between the hull and the fixed object, converts the vertical movement of the hull into rotational movement. The port has a valve for adjusting the flow of water into and out of the harborage.

In accordance with one aspect of the present invention, the harborage comprises side walls and a door that allows the vessel hull to be floated into the harborage. The door is capable of opening and closing.

In accordance with still another aspect of the present invention, the harborage is surrounded on all sides by water.

In accordance with still another aspect of the present invention, the harborage is set into land.

In accordance with still another aspect of the present invention, the valve in the port comprises a door.

In accordance with another aspect of the present invention, a turbine is subjected to the water flowing through the port.

In accordance with still another aspect of the present invention, the vessel hull comprises a ship with a tapered bow when viewed from above.

In accordance with still another aspect of the present invention, the converter comprises a hydraulic piston-cylinder arrangement located between the hull and the fixed object. The hydraulic piston-cylinder produces pressurized fluid when the hull moves vertically.

In accordance with another aspect of the present invention, the pressurized fluid drives a turbine.

In accordance with another aspect of the present invention, the piston-cylinder arrangement has two ends, one end of which is fixed to the hull and the other end being fixed to the fixed object.

In accordance with still another aspect of the present invention, the piston-cylinder arrangement has two ends that are each pivotally coupled to the hull and the fixed object.

In accordance with still another aspect of the present invention, the harborage has at least one covered duct along a side of the harborage.

In accordance with another aspect of the present invention, the harborage is covered by a top.

In accordance with another aspect of the present invention, the harborage comprises a lock, which lock comprises an input of water with a head relative to the lock and an output of water that is below the head.

Brief Description of the Drawings

Fig. 1 is a plan view of a hull and harborage enclosure arrangement as used with the present invention, in accordance with a preferred embodiment.

Fig. 2 is a cross-sectional view, taken through lines II-II of Fig. 1.

Fig. 3 is a cross-sectional view of a side wall of the harborage enclosure taken through lines III-III of Fig. 2.

Fig. 4 is an end view of the harborage enclosure, in accordance with another embodiment.

Fig. 4A is a cross-sectional view of a port in the harborage enclosure.

Fig. 5 illustrates one type of linear-to-rotary converter, namely a piston-cylinder arrangement, between the vessel hull and a fixed object.

Fig. 6 shows an arrangement of piston-cylinders along a vessel side.

Fig. 7 is a longitudinal cross-sectional view of a master-slave cylinder arrangement, in accordance with another embodiment.

Fig. 8 is a longitudinal cross-sectional view of one of the slave piston-cylinders of Fig. 7.

Fig. 9 is a cross-sectional view, taken at lines IX-IX of Fig. 7.

Fig. 10 is a schematic view showing the power generation system of the present invention, in accordance with a preferred embodiment.

Fig. 11 shows a linear-to-rotary converter between the vessel and the harborage, in accordance with another embodiment.

Fig. 12 is a detailed view of a gear arrangement used with the converter of Fig. 11.

Fig. 13 is a view of the vessel hull, in accordance with another embodiment.

Fig. 14 is a detail view showing a vertical guide for the vessel hull of Fig. 13.

Figs. 15-17 show the vessel hull of Fig. 13 in various vertical positions. Fig. 15 shows the vessel hull rising. Fig. 16 shows the vessel hull at maximum vertical elevation with the vessel hull taking on water. Fig. 17 shows the vessel hull at minimum vertical elevation with the water being discharged therefrom.

Fig. 18 shows a lock or harborage, in accordance with another embodiment.

Fig. 19 shows the lock or harborage of Fig. 18 installed in a river environment, in accordance with one embodiment.

Fig. 20 is another embodiment that shows conduits in the bed of the river, which conduits have power generating turbines therein.

Description of the Preferred Embodiment

The present invention provides a way to extract energy from the rise and fall of the tides. A vessel hull is provided in a protective harborage enclosure. Water from the tides is admitted into the harborage so as to raise the vessel hull and released so as to lower the vessel hull. Mechanical converters are attached between the movable hull and a fixed object, such as the harborage itself; the converters convert the vertical movement of the hull into rotational mechanical energy, which is used to power an electrical generator. The electricity can be transmitted over conventional power lines to users.

The vessel hull can be an ocean-going ship, an inland (fresh water) ship, a barge, etc. The vessel hull 11 can be a ship hull (see Figs. 1 and 2). After a ship has served a useful life, whether commercially or militarily, it is mothballed or scrapped. Using a scrapped ship hull in this invention reduces costs and allows the serviceable life of the hull to be extended.

The hull is stripped of all non-essential equipment such as engines. In addition, the hull is sealed and made water tight. For example, the propeller shaft can be removed and the shaft opening sealed. Components subject to bimetallic degradation are removed. The deck can also be sealed in order to minimize the amount of freeboard. Minimizing the amount of freeboard allows for increased hull displacement, which in turn allows for an increase in power generation.

The vessel hull need not be a used hull, but could be constructed for this particular purpose. For example, because the hull need only move up and down and does not need to move horizontally, the hull can be a large rectangular box without any drag-minimizing shapes or configurations. Such a hull can be designed to maximize buoyancy. The hull can be made of metal, wood, composites (such as fiberglass) or other materials. A deck or a top is provided on the hull in order to keep rain and water from entering the hull. The weight of the hull 11 can be adjusted with ballast and equipment. Most if not all of the electrical generation equipment can be located in the hull 11.

The side walls of the hull 11 can be strengthened if need be. To this end, steel plates can be welded onto the inside or outside of a hull.

The harborage 13 receives the vessel hull 11 and allows the vessel hull to move vertically up and down with varying water levels. In some installations, the harborage protects the vessel hull and the other equipment (such as the linear-to-rotary converters discussed below). In some installations, the harborage serves to regulate the water level and thus the vertical movement of the vessel hull.

Referring to Figs. 1-4, the harborage 13 surrounds the sides of the hull 11 so as to protect the hull from wind and wave action. This is particularly desirable where the harborage is located in bays or open water and is subject to storms, ice or tsunamis. In most locations, the harborage completely surrounds the hull. However, in some locations, the harborage need not surround the hull but need only be between the rough water and the hull, much like a break water. The harborage 13 has side walls 15. The side walls can be set into the bottom of a water body, such as a bay or channel, or it can be attached to a bottom wall 17 which bears on the bottom of a water body. Underneath the bottom wall 17 is some foundational structure. One of the walls forms a door 19 (see Fig. 4) or doors that can be opened and closed. This allows the hull to be floated through the open doors into the harborage, with the doors closing. Alternatively, the harborage can be left open with one wall missing, until the hull is located therein. After the hull is located inside of the harborage, then the wall can be attached to close off the access opening. A roof 21 or top wall can be provided so as to fully enclose the hull and allow the interior to be sheltered from the weather.

The harborage 13 can be of metal or concrete. For example, the harborage could be a dry dock that is to be mothballed or a caisson that is floated to the desired location and then sunk. The harborage could also be of the cofferdam type which has vertical steel panels inserted into the bottom of a water body.

The harborage 13 is not water tight so as to allow water 22 to flow in and out. One or more ports 23, or openings, are provided in one or more of the side walls 15. The ports 23 are located below the lowest level of water outside of the harborage, such as below the lowest tide.

In the preferred embodiment, the ports 23 are equipped with valves 25 (see Fig. 4A). When the water level is lowered and the valves 25 are closed, the harborage can be used to maintain or repair the vessel hull, much like a dry dock.

The ports 23 can also be equipped with impellers or turbines 27. The valves 25 are selectively opened and closed to regulate the amount of water flowing through the ports 23. The turbines 27 rotate when water moves through the ports. The turbines are connected to electric generators. The turbines can be directly connected to generators, such as by shafts 28 and gears. Alternatively, the turbines could drive hydraulic motors which in turn drive the electrical generators.

The harborage 13 is located so as to be subjected to different water levels. For example, the harborage could be located in a water body such as a harbor or bay. Preferably, the harborage is located in an area with a large tidal swing, such as off the coasts of New England, or of France, or in the Bay of Fundy, the Bay of Bengal or the Arabian Sea along India. The harborage could also be located in open water, much like a platform for oil and gas wells. The Gulf of Mexico, off the Louisiana coast, is heavily populated with such platforms. Alternatively, the harborage could be set into land, with a water channel that subjects the hull inside of the harborage to tidal activity or variable water levels. Such a harborage would be surrounded by land on three sides with the remaining side having one or more openings to the water. Alternatively, the harborage could access a water body with tidal activity via a channel, such as a river, canal or large ducts.

Fig. 4 shows a harborage 13A in accordance with another embodiment. The harborage 13A blocks a passage, such as in a break water, or a barrier. Ducts 28 are covered to protect the water on the sides from freezing in cold weather. Alternatively, the ducts could serve as canals 28 on one or both sides allow water to flow past the harborage. In this embodiment, the harborage can act as a lock.

The harborage 13 is deep enough and large enough so that the hull is always floating, even with low tide or low water levels. If the harborage is not deep enough, and there is no bottom wall, the bottom can be dredged out or excavated to increase the depth beneath the hull. The side walls of the harborage are high enough to offer protection from wind and waves, particularly in stormy weather. To minimize damage, the hull should be shielded from exposure to high wind and waves.

As the tides change, water moves in and out of the harborage. In the preferred embodiment, the water ingresses and egresses the harborage through the ports 23. The doors 19 could be opened and closed to allow water to move in and out of the harborage. When the tide is coming in, water enters the harborage through the ports 23, spins the turbines 27, and lifts the hull 11. When the tide is leaving, the water exits the harborage through the ports, spinning the turbines 27 and allowing the hull to lower. Thus, the hull moves vertically up and down inside of the harborage.

This motion of the hull 11 is captured by linear-to-rotary converters between the hull and a fixed object, such as the harborage, the water body bottom, or in the case of an harborage adjacent to land, then the land itself. The hull movement can be captured by a number of types of devices. One such converter is a hydraulic cylinder and piston. Another type of converter uses levers and gears, while another uses cables and pulleys, while still another uses a rack and pinion gear.

Referring to Fig. 5, there is shown a double acting piston and cylinder 31. In the preferred embodiment, the cylinder 33 is coupled to the vessel hull 11, while the piston 35, mounted on a rod 37, is coupled to a fixed object 38, such as the harborage 13. Thus, the cylinder 33 moves with the hull 11, while the piston 35 is fixed. The piston 35 divides the cylinder 33 into an upper chamber 39 and a lower chamber 41. Hydraulic lines 43 extend from each chamber through the vessel hull to a turbine 65 located in the vessel or on shore. As the vessel 11 rises, with an incoming tide or rising water level, the cylinder 33 moves up. The piston 35 pressurizes the hydraulic fluid in the lower chamber 41 and provides a partial vacuum to the hydraulic fluid in the upper chamber 39. Conversely, as the vessel falls, with a receding tide, the piston pressurizes the hydraulic fluid in the upper chamber 39 and provides a partial vacuum to the hydraulic fluid in the lower chamber 41. The hydraulic fluid can be a liquid or gas or a combination of both. The hydraulic fluid is preferably water, or even more preferably, a polymer or oil based liquid. A long chain polymer liquid is less likely to leak around the piston.

The piston and cylinder can be made of ceramic. Ceramic is strong and can withstand large forces that are applied to the piston and cylinder. Ceramic can be finely machined to provide for tight tolerances between the piston and the cylinder. With tight tolerances, such as on the order of microns of clearance between the piston and the cylinder, no seal between the piston and the cylinder is required. A hydraulic fluid with long chain polymers will not leak past the cylinder.

As an alternative, the piston 35 could be coupled to the vessel wall and the cylinder 33 fixed stationary.

What makes a ship hull 11 particularly suited for reaping power from the tides is the large size of the vessel. The vessel has a large displacement (typically several thousands of tons, up to tens of thousands of tons). Thus, the force available is large, which in turn means that large amounts of electrical power can be generated. As shown in Fig. 6, a number of piston-cylinders 31 can be attached along each side of the vessel hull, with all sides having piston-cylinders. The cylinders 33 can be vertically staggered so as to allow for tighter packing and to increase the number of cylinders along a side of the hull. The piston-cylinders allow the vessel hull to move vertically, but constrain the vessel hull from moving horizontally.

The bottom of the vessel hull can be provided with piston-cylinders. Thus, the piston-cylinders or other linear-to-rotary converters, can be placed along the sides of the vessel hull and the bottom of the vessel hull.

Figs. 7-9 illustrate another type of hydraulic cylinder. There is provided a master cylinder 42, or outer cylinder. A number of smaller cylinders, or slave cylinders 44, are provided on the inside of the master cylinder 42. The smaller cylinders 44 are ganged together so as to work in unison.

This master cylinder arrangement is useful where wide temperature ranges are experienced. Such wide temperature variations make cylinders prone to leakage around the pistons, particularly under high pressure.

The master cylinder 42 is equipped with two end plates 45, as shown in Fig. 7. The plates 45 are movable with respect to the master cylinder 42. The master cylinder 42 is configured as is the cylinder 33 shown in Fig. 5, in that the master cylinder moves with the hull 11 and the plates 45 and their rods 47 are fixed. The piston rods 49 of the slave cylinders 44 are attached to the master cylinder plates 45. The cylinders 51 of the slave cylinders 43 are attached to the master cylinder 42. Thus, any movement of the master cylinder also moves the slave cylinders 51 about their fixed slave pistons 53. The master cylinder protects the slave cylinders from the environment and provides some thermal protection.

Fig. 8 shows a slave piston 53. The piston 53 has ceramic or metal plates 55, interweaved with air or graphite plates or elements 57. This arrangement provides a seal, particularly under high pressures. The piston arrangement of Fig. 8 can also be used in a single cylinder and need not be used in a slave cylinder.

The slave cylinders 44 are packed into the master cylinder 42. Fig. 9 illustrates such an arrangement, where there is an outer ring of slave cylinders and a center slave cylinder.

Fig. 10 shows how electrical power is generated from a piston-cylinder 31. The pressurized hydraulic fluid is output from each piston-cylinder 31 into a turbine 65, impeller, compressor or gear motor, wherein the pressurized fluid does the work by imparting rotation to the turbine. An impeller is a wheel-like device having vanes or cups on its outer periphery. The pressurized fluid impacts the impeller to rotate the impeller. There is little or no leakage, or slippage, of the pressurized fluid past the vanes or cups in the impeller, thereby providing a high degree of efficiency. This rotation drives a gear box 61, which in turn drives an electric generator 67. One-way, or check, valves 63 are located in each line 43 between the cylinder 31 and the turbine 65. The valves 63 direct the pressurized fluid from the cylinder into the turbine and away from the low pressure side of the cylinder. Fluid exits the turbine 65 and returns to the low pressure side of the cylinder through check valves 71. An accumulator can be optionally used on the high pressure side of the cylinder. A low pressure accumulator can be optionally used on the low pressure side of the cylinder. Also, the lines 43 from several piston-cylinders 31 can be connected together to drive a single turbine. Because the cylinders are double acting, pressurized fluid is produced on both the rising and the ebbing tides.

The tides have slack periods, namely at high tide and at low tide. These slack periods are when the flow of water in a water body changes direction. During slack tides, no pressurized fluid is produced by the vessel. Also, the tides are not constant. Neap tides are lower than normal, while spring tides are higher than normal. Neap and spring tides occur over numerous cycles.

Because it is uneconomical to store large amounts of electricity in batteries, electricity must be produced as it is used. One way to smooth out the fluctuations in the tides and produce electricity constantly, or nearly so, is to regulate the water flowing through the ports 23 (see Fig. 4A) of the harborage 13. The ports are equipped with valves 25 that regulate the size of the openings. The ports are sized small enough, with the valves, to slow the filling of the harborage or release of water therefrom. For example, if high tide occurs at 6:00 am, with slack tide between 5:00 to 7:00 am, then the ports are sized so that the water continues to flow into the harborage until 7:00 am. The ports are sized by knowing the water capacity of the harborage and the height of the tides. At 7:00 am, the tide starts to recede and water begins to exit the harborage. A slack or low tide is between 5:00 pm and 7:00 pm, so water exits the harborage until 7:00 pm. In other words, the ports are sized to slow the flow of water in and out of the harborage. This allows the vessel hull 11 to almost always be moving either up or down. The short periods of time when the vessel changes direction can be compensated for by the high pressure accumulator 61. Because the height and speed of the tides vary, the valves 25 can be adjusted on a frequent basis.

Still another way to smooth out the tidal variations and slack tides is to retard the vertical movement of the vessel hull. For example, on a rising tide, the piston-cylinders can retard the rise of the hull. This can be accomplished by putting an orifice on the output lines 43 of the piston-cylinder, which orifice limits the amount of fluid exiting from the cylinder. Thus, as the vessel hull is being buoyed up by the rising water in the harborage, the piston-cylinders extend at a slower rate due to the resistance of the orifices, and effectively slows the ascent of the vessel hull. Conversely, as the water level in the harborage drops, such as due to an ebbing tide, descent of the vessel hull is slowed by contracting of the piston-cylinders, which contraction is slowed by orifices in the hydraulic lines. Regulating the fluid output of the piston-cylinders allows for smoother operation of the electrical generation equipment. The orifices can be fixed or variable.

Retarding, or resisting, the vertical movement of the vessel hull also alters the displacement of the vessel hull. For example, on a rising tide, the vessel hull displacement increases as the water line on the vessel hull moves up. On a receding tide, the vessel hull displacement decreases, as the water line on the vessel hull drops down. In both cases, potential energy is accumulated. This potential energy can be captured by opening the orifices and allowing the vessel hull to move to its normal displacement.

Regulating the flow of water in and out of the harborage or retarding vertical movement of the hull serve to desynchronize the vertical movement of the vessel hull from the tidal variations. Specifically, the vertical movement of the vessel hull lags the tidal variations. This allows energy to be stored and used during slack tides.

Fig. 11 shows another converter, in accordance with another embodiment. The converter 71 is a hydraulic cylinder having two ends 73, 75. One end 73 is pivotally coupled to the vessel hull 11, while the other end 75 is pivotally coupled to a fixed object. The cylinder 71 has a piston contained therein. The piston can be a double acting piston or a single acting piston. All sides of the vessel wall will have the converters 71.

As the vessel rises and falls, the orientation of the cylinder changes. This causes the overall length between the two ends 73, 75 to change, thereby moving the piston within the cylinder and producing pressurized fluid. The hydraulic cylinders 71 minimize horizontal movement of the vessel hull so as to keep the hull centered or otherwise properly positioned in the desired location. The hydraulic cylinders 71 act as shock absorbers and reduce the stress on the hull. The hydraulic cylinder 71-vessel hull arrangement of Fig. 11 can be used without a harborage.

The rotary movement of the piston-cylinder at the ends 73, 75 can be tapped for electrical generation. A set of gears is located at each end to amplify or increase the rotational speed. Fig. 12 illustrates one such gear amplifier. A primary gear 77 is fixed to the cylinder or arm at the respective end. The primary gear 77 and a secondary gear 79 form a planetary gear arrangement. Other gears 81, 83, 85 are used if needed to obtain the speed necessary to drive an electrical generator.

The present invention can also be used in non-tidal situations. The rise and fall of the tides can be emulated by a lock in a river or other downhill flowing water body. In a lock, a vessel hull is raised by filling the lock with water from upstream. The vessel hull is lowered by draining the water from the lock on the downstream side.

Fig. 4 illustrates a harborage that can be used as a lock. Fig. 4 shows an end view, such as from the downstream end. The main body of the lock receives the vessel hull. Doors on hinges are shown on the downstream end. Both ends, the downstream end and the upstream end, have ports (or ducts or channels) for the ingress and egress of water to and from the harborage or lock. The ports have valves so as to control the flow of water through the ports.

In operation, the upstream ports are opened to allow water to flow into the lock. The vessel hull rises. Linear-to-rotary converters, such as the piston-cylinder arrangements described above, convert the upward movement of hull to rotary movement. Once the hull is at its maximum vertical height, the upstream ports are closed and the downstream ports are opened to release water from the lock. The vessel hull drops in elevation and the linear-to-rotary converters convert the downward movement of the hull to rotary movement. In lieu of ports in the doors, the upstream doors can be opened to admit water to the lock, while the downstream doors can be opened to release water from the lock.

The linear-to-rotary converters described herein limit the horizontal movement of the vessel hull. Thus, for example, in the lock arrangement, the doors can be opened and the vessel remains inside, merely rising or falling in a vertical manner. The vessel thus stays in the lock.

Because the vessel hull need not move horizontally, the vessel hull can be designed so as to maximize the displacement-to-perimeter ratio. For example, with an ocean going ship, the hull is tapered, especially at the bow and stern sections. The vessel hull in a lock or harborage can be box-like in order to maximize its displacement. The perimeter of the hull, where the linear-to-rotary converters connect to, can be small relative to this displacement. By so maximizing the displacement-to-perimeter ratio, the vertical rise and fall of the vessel hull can be fully taken advantage of.

An advantage of the lock arrangement is that the frequency of vertical hull movement is independent of the tides. In some locations, a tidal cycle of a high tide and a low tide may span 24 hours. This allows only a single rise and a single fall of the vessel hull. With a lock positioned by a water body with some head relative to sea level, such as at a dam or in a river, the number of rises and falls of the vessel hull can be increased over a 24 hour period, thereby generating far more energy.

The lock of Fig. 4 shows two lateral canals. These are optional and allow water to flow on one or both sides of the lock.

The harborage can be used as a lock or as an ancillary device to a lock. In a lock, a vessel is transported between an upper water level and a lower water level. As an ancillary device to a lock, the water from the lock is discharged into the harborage. The vessel hull in the harborage is raised by the water discharged from the lock. To lower the vessel hull, water is discharged from the harborage. Thus, vessel transport can be accommodated by the lock, while power can be generated by the water used in the lock. The harborage can be at the same elevation as the lock, wherein, the water level in the harborage can only rise to part of the elevation of the upper water level. When the two water levels in the lock and harborage are equal, the remaining water in the lock is discharged downstream and not into the harborage. Alternatively, the harborage may be set at a lower elevation than the lock so as to achieve a higher vertical movement of the vessel hull.

The harborage can also be used independently of a lock. For example, a river has a drop in elevation over some distance. Water from upstream, the upper water level, can be conveyed by a channel or conduit independent of the river channel to the harborage, and water can be discharged from the harborage to a lower water level in the river by conduit or channel.

Figs. 13-17 show the vessel hull 111 in accordance with another embodiment. The linear-to-rotary converters can be coupled to the bottom of the vessel hull, as shown in Fig. 13. The converters are shown as piston-cylinder arrangements 31. The cylinders 33 can be coupled either to earth 38 (shown on the left side of Fig. 13) or to the vessel hull (shown on the right side of Fig. 13), while the pistons are coupled to the opposite member of the cylinder.

The vessel hull 111 is unique in that its displacement changes, depending upon its vertical position. On a rising water level, the displacement of the vessel hull is lower than when the water level is dropping. Because the displacement changes, more energy can be extracted from the vertical movement. On a rising water level, the lower displacement exerts a greater pull on the piston-cylinder arrangements 31. This results in higher pressures developed by the piston-cylinder arrangements 31. On a falling water level, the heavier displacement exerts a greater push on the piston-cylinder arrangements, once again providing higher pressures therefrom. The vessel hull 111 need not have a harborage and can be used in salt or fresh water environments (such as a lock).

The vessel hull 111 has a base 113 and side walls 115. The base 113 and side walls 115 form a container that can hold water. The container is interior of the vessel hull. The top of the vessel hull can be either open or closed with a deck. If closed, a vent to the interior is provided to allow the taking on and discharge of water to and from the interior. The bottom of the side walls 115 is open, unless closed by the base 113. A seal 117 is provided between the side walls and the base to form a water-tight container. The base 113 floats and has positive buoyancy, while the side walls 115 have neutral buoyancy, or even negative buoyancy.

As shown in Fig. 14, the vertical movement of the vessel hull is along guides 119 or posts. The posts 119 are securely anchored to the earth 38. The base 113 has openings 121 therethrough for receiving the posts 119. The base can move vertically along the posts. Seals or bushings (not shown) are provided in the base openings to limit the leakage of water therethrough. The side walls 115 have cavities 123 therein, which cavities are open at the bottom of the side walls and receive the upper ends of the posts 119. The thickness of the side walls at the cavities can be increased in order to accommodate the cavities. Each cavity 123 has a top end 125 which acts as a stop to the lower movement in the side walls. The base has no such limitation on its lowermost movement. The upper end of each post has a stop 127 for limiting upper movement of the base and the side walls. The stop for limiting the upper movement can be on the exterior of the vessel hull, such as a wall that contacts the upper side of the side walls. Likewise, the stop for limiting the lower movement of the side walls can also be exterior of the vessel hull.

The operation of the vessel hull 111 will now be described with reference to Figs. 15-17. Fig. 15 depicts the vessel hull 111 on a rising water level 131. The base 113 and side walls 115 are together and form a water-tight vessel hull. The vessel hull is empty of water and thereby floats high on the water, following the water up in vertical elevation, guided by the posts 119. The piston-cylinder arrangements 31 create pressurized fluid from this vertical movement.

The upward movement of the vessel hull is limited by stops 127 (see Fig. 14) on the posts 119. The stops engage the base (or optionally the side walls) and prevent the vessel hull from floating up beyond a top position. Because the side walls are not positively buoyant, the side walls stay engaged on the base as the water rises.

The upper limit of the vessel hull is designed so that the water level can continue to rise along the side walls 115 of the vessel hull. As shown in Fig. 16, when the water rises high enough, the water enters the vessel hull either over the top rim or through ports. The ports can be set below the top rim of the vessel hull to prevent complete filling of the vessel hull and maintains some positive buoyancy. The addition of water to the vessel hull increases the mass and thus the displacement of the vessel hull.

When the water level falls outside of the vessel hull, the vessel hull drops in elevation, along the posts 119 and the piston-cylinder arrangements 31 create pressurized fluid. The top ends of the posts then contact the stop surfaces 125 (see Fig. 14) in the side walls to limit the downward movement of the side walls. The base has no such limitation and continues its downward motion. Thus, the base separates from the side walls, breaking the seal so as to form a port or opening and allowing the water inside the vessel hull to discharge, as shown in Fig. 17. The water level outside the side walls will drop to a position where the base breaks free of the side walls.

On the next rising water level, the base rejoins with the side walls, being pushed up by the water level to engage the side walls and form a water-tight vessel hull once again. The base 113 is preferably provided with a lip around the outer periphery thereof.

The vessel hull can also be provided with ports in the nature of those shown in Fig. 4A. That is to say, that the vessel hull can be provided with ports equipped with turbines so that as water flows in and out of the vessel hull, this flow can be used to generate rotational movement and in turn used to generate electrical power.

Figs. 18 and 19 show a lock or harborage 201 used in conjunction with a river environment. The lock or harborage 201 has a vessel 203 therein. When used as a harborage, the vessel 203 remains inside as the level of water rises and falls. The vessel is connected to linear-to-rotary converters as discussed above. When used as a lock, the vessel 203 passes through, using the lock to raise or lower to a desired elevation. The vessel in lock is typically not connected to linear-to-rotary converters. Whether used as a harborage or lock 201, power is generated from water flowing into and out of the harborage or lock (hereinafter referred to as a "harborage").

The harborage 201 has an inlet conduit 205 and an outlet conduit 207. The inlet or outlet conduits 205, 207 are provided with valves 208. The inlet conduit 205 extends to a first body of water 209, while the outlet conduit 207 extends to a second body of water 211. The elevation of the first body of water 209 is higher than the elevation in the second body of water 211, thus creating a pressure differential or head. A turbine 27 is located in either the inlet conduit 205, the outlet conduit 207 or both. The turbine 27 is connected to an electrical generator 67 as described above. The turbine 27 rotates and generates electrical power when the water flows through the respective conduit. If the harborage 201 is filling, water flows into the harborage via the inlet conduit 205. The flowing water rotates the turbine 27 in the inlet conduit. The turbine in turn drives an electrical generator 67 to produce electrical power. The outlet conduit 207 is closed during filling of the harborage. The water level in the harborage 201 rises, as does the vessel. If the water level in the harborage 201 is lowered, water flows through the outlet conduit 207, rotating the turbine therein. The inlet conduit 205 is closed during emptying of the harborage. The water level inside of the harborage falls, thereby lowering the vessel 203. If the vessel 203 is coupled to a linear-to-rotary converter, then electrical power can be produced from filling and emptying the harborage and raising and lowering the vessel 203.

The head across the turbine 27 and thus the amount of energy that can be extracted can be increased by extending one or more conduits 205, 207 to a body of water with a more extreme head. Referring to Fig. 19 for example, the harborage 201 is located near a dam 213. The inlet conduit 205 thus draws water from the lake 209 impounded by the dam.

Suppose that the level of lake 209 is 458 feet above sea level. The outlet conduit 207 can drain to the water below the dam. Suppose that the water level immediately below the dam (point A) is 412 feet above sea level. The water level 6.7 miles downstream from the dam is 405 feet. If the outlet conduit 207 discharges immediately below the dam, the head would be 46 feet. If the outlet conduit discharges several miles downstream from the dam, at point B in Fig. 19, the head would be 53 feet. Thus, the head is increased by extending the outlet conduit 207 further downstream. Likewise, the harborage can be located at a lower elevation, such as at point B, downstream from the dam, while the inlet conduit 205 is located at the impounded lake 209.

The harborage 201 and conduits 205, 207 can be used without a dam.

Fig. 19 illustrates that the conduits 205, 207 can be located outside of the stream or river bed 215. The conduit can cut across a bend in the river. This shortens the amount of conduit needed. For example, if the river 215 is 6.7 miles from point A to point B, which river bed has a curve or bend, the conduit, without curves, is only 3.88 miles from point A to point B.

Fig. 20 illustrates the conduit 205 located within the river bed 215. This is particularly useful where the river is straight, but can also be used on a river with bends and curves. In Fig. 20, the harborage 201 is located downstream. The conduit 205 has a turbine 27 therein, located near the harborage 201. The conduit can be submerged so as to be out of sight and so as not to interfere with navigation. The upper end of the conduit has a collector 217 so that some water flowing downstream will enter the conduit. The upper end, or intake end, can be elevated from the river bottom in order to minimize the amount of silt collected by the conduit.

Fig. 20 also illustrates the use of conduits and turbines without harborages. A conduit 221 has an upper end 223 at a first elevation and a lower end 225 at a second elevation, which is lower than the first elevation. The upper end 223 collects water, which water flows through the conduit due to the drop in elevation. The flowing water turns the turbine 27, which turbine then generates electrical power by way of a generator. The water is discharged back into the river. Thus, the conduit 221 is similar to the conduit 205, except as to where the water is discharged. The conduit 205 discharges into a harborage, while the conduit 221 discharges into the river.

The lower end 225 of the conduit 221 has a venturi. The venturi, or expander, causes a pressure drop after the turbine 27. The venturi is useful for increasing the pressure differential or head across the turbine. The venturi is particularly useful in increasing head in a river or stream bed that is relatively flat or has a low head. The venturi need not be located at the lower end of the conduit, but can be located upstream or above the lower end.

Another conduit 227 is similar to conduit 221 but discharges into a water utilization system 229, such as a water treatment plant. Conduit 227 is especially useful for bringing water from a pure source downstream to where the river is polluted.

The conduits 205, 207, 221, 227 of the present invention do not interfere with the flow of water in a river bed or channel. This is a distinct advantage over building a dam, which necessarily interferes with the flow of water by virtue of the fact that the water is impounded by the dam. Furthermore, the building of a conduit or pipeline is less expensive than the building of a dam. A conduit or pipeline can create the same head or pressure as the dam but without the capital expense. In addition, because water is not impounded, thereby altering the riverbank, the conduit of the present invention will not affect wildlife or populations located along the banks of the river as does the dam. Furthermore, because the water flow is not impeded by the conduit, as it is with the dam, there is no silting problem. With dams, as water enters the reservoir impacted by the dam, the water typically contains a load of silt which is deposited on the bottom of the reservoir. Over a period of years, this silt builds up and diminishes the capacity of the reservoir.

The foregoing disclosure and showings made in the drawings are merely illustrative of the principles of this invention and are not to be interpreted in a limiting sense.

TIDAL POWER GENERATION

CLAIMS

1. A method of generating power, comprising the steps of:

a) providing a harborage with an interior and an exterior, the exterior being subject to tidal variations;

b) floating a vessel hull in the interior of the harborage;

c) allowing water to flow between the interior and the exterior of the harborage so as to vary the water level in the harborage interior and move the vessel hull vertically;

d) desynchronizing the vertical movement of the vessel hull from the tidal variations;

e) generating power from the vertical movement of the vessel hull.

2. The method of claim 1 wherein the step of desynchronizing the vertical movement of the vessel hull from the tidal variations further comprises the step of retarding the vertical movement of the vessel hull so as to vary the displacement of the vessel hull within the harborage.

3. The method of claim 1 wherein the step of desynchronizing the vertical movement of the vessel hull from the tidal variations further comprises the step of regulating the flow of water between

the interior and the exterior of the harborage so as to lag the tidal variations.

4. The method of claim 1, wherein:

a) the step of floating a vessel wall in the interior of the harborage further comprises floating a vessel hull with a displacement;

b) varying the displacement of the vessel hull so that the vessel hull has a first displacement on a rising water level and a second displacement on a falling water level, with the second displacement being greater than the first displacement.

5. The method of claim 4 wherein the step of varying the displacement of the vessel hull further comprises the step of taking on water and discharging water from the vessel hull.

6. The method of claim 5 wherein the step of taking on water and discharging water from the vessel hull further comprises the steps of:

a) providing a port in the vessel hull that allows water to flow out of the vessel hull;

b) providing a buoyant cover for the port;

c) allowing the cover to move between open and closed positions relative to the port, wherein on a rising water level, the cover is in the closed portion and on a falling water level, the cover moves to the open position.

7. The method of claim 1, wherein the step of generating power from the vertical movement of the vessel hull further comprises the steps of:

a) producing pressurized fluid from the vertical movement of the vessel hull;

b) rotating a turbine with the pressurized fluid.

8. The method of claim 1 wherein the step of allowing water to flow between the interior and the exterior of the harborage so as to vary the water level in the harborage interior and move the vessel hull vertically further comprises the step of generating power from the flow of water between the interior and the exterior of the harborage.

9. A power generator, comprising:

a) a body of water having a top level that fluctuates;

b) a vessel hull buoyantly located on the water body, the hull being free to move vertically as the top level fluctuates;

c) a piston-cylinder arrangement coupled between the vessel hull and a fixed object, the cylinder having an output for pressurized fluid when the vessel moves vertically, the piston-cylinder arrangement constraining horizontal movement of the vessel hull;

d) a turbine having an input which is connected to the cylinder output, wherein pressurized fluid from the cylinder rotates the turbine.

10. The power generator of claim 9 wherein the body of water is contained within a harborage that is subject to tidal activity.

11. The power generator of claim 9 wherein the body of water is contained within a lock, which lock comprises an input of water with a head relative to the lock and an output of water that is below the head.

12. The power generator of claim 9 wherein the vessel hull has a high displacement-to-perimeter ratio.

13. The power generator of claim 9 wherein the piston-cylinder arrangement has two ends, one end of which is fixed to the hull and the other end being fixed to the fixed object.

14. The power generator of claim 9 wherein the piston-cylinder arrangement has two ends that are each respectively pivotally coupled to the hull and the fixed object.

15. A method of generating power, comprising the steps of:

a) providing a vessel hull that has a displacement;

b) floating the vessel hull on a varying water level, wherein the vessel hull moves vertically;

c) varying the displacement of the vessel hull so that the vessel hull has a first displacement on a rising water level and a second displacement on a falling water level, with the second displacement being greater than the first displacement;

d) generating power from the vertical movement of a vessel hull.

16. The method of claim 15 wherein the step of varying the displacement of the vessel hull further comprises the step of taking on water and discharging water from the vessel hull.

17. The method of claim 16 wherein the step of taking on water and discharging water from the vessel hull further comprises the steps of:

a) providing a port in the vessel hull that allows water to flow out of the vessel hull;

b) providing a buoyant cover for the port;

c) allowing the cover to move between open and closed positions relative to the port, wherein on a rising water level, the cover is in the closed position and on a falling water level, the cover moves to the open position.

18. An apparatus for producing power, comprising:

a) a floating vessel hull having an interior for containing water;

b) the vessel hull located on a body of water that has a rising and falling water level;

c) the vessel hull moves vertically between a top position, wherein the vessel hull takes on water into its interior, and a bottom position, wherein the vessel hull discharges water from its interior;

d) a generator that converts the vertical movement of the vessel hull into electricity.

19. The apparatus of claim 18, wherein:

a) the vessel hull has side walls and a base that move vertically along guides, the base opening and closing a first port to the vessel hull interior;

b) the vessel hull having a second port to the interior, the second port communicating with the water body when the vessel hull is at the top position;

c) when the vessel hull is at the bottom position, the base separates from the vessel hull to open the first port, the base being more buoyant than the side wall.

20. A system for generating electrical power from water flowing in a channel, comprising:

a) a conduit having intake and discharge ends, the intake end communicating with water in the channel and located at a first elevation, the discharge end located at a lower elevation than the first elevation;

b) a turbine located in the conduit;

c) a generator operatively connected to the turbine;

d) the conduit allowing water to flow in the channel as well as inside the conduit.

21. The system of claim 20 wherein the conduit is located outside of the channel.

22. The system of claim 20 wherein the conduit is located inside of the channel.

23. The system of claim 20 wherein the conduit is a pipeline.

24. The system of claim 20 wherein one of the intake or discharge ends is connected to a harborage, which harborage has a rising and falling water level.

25. The system of claim 24 wherein the harborage comprises a lock that allows vessels to pass therethrough.

26. The system of claim 24 further comprising a vessel located in the harborage and a linear-to-rotary converter, at least part of which is coupled between the vessel and a fixed object, the converter

converting the vertical movement of the vessel into rotational movement.

27. A tidal power generator, comprising:

a) a harborage located so as to be subject to fluctuating water levels, the harborage having at least one port for allowing water to ingress and egress;

b) a vessel hull located in the harborage, the hull being free to move vertically as the water level inside of the harborage rises and falls;

c) a linear-to-rotary converter, at least part of which is coupled between the hull and a fixed object, the converter converting the vertical movement of the hull into rotational movement;

d) the port having a valve for adjusting the flow of water into and out of the harborage.

28. The tidal power generator of claim 27 wherein the harborage comprises side walls and a door that allows the vessel hull to be floated into the harborage, the door capable of opening and closing.

29. The tidal power generator of claim 27 wherein the harborage is surrounded on all sides by water.

30. The tidal power generator of claim 27 wherein the harborage is set into land.

31. The tidal power generator of claim 27 wherein the valve in the port comprises a door.

32. The tidal power generator of claim 1 comprising a turbine subjected to the water flowing through the port.

33. The tidal power generator of claim 27 wherein the vessel hull comprises a ship with a tapered bow when viewed from above.

34. The tidal power generator of claim 27 wherein the converter comprises a hydraulic piston-cylinder arrangement located between the hull and the fixed object, the hydraulic piston-cylinder producing pressurized fluid when the hull moves vertically.

35. The tidal power generator of claim 34 wherein the pressurized fluid drives a turbine.

36. The tidal power generator of claim 1, comprising the piston-cylinder arrangement has two ends one end of which is fixed to the hull and the other end being fixed to the fixed object.

37. The tidal power generator of claim 1, comprising the piston-cylinder arrangement has two ends that are each pivotally coupled to the hull and the fixed object.

38. The tidal power generator of claim 27 wherein the harborage has at least one covered duct along a side of the harborage.

39. The tidal power generator of claim 27 wherein harborage is covered by a top.

40. The tidal power generator of claim 27 wherein harborage comprises a lock, which lock comprises an input of water with a head relative to the lock and an output of water that is below the head.

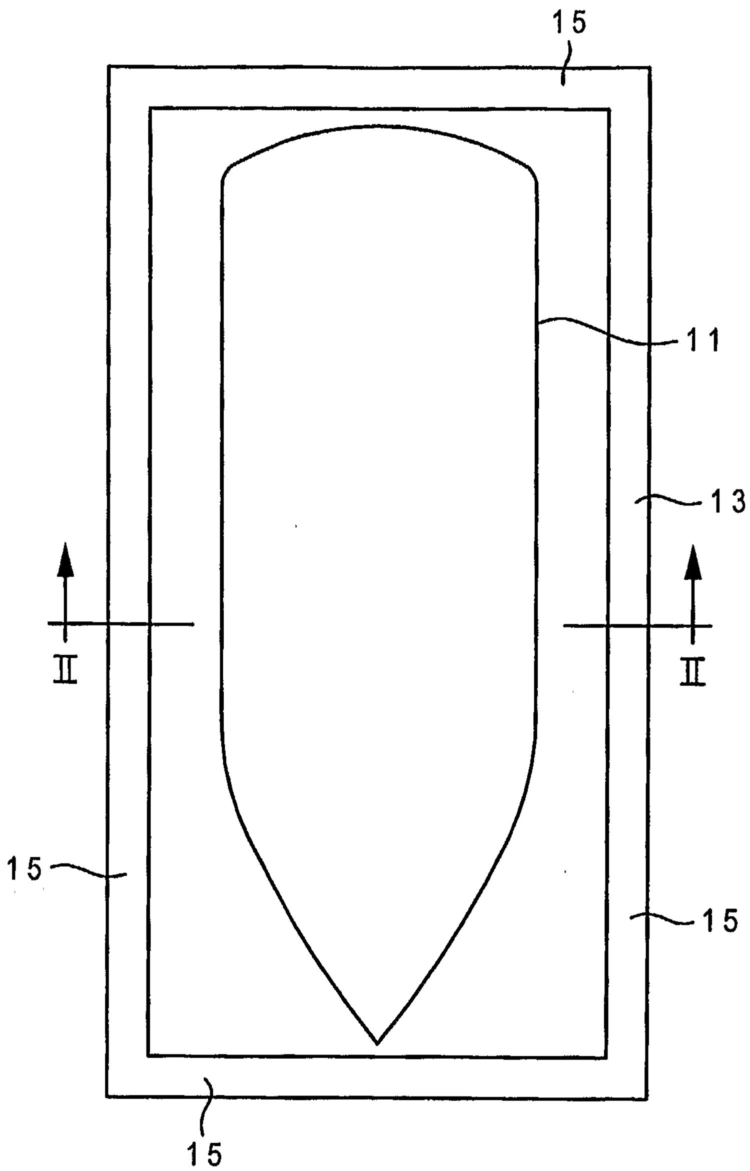


Fig. 1

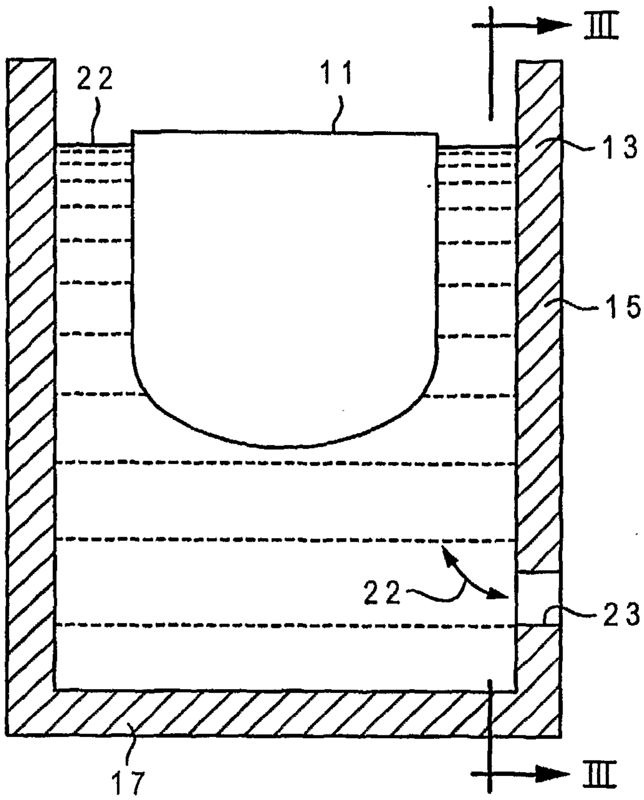


Fig. 2

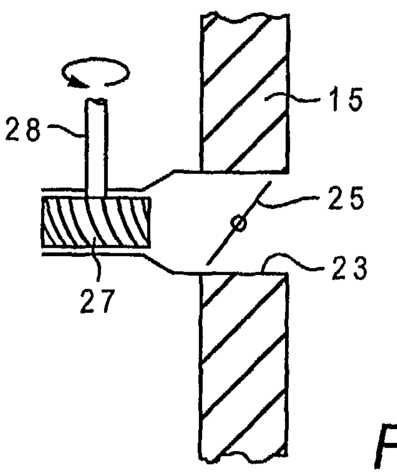


Fig. 4A

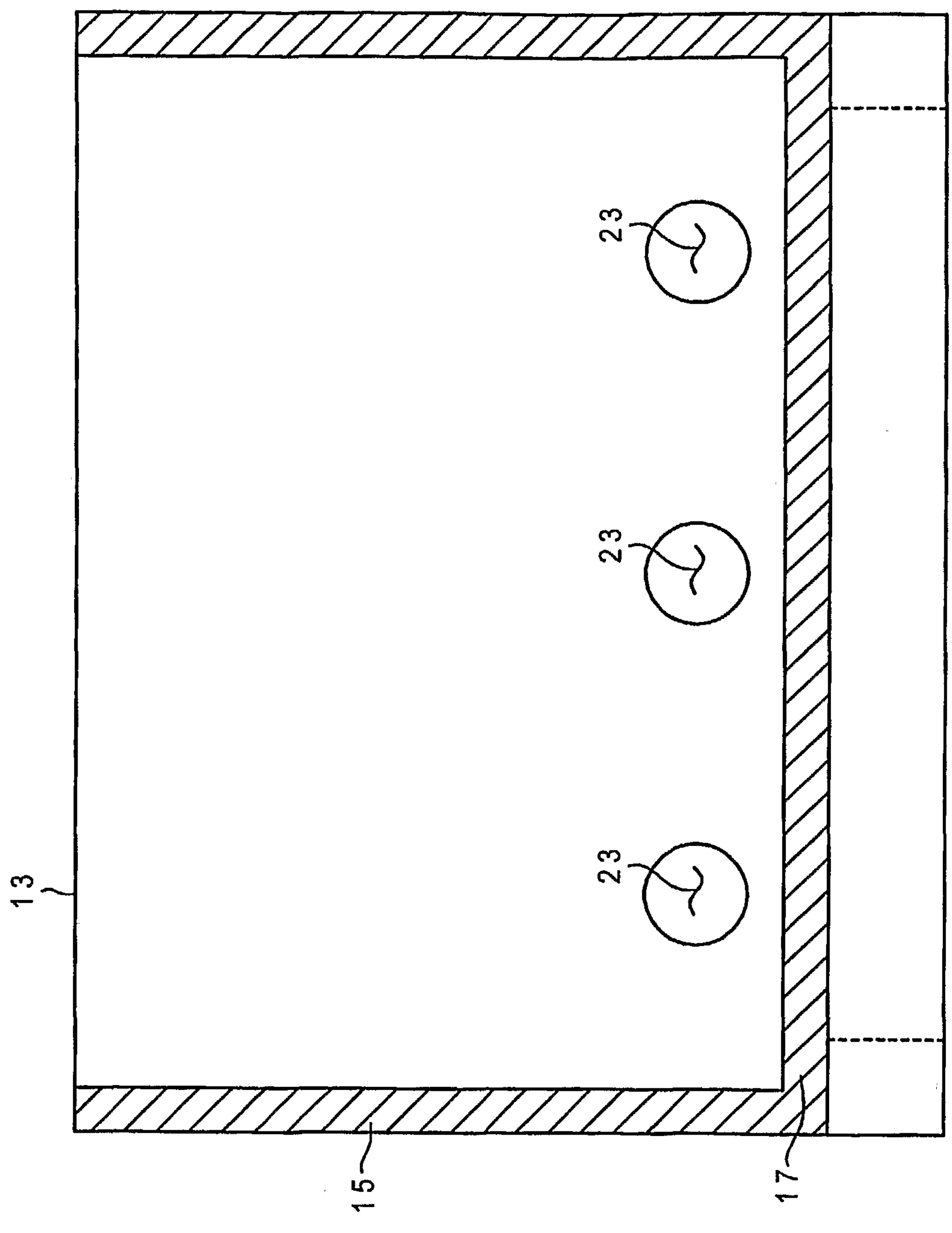
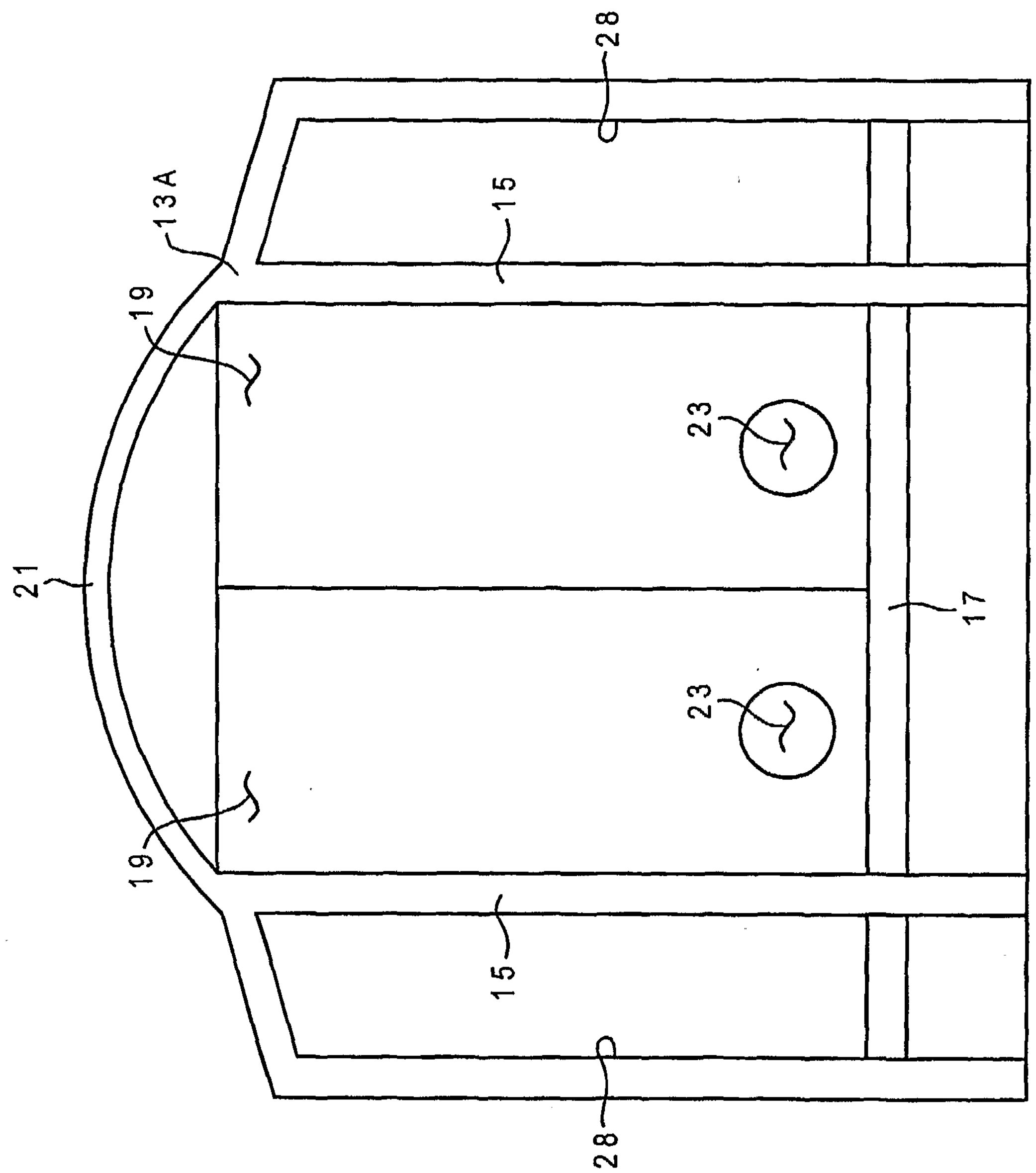


Fig. 3



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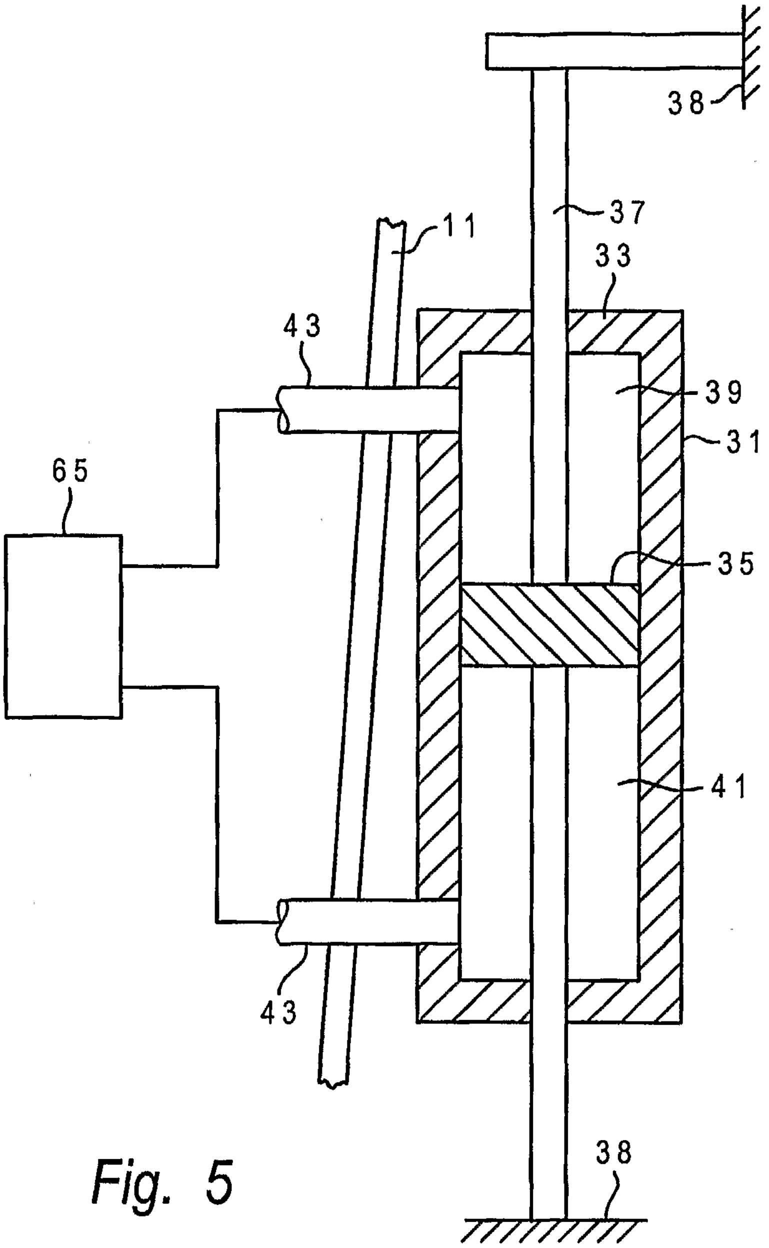


Fig. 5

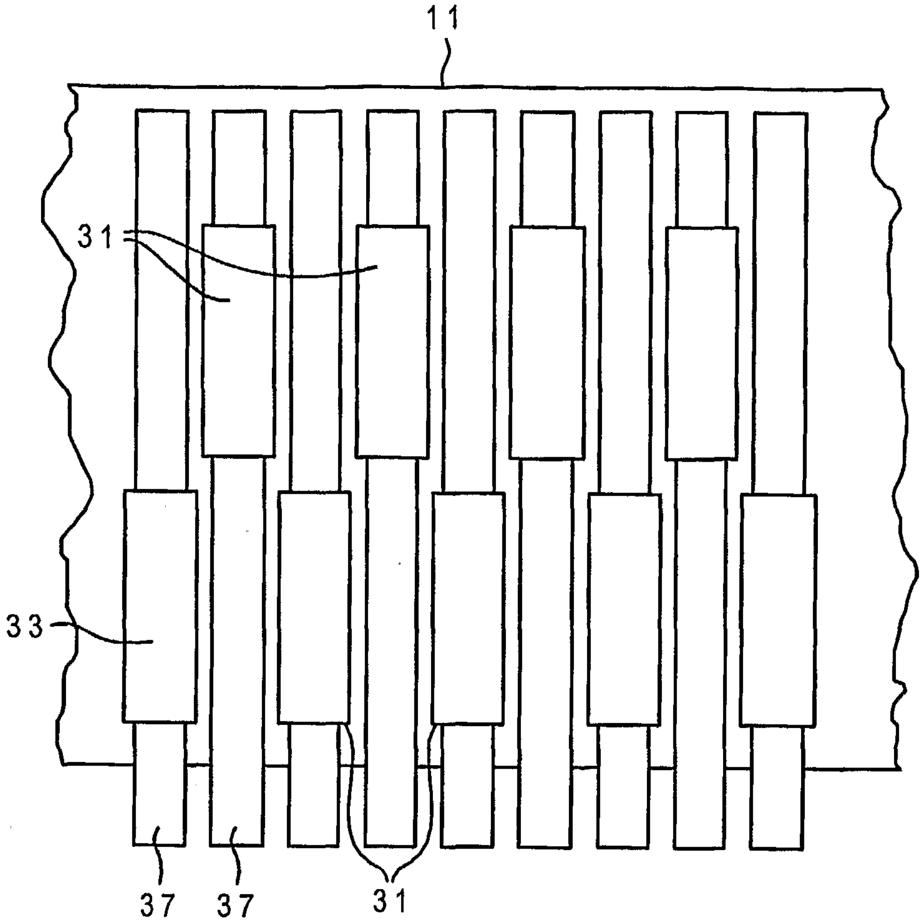


Fig. 6

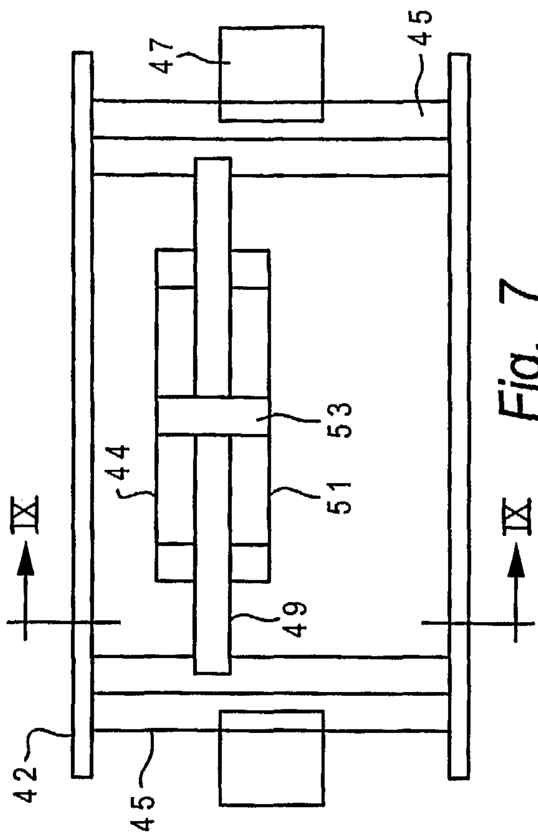


Fig. 7

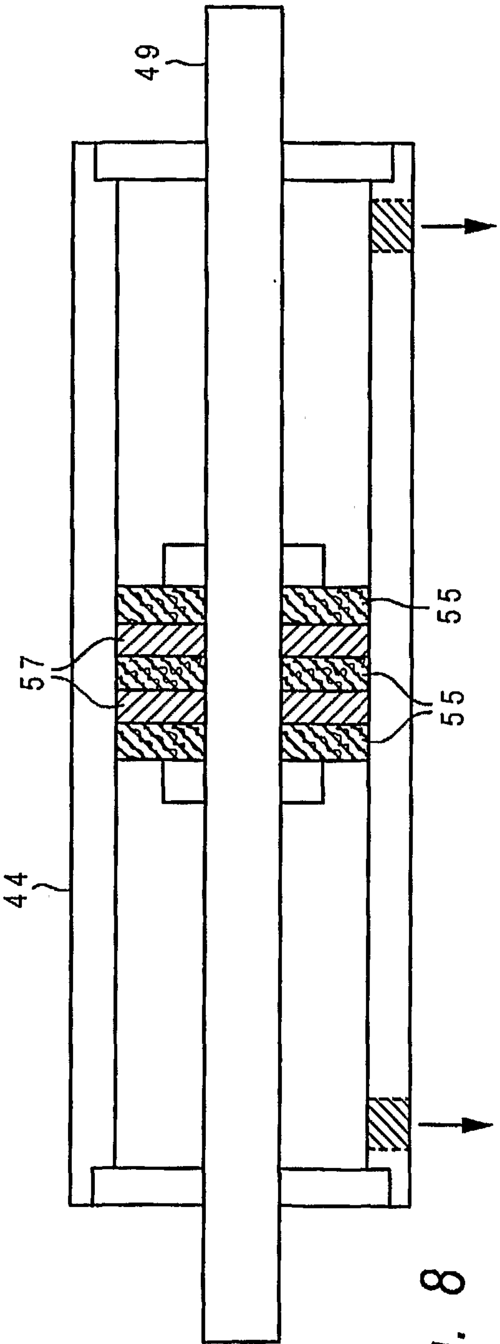


Fig. 8

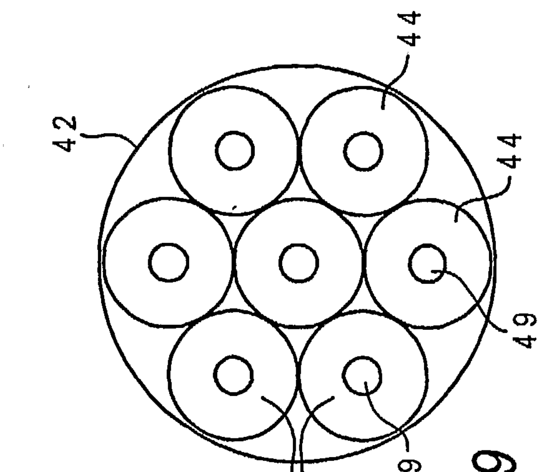


Fig. 9

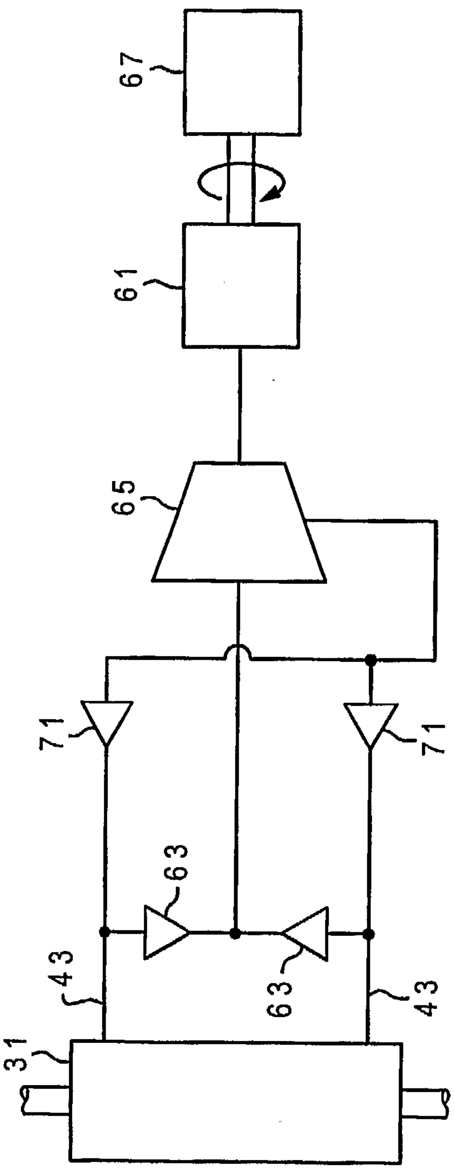


Fig. 10

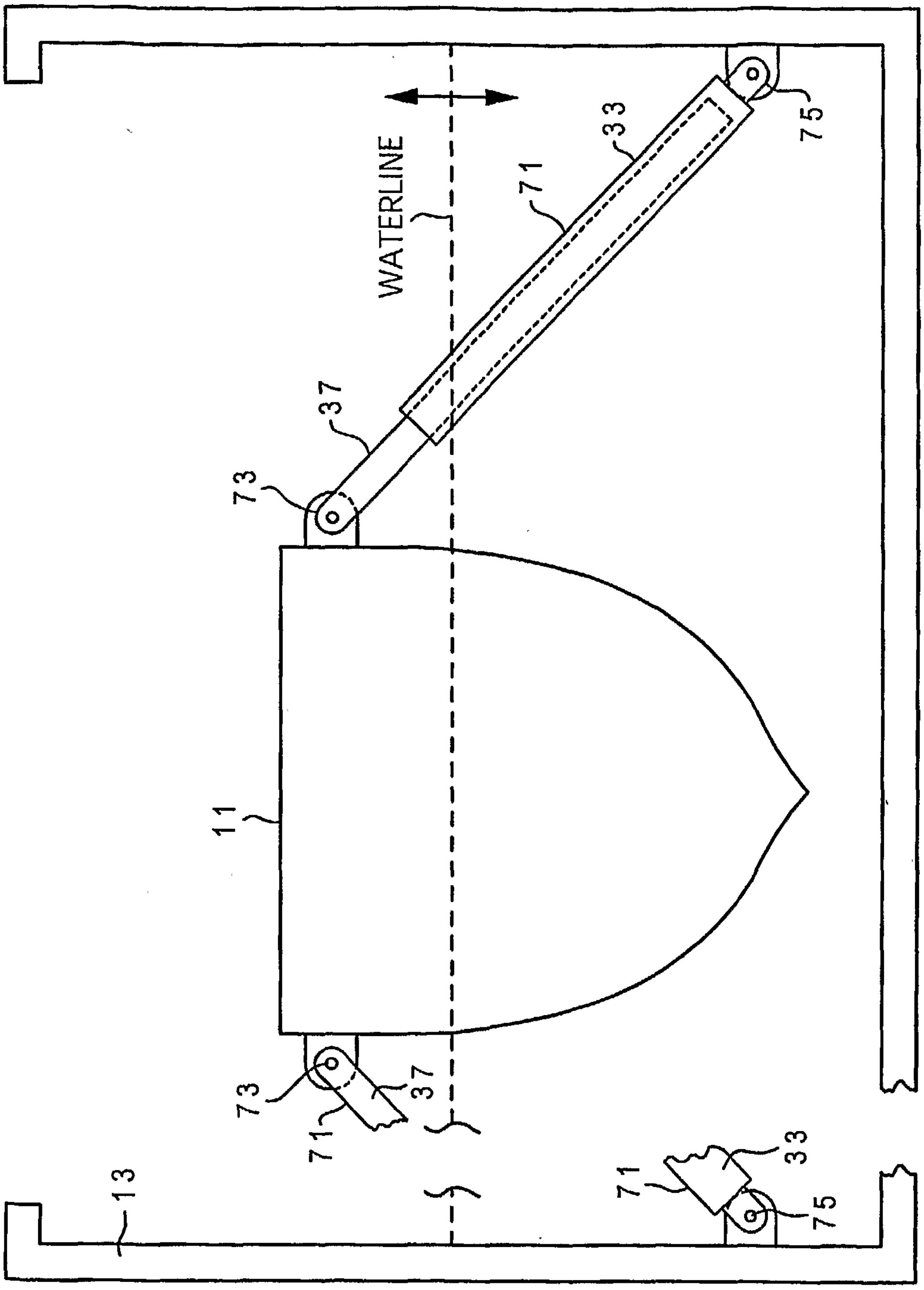
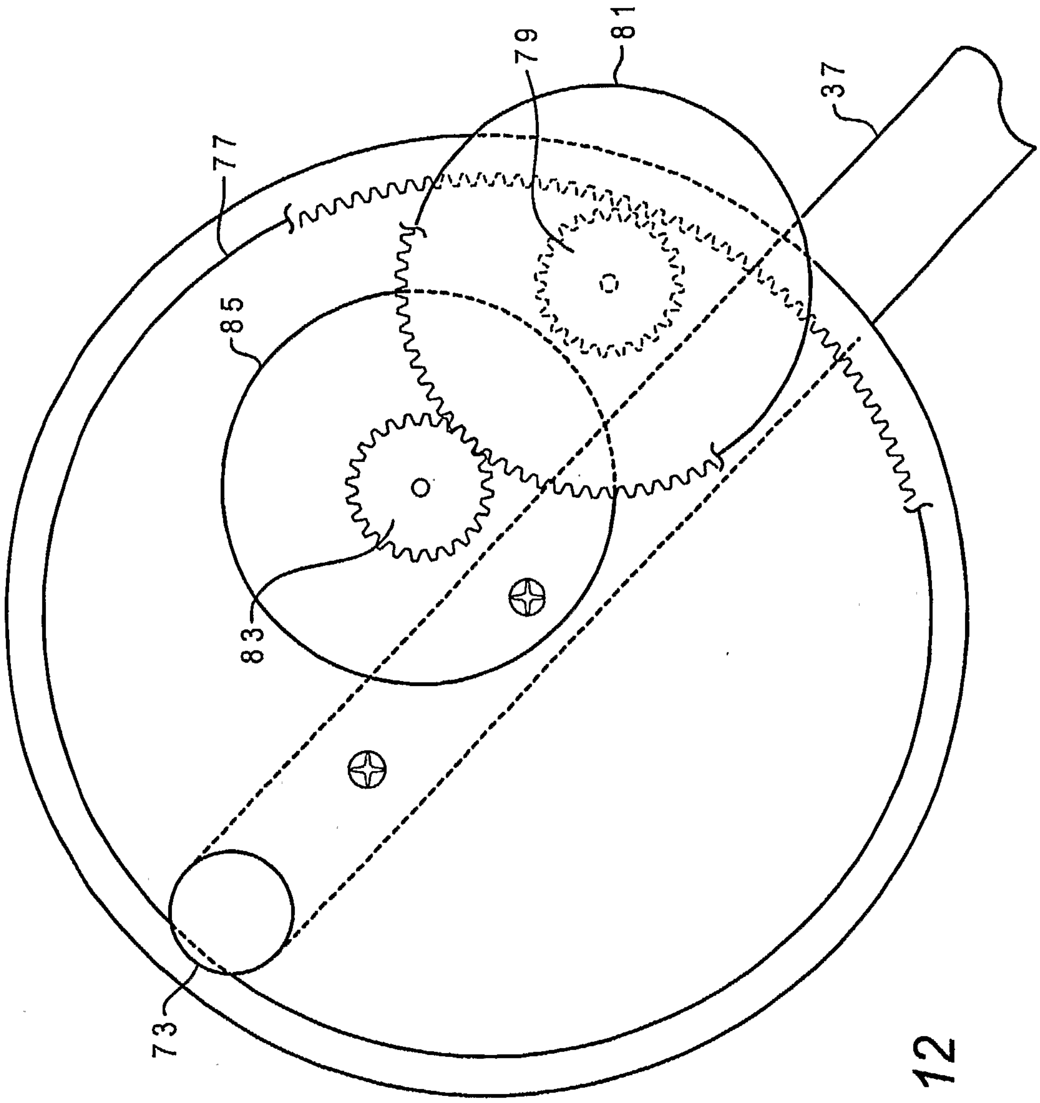


Fig. 11



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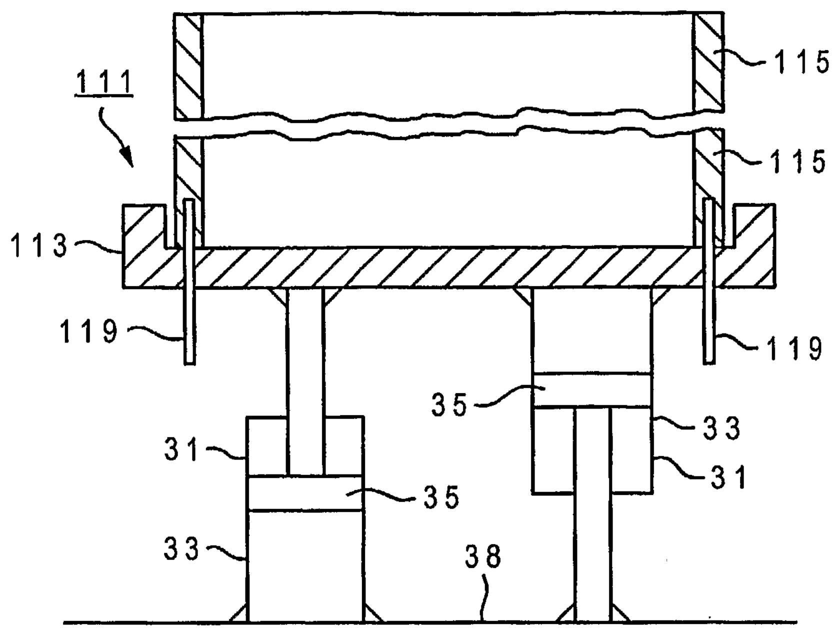
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Fig. 13

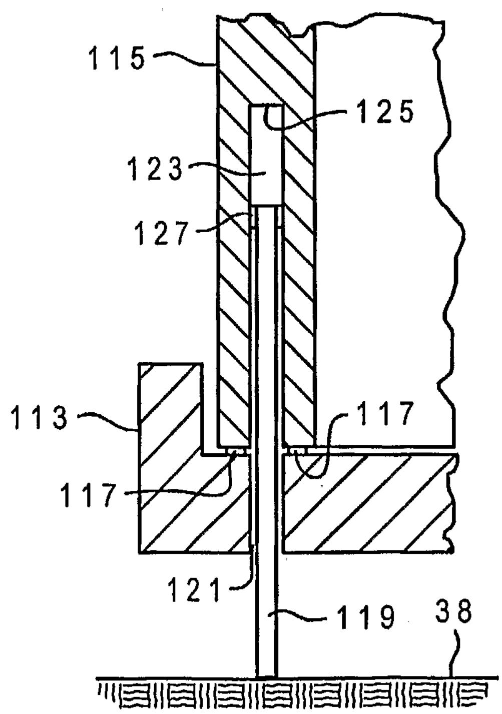
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Fig. 14

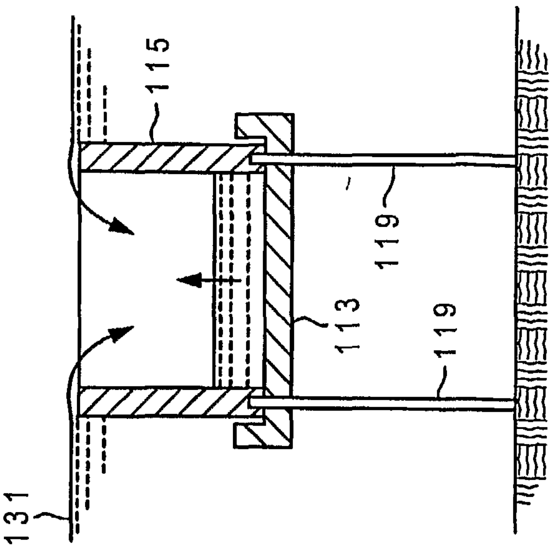


Fig. 16

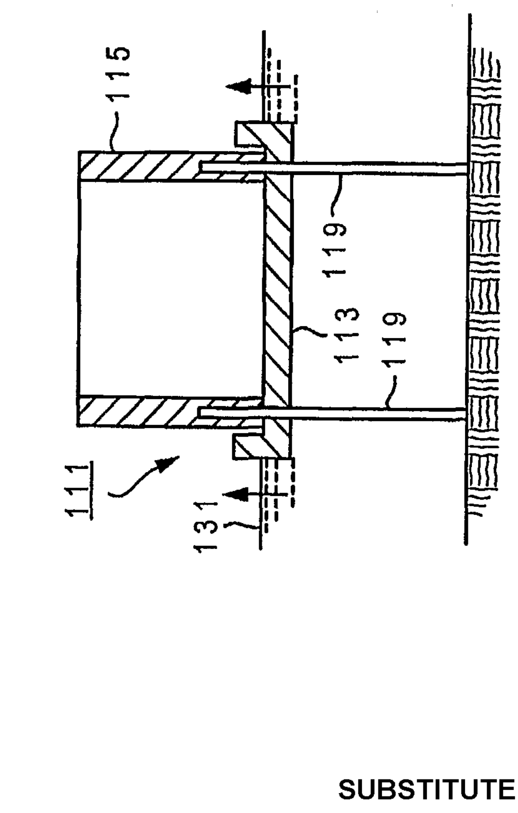


Fig. 15

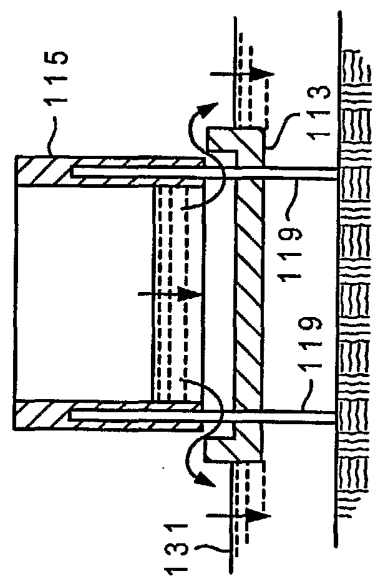


Fig. 17

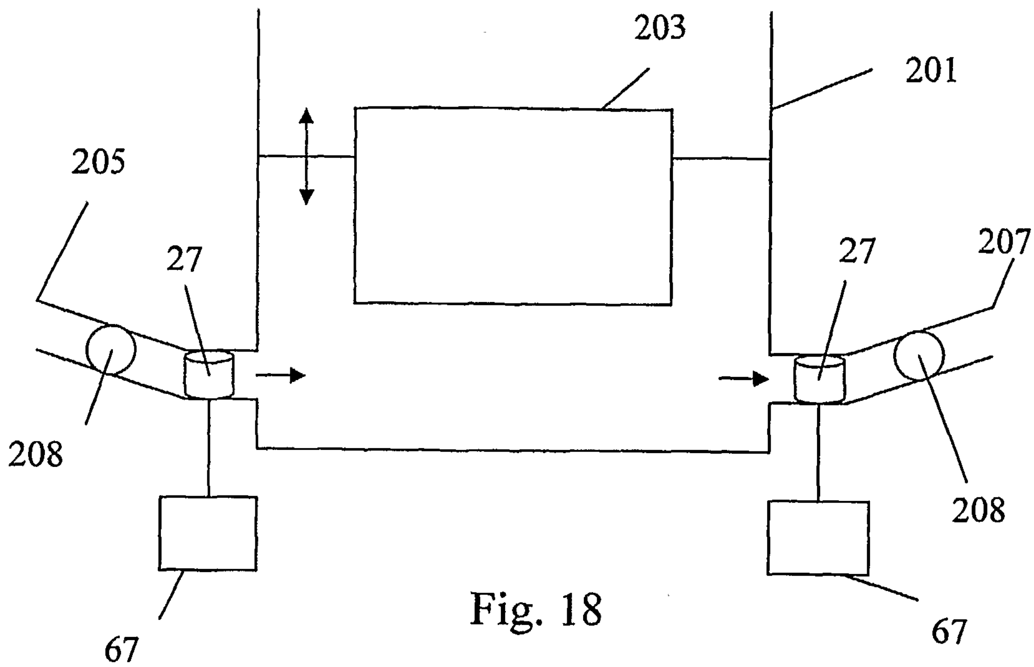
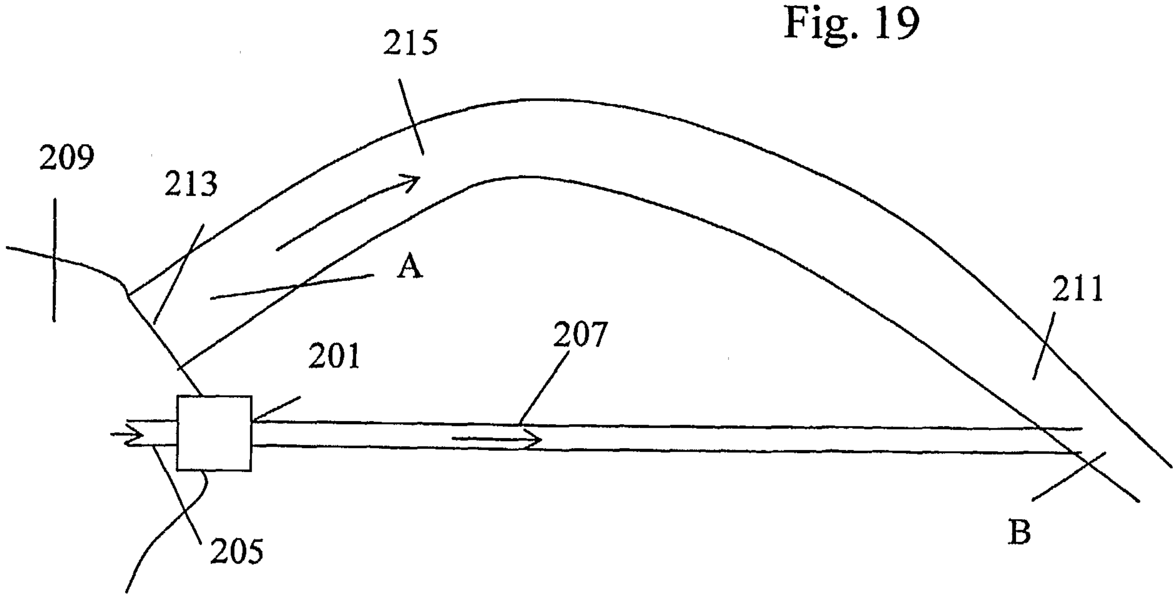


Fig. 18

Fig. 19



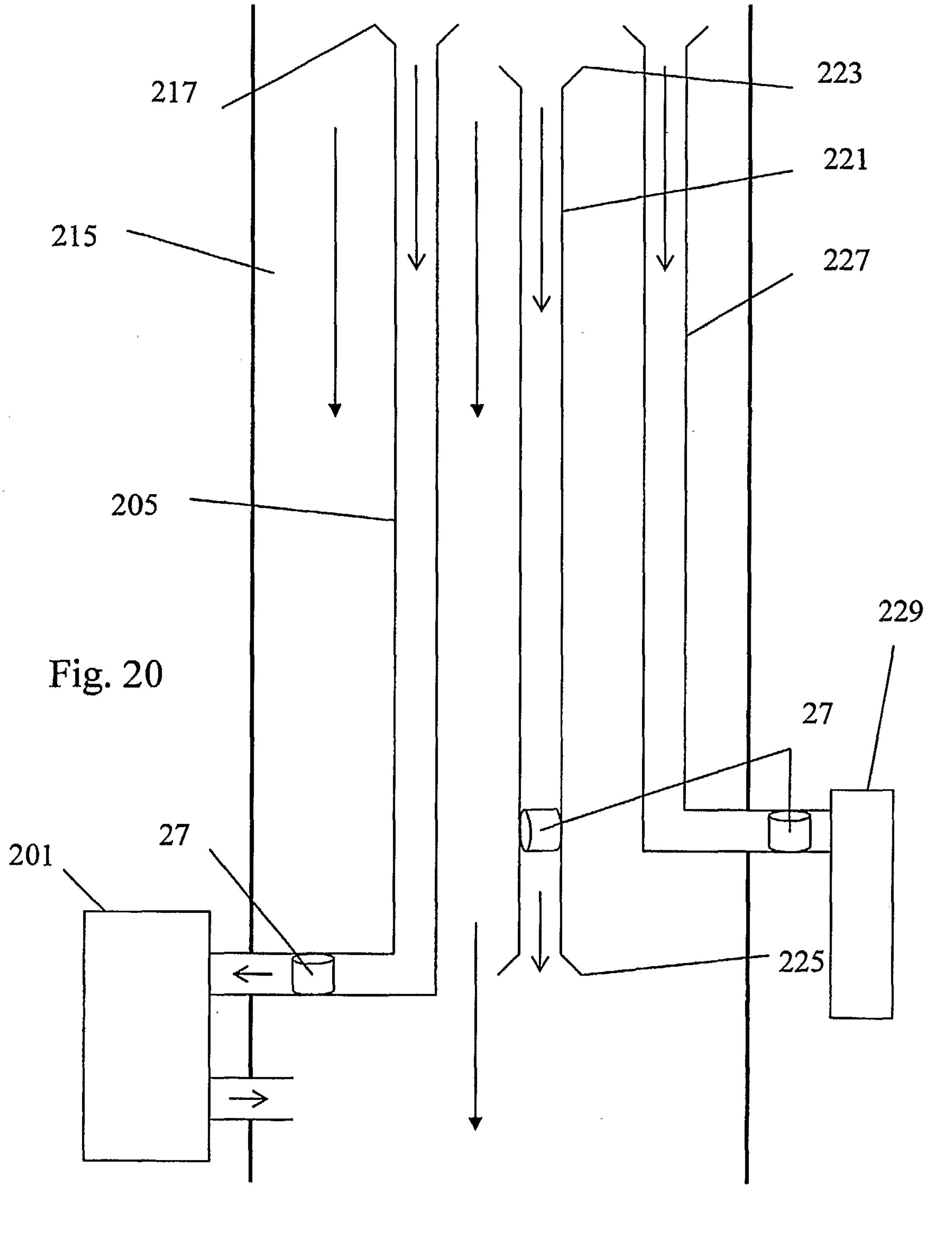
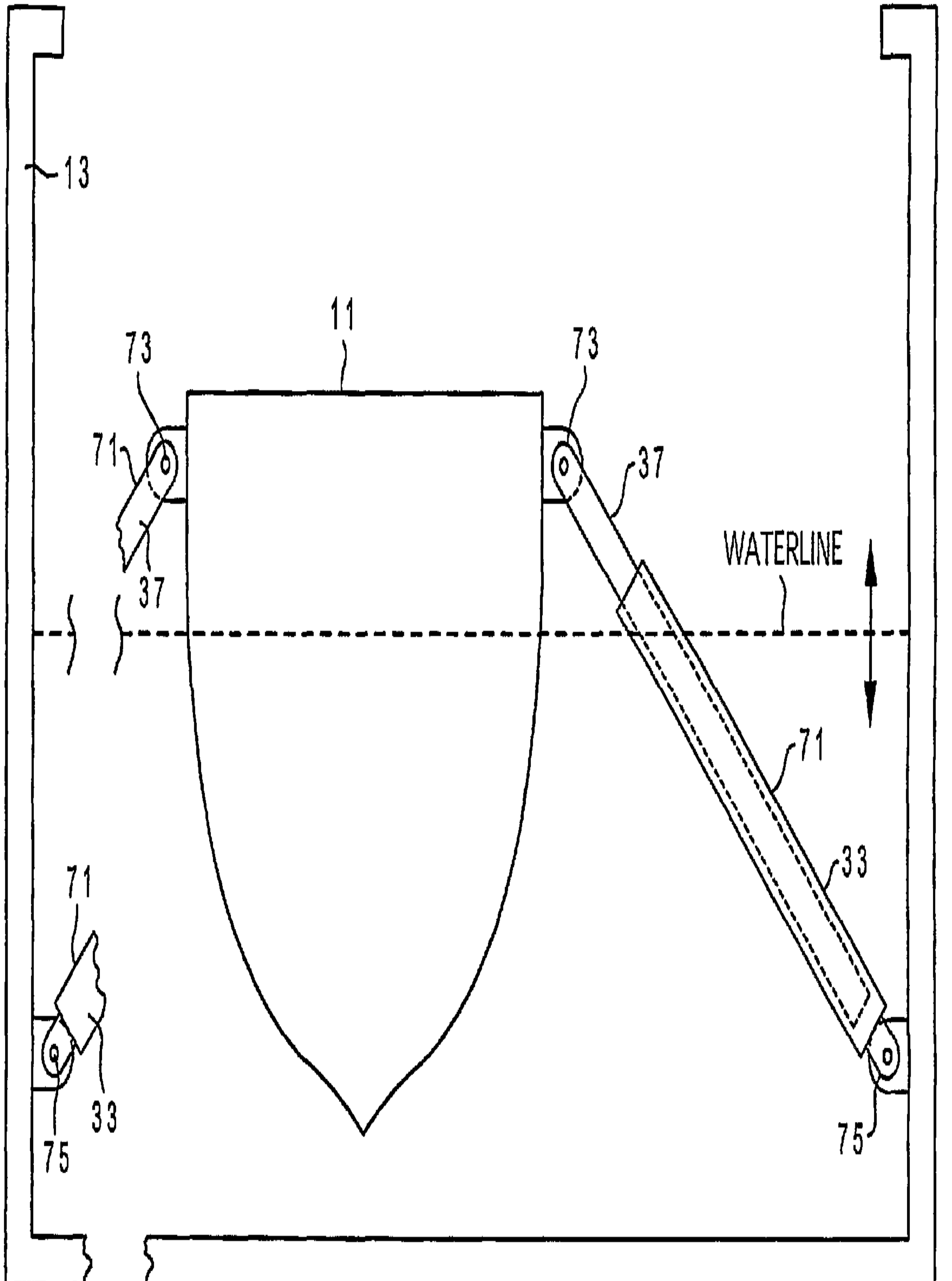


Fig. 20



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United States Patent [19]

Dubois et al.

[11] **4,392,061**

[45] **Jul. 5, 1983**

[54] **APPARATUS FOR UTILIZING THE ENERGY OF WAVE SWELLS AND WAVES**

[76] Inventors: **Yves Dubois,** 95, avenue Poincaré, 59700 Marcq en Baroeul; **François Y. Dubois,** 13, rue de la Poissonnerie, 22100 Dinan, both of France

[21] Appl. No.: **353,104**

[22] Filed: **Mar. 1, 1982**

[30] **Foreign Application Priority Data**

Feb. 27, 1981 [FR] France 81 04375

[51] **Int. Cl.**[3] **F03B 13/12**

[52] **U.S. Cl.** **290/53;** 60/502; 417/330

[58] **Field of Search** 290/42, 53; 60/496, 60/501, 502; 417/100, 330, 337

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Primary Examiner—J. V. Truhe

Assistant Examiner—Shelley Wade

Attorney, Agent, or Firm—Harding, Earley, Follmer & Frailey

[57] **ABSTRACT**

The invention involves a device for utilizing the energy from sea swells and waves. The device is characterized by the combination of:

(a) a vessel adapted to follow the regular undulations of sea swells at a place of anchorage, and constructed in a manner to face the swells so as to pitch and not to roll while anchored;

(b) air cylinders disposed at least at one extremity of the vessel to moderate more or less the amplitude of the pitching;

(c) watertight compartments containing a liquid;

(d) prime movers, such as continuously powered turbines, located in the path of the liquid and suited to harness energy from the liquid as it moves so as to supply mechanical energy to at least one rotatable shaft; and

(e) liquid deflectors located at the extremities of each water-tight compartment.

13 Claims, 9 Drawing Figures

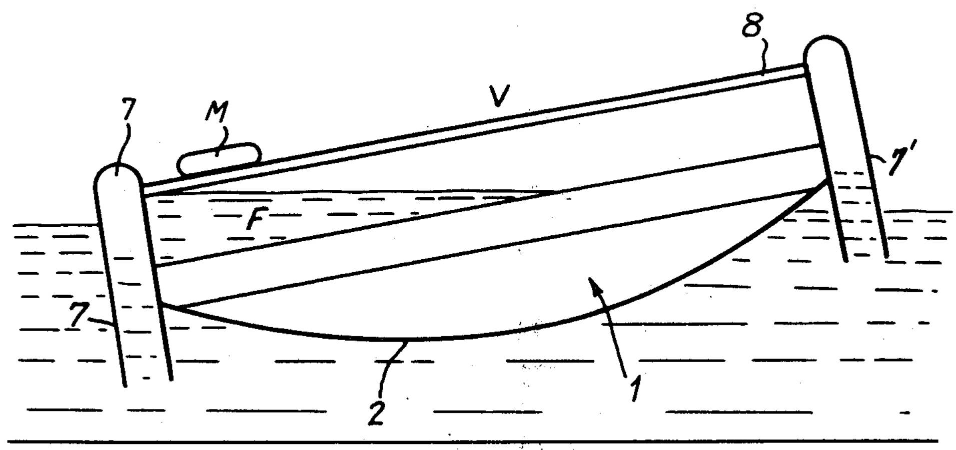


Fig:1

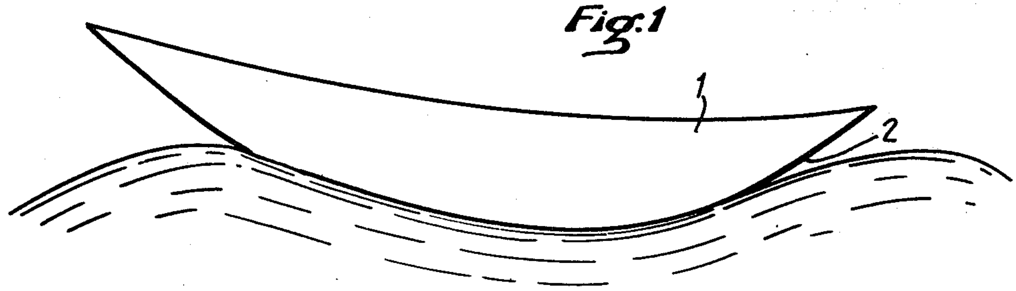


Fig:2

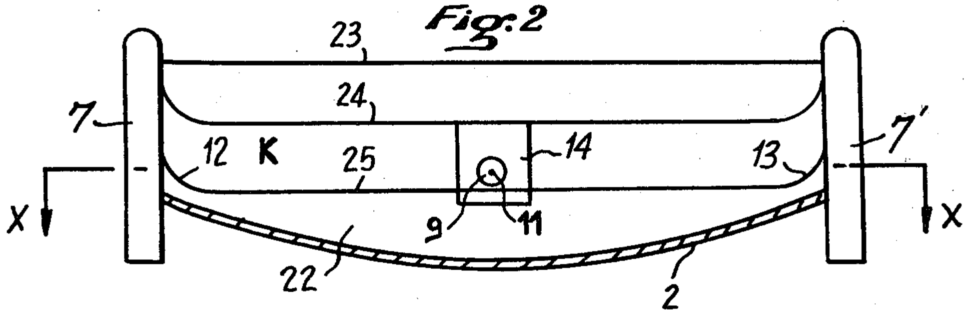
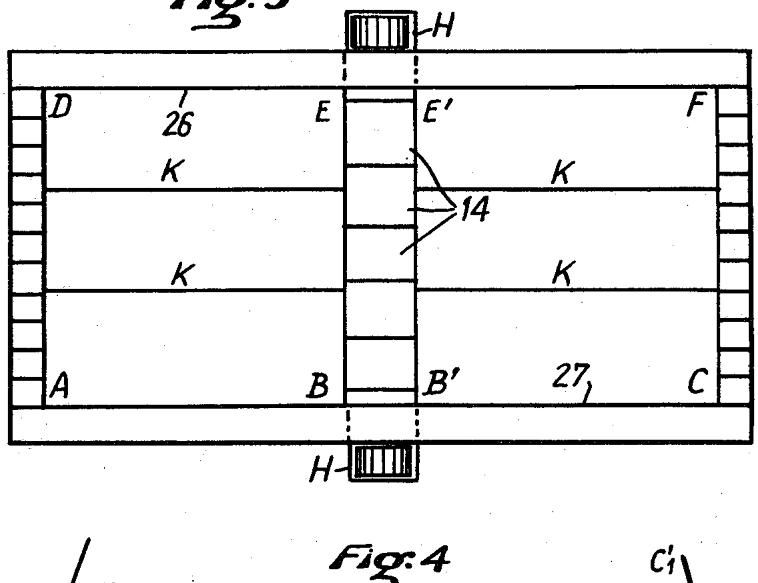


Fig:3



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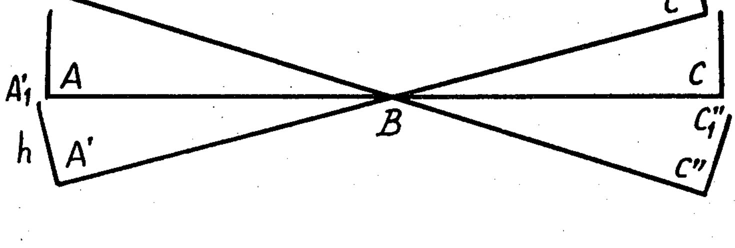


Fig. 6

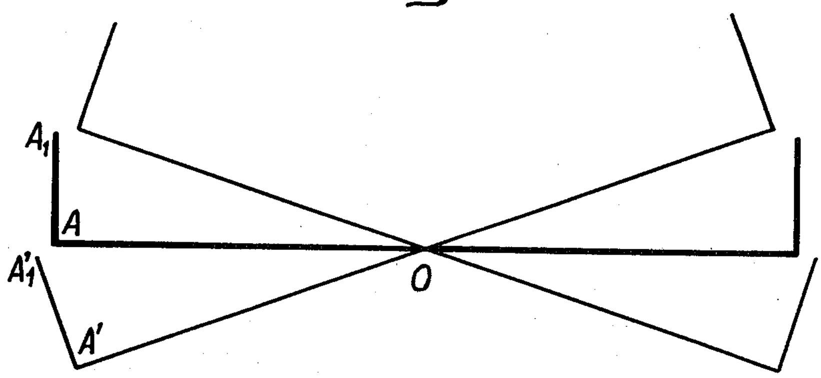


Fig. 5

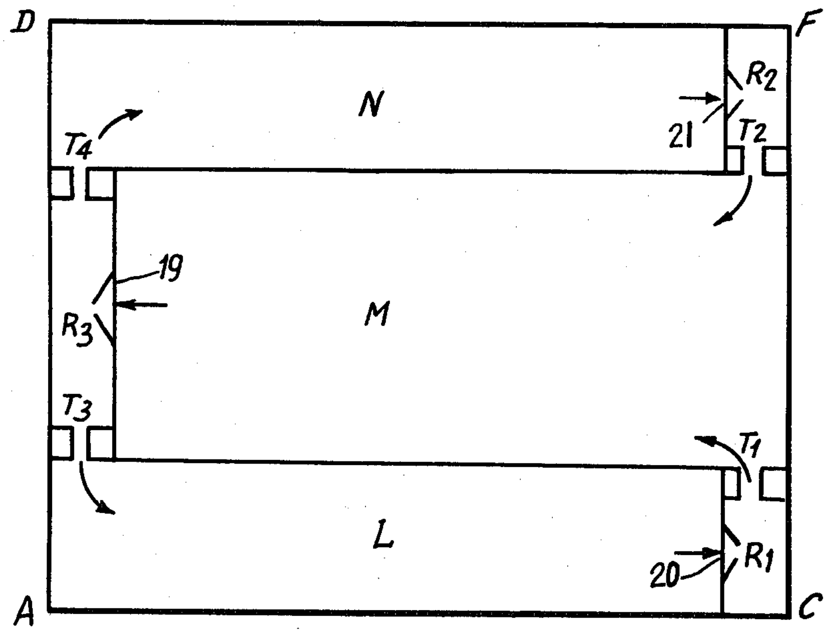


Fig: 7

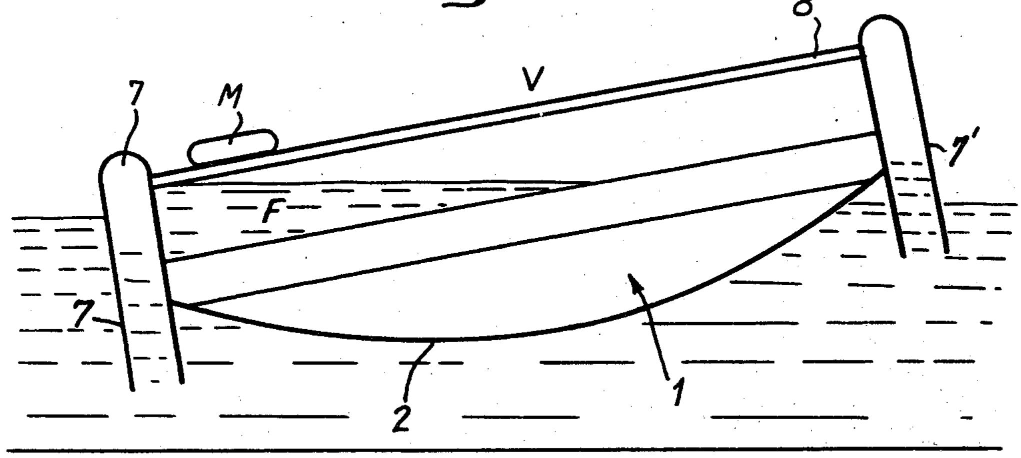


Fig: 8

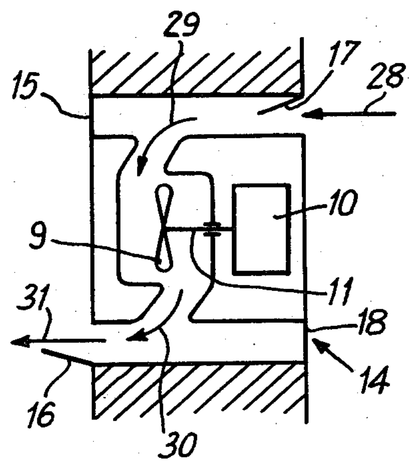
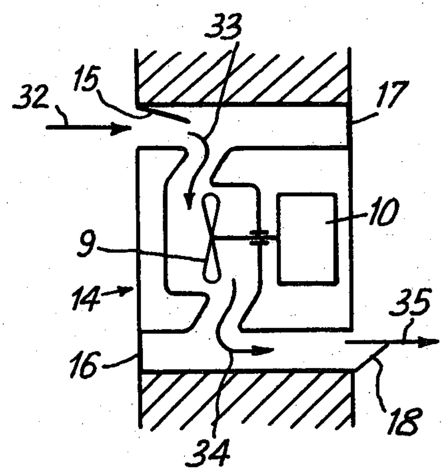


Fig: 9



APPARATUS FOR UTILIZING THE ENERGY OF WAVE SWELLS AND WAVES

FIELD OF THE INVENTION

The present invention involves a device for utilizing the energy from sea swells or waves to produce electricity or other forms of energy utilizable on land, such energy originating from an anchored vessel which possesses means of producing and transporting the energy to the land.

In the field of energy research, it is recognized that sea swells exist almost everywhere along unsheltered coasts. Such swells have a period that is more or less prolonged, depending on the surface of the ocean waters, and may vary from 6 to 12 seconds. It is highly desirable to attempt to harness this non-polluting energy.

STATE OF THE PRIOR ART

Efforts to obtain energy from sea swells are not new. They may be divided into two major categories:

(1) those which transform the energy from waves by variation of pressure or hydrostatic equilibrium;

(2) those which convert undulatory movement into rotating or rocking movement of mechanical elements.

Sir Christopher Cockerell's rafts and Professor Stephen Salter's "ducks" belong to this category. Those devices are fragile upon exposure to storms. The present invention is designed to remedy such drawback.

SUMMARY OF THE INVENTION

The invention involves harnessing energy from sea swells or waves by means of liquids retained in an enclosed space and displaced in accordance with a back and forth pitching motion. These liquids, of very large masses, activated at great speeds, drive hydraulic wheels, turbines or other means for the transformation or direct utilization of such energy.

More precisely, the device of the invention is characterized by the combination of:

(a) a vessel anchored at its bow and adapted to float on the surface of and to follow the regular frequencies or undulations of the sea swells at the place of the anchorage, and constituted with the aid of mechanical means to face the swells so as to pitch and not to roll;

(b) means disposed at least at one extremity of the vessel and designed to modify more or less the amplitude of the pitching;

(c) water-tight compartments containing a liquid which moves along the length of the vessel with the frequency of the pitching;

(d) means, such as turbines, located along the path of the moving liquid and suitable to harness the energy from the moving liquid so as to furnish mechanical energy to at least one rotatable shaft, energy which can be utilized to drive at least one electric generator or alternator;

(e) deflectors located at the extremities of each water-tight compartment and designed to reduce the impact of the liquid when it reaches the end of the compartment at the completion of its down stroke.

Normally, the anchored vessel is disposed so as to face the sea swells and is maintained in that position with the aid of lateral propellers such as paddle wheels, or with the aid of stern propellers which push the back of the vessel sidewise from one side or the other.

One interesting feature of the invention resides in the fact that the amplitude of pitching is controlled by means of cylinders arranged vertically at the front and at the back of the vessel, in the upper parts of which air pressure is controlled selectively by any suitable means, such as by remotely controlled valves.

The amplitude of the pitching can also be controlled by a mass which moves in a controlled way manner from the front toward the back and vice-versa.

In one embodiment of the invention, plural longitudinal water-tight compartments extending lengthwise of the vessel are interrupted by machine compartments which are located approximate the middle of the vessel. Such machine compartments may contain offset turbine-generator or turbine-alternator units having blades that change direction with each change in the inclination of the vessel. These compartments also can include, with a turbine, at least two wide flap-valves placed upstream and at least two placed downstream of each of the turbines in order to ensure a continuous flow of liquid in the same direction relative to the turbine, regardless of the direction of the flow of the liquid along the vessel.

In a second embodiment, a continuous circuit is provided for the drive liquid for the turbines, which flows through transfer passages toward the back and toward the front of the vessel, and into and out of storage compartments at the front and at the back of the vessel. The turbines are disposed at the exit of each storage compartment, and wide flap-valves are provided at the end of each transfer compartment, at the entrance to each storage compartment, to ensure continual flow of the liquid in the same direction through the circuit.

It is understood that the displacement or flow of the liquid inside the ship is determined by its pitching and that it therefore is necessary to give the vessel a hull having a shape which facilitates pitching, but avoids sinking under the waves. To achieve that, the bottom of the boat is arcuately rounded like transversely, a large diameter cylindrical segment and both its bow and stern are finely streamlined.

According to a secondary feature, tanks are provided in the bottom of the hold in order to store the work liquid in the event of an interruption in operations. Indeed, this liquid could be sea water, in which case its recovery would not be of any interest. However, as will be seen, it may be advantageous to utilize a denser liquid, the cost of which is significant and for which recovery would be necessary.

The device of the invention utilizes a type of vessel with which a great deal of practical experience exists, and which can be built to resist storms effectively. The device utilizes turbines or turbine generator units which are well-known. The novelty lies in the interior arrangement of the hull, which can be furnished from existing hulls that are restored and modified. These modifications are available at any marine yard. Other parts utilized are flap-valves, the technology of which is well-known, but which will require significant dimensions here.

This invention will be better understood with the aid of the description which follows, disclosing two non-limiting examples of its practical application, which are illustrated in the attached drawings.

BRIEF DESCRIPTION OF THE FIGURES OF THE DRAWINGS

Regarding the drawings:

FIG. 1 is a view in side elevation of a simple vessel caught in a sea swell.

FIG. 2 is a schematic view in vertical longitudinal section of another version of the vessel with cylinders in the bow and in the stern and with machinery compartments in the center.

FIG. 3 is a schematic view in top plan of a vessel like that in FIG. 2.

FIG. 4 is a schematic view of the oscillatory movement of the vessel shown in FIG. 3.

FIG. 5 is a schematic view in horizontal section of a second version of the vessel illustrating a circuit for the drive liquid of the turbines.

FIG. 6 is a schematic view of the movement of the vessel shown in FIG. 5.

FIG. 7 is a schematic view in vertical longitudinal section showing a third version of the vessel provided with a mass for controlling the amplitude of the pitching.

FIG. 8 is a fragmentary schematic view indicated by the arrows X—X of FIG. 2 showing a machine compartment and illustrating the flow of the liquid in a first direction.

FIG. 9 is a fragmentary schematic view of the machine compartment of FIG. 8 illustrating the flow of the liquid in the opposite direction.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Turbines are known which operate with a low fall by absorbing a large input with high outputs and which drive alternators with sufficient steadiness or continuity.

The ensemble is mounted on a boat **1** which can be a ship or any floating hulk or craft having a hull. It must be sturdy, solid and able to withstand the most violent of storms and perform by its own means.

It is moored by long towlines to orient it at a location where the sea swells are constant and sufficiently strong. It possesses specific characteristics which may vary according to the character of the sea swells. In general, and without being limited thereto, they are defined as follows:

Normal and maximum pitching of a boat is obtained when its length, at the water-line, is substantially equal to the wave length of the sea swells. But the latter vary. For the best performance, a very sheer hull is preferred. THe bottom **2** in transverse cross-section constitutes a large diameter cylindrical segment or arc, parallel to the swells, whereby it pitches unrestrained. The contour is such that it is able to follow sea swells of very different wave lengths (FIG. **1**) and only rarely is balanced on three crests.

The width of the vessel is a function of the desired power. It is designed to keep its stability in all circumstances. Yet, as shown in FIGS. **1**, **7**, it has a relatively high freeboard.

The center of gravity is maintained rather high in order to enhance pitching. Its position can be modified by ballast, to increase or decrease the length of the boat at the waterline in accordance with the swells. For the purpose of perfect stability, calculated along with movable loads, the hull bottoms are reduced. The top-sides are significant, because the displacement, in a few seconds, of the drive fluid of several thousands of tons results in a tremendous plunge. The dip of the vessel must be cushioned and it must rise easily and rapidly. For that, and to avoid sinking, the bow and the stern are widened considerably and along each of their extremities are secured several hollow, vertical air cylinders **7**, **7'** open at their bottoms (which always remain immersed) and closed at their upper ends. With each incidence of down pitching, air pressure rises in cylinders **7**, **7'**, and, according to how air intake or discharge valves (not shown) are controlled, which are located in the upper parts of the cylinders, the amplitude of the pitching of the vessel is regulated. The maneuver is accomplished automatically in unison by a selected number of cylinders shown between A and D at one end of the vessel as well as between C and F at the other end (FIG. **3**).

The volume of the cylinders **7**, **7'** is calculated according to the movable load of the boat.

The interior arrangement includes (FIG. **2**):

- an upper deck **23** with all security and navigation material and material for secure anchorage (not shown);
- one or several intermediary decks **24**, **25** holding the drive fluids, which can be different. The highest **24** may contain sea water which if necessary may be pumped overboard. A second **25** contains a dense fluid to be stored in tanks **22** located at the bottom of the hold and thus constituting a good ballast.

On each side, one or two paddle wheels H are provided, activated by the sea current and producing electricity for on board needs. These wheels are reversible; becoming propulsive, they can be used for maneuvering and berthing, notably for positioning to face the sea swells.

At least one stern propeller (not shown) also is provided in order to prevent the movement of the vessel from one side to the other, i.e. swinging at anchor.

Longitudinal bulkheads K divide the decks **24** and **25** into plural water-tight compartments, passages or conduits for the liquids while preventing lateral flow of the liquids to avoid the danger of significant listing or capsizing.

The drive fluid is therefore displaced from the front to the back and then returns. The drive wheels or the turbines **9** can be placed in the middle of the hull (FIGS. **2**, **3**), or at the extremities (FIG. **5**). Numeral **14** indicates machine compartments in the middle of the hull (FIG. **3**) intermediate the longitudinal water-tight compartments aforesaid located in the front and the rear of the vessel and defined by bulkheads K.

The drop of fall being at the end AD (FIG. **3**), the liquid fills the volume $A'A_1'B/AD$, position **1** in FIG. **4**. The wave arriving, the liquid is lifted and flows into space $C''C_1''B/CF$, position **2** in FIG. **4**, passing through space BEB'E' (FIG. **3**) where there are installed the machine compartments **14** for the turbines **9**. The liquid then flows back into position **1**, and so on and so forth repetitively, activating the turbines **9** with each passing.

In order to better understand this operation, reference now is made to FIGS. **8** and **9**. When end AD falls or dips, liquid flows in the direction of the arrow **28** (FIG. **8**), pushing open the flap-valve **17** and closing the flap-valves **15** and **18**. The liquid, following the arrow **29**, passes through the turbine **9** which drives the generator **10** by the shaft **11**. It discharges in the direction of the arrows **30** and **31**, opening the flap-valve **16**.

When end CF falls or dips, the liquid flows in the direction of the arrow **32** (FIG. **9**), pushing open the flap-valve **15** and closing the flap-valves **16** and **17**. The liquid, following the arrow **33**, passes through the turbine **9** which drives the generator **10** by the shaft **11**. It discharges in the direction of the arrows **34** and **35**, opening the flap-valve **18**.

The extremities of the decks **24**, **25** have roundings or deflectors **12**, **13** (FIG. **2**) in order to reduce the impact of the liquid against the walls and to enhance the rising. The depth of the maximum fall "h" (FIG. **4**) is thus increased; the depth of the average fall being "h'" (not shown).

FIG. **3** schematizes one level. It is a rectangle, but also may be a polygon, or two trapezoids joined at their wide bases, or even a rhombus. For the same volume, the liquid rises at the top of its stroke, and this results in a greater speed at the entrance to the turbines. The value of "h" varies, but several simple devices already well known enable the turbines always to turn in the same direction and regularize their speeds to drive the alternators **10** directly. This may be effectuated by sluicing and by the maintenance of a reserve of liquid in BEB'E' (FIG. **3**).

The turbines also may be placed near the extremities of the hull (FIG. **5**). In such case, the fall height is greater. The fluid speed v at the entrance to the turbines is higher than in the previous case, but is not double, because the speed "v" varies as $\sqrt{h}$. The path is longer. In order for the turbines to be powered at a steady rate, a reserve of water at each extremity is provided.

The hull or hold is divided into three longitudinal water-tight compartments or passages L, M, N, in order to maintain the boat in equilibrium. Passages L and N (at the sides) have the same width; passage M (central) is double that width. The operation is as follows (FIGS. **5** and **6**):

When end AD is in a trough, tank R_3 is full. The fluid flows into passages L and N via turbines T_3 and T_4.

When the next wave arrives, end AD rises, and end CF falls into a trough. Tanks R_1 and R_2 are filled through flap-valves **20**, **21**, and discharge through turbines T_1 and T_2. The fluid flows into passage M. Then end CF rises.

Tank R_3 fills through flap-valve **19** and discharges through turbines T_3 and T_4 and the cycle continues.

Tanks R_1, R_2, R_3 are never completely empty. THe sluices or flap-valves **19**, **20**, **21** being carefully regulated, the turbines turn normally.

In FIG. **5**, four turbines T_1, T_2, T_3, T_4 have been put in place. Many more can be added, two or three in each group, or eight or twelve per line, according to the weight of the fluid.

On a boat that is large enough, two or three lines of turbines with three compartments per line can be installed.

Some exemplary figures offer an idea of the considerable power that may be obtained and harnessed by this invention:

I Turbines in the Middle of the Hull

Example—FIGS. **3** and **4**

AC=60 m, AB=25 m, AD=60 m

Swell: wave length 50 m, trough 4 m, period 6 seconds.

Distance of fall $A'A_1'=h=8$ m.

Two falls per period, one toward the front, one toward the back, or one every three seconds.

The liquid fills the volume: area of the triangle $A'A_1'B$ multiplied by the width AD. Or:

$$\frac{A'A'_1B}{2} \times AD = \frac{8 \times 25 \times 60}{2} = 6000 \text{ m}^3$$

displaced in three seconds or 2000 m^3 per second.

When the bow is raised, it is assumed that the average minimum height h' of the liquid producing the drive is equal to 4 meters.

The power produced is calculated by the formula

$$P = \frac{Qd}{2g}(v^2 - z^2),$$

where

$v=\sqrt{2gh'}$

Q=Volume of liquid displaced per second in the turbine.

d=Density of the liquid; for water d=1

v=Speed of the liquid at the entrance of the turbine.

z=Speed of the liquid at the discharge from the turbine. z being very low in proportion to v, it is omitted in the folloiwng calculations.

h=Depth of the maximum fall of the liquid generating the speed.

h'=Average depth of the fall of the liquid.

In this example,

$Q=2000$ m^3,

d=1,

h'=4 m

$v=\sqrt{2\times9.81\times4}$

$v^2=2\times9.81\times4$

$P_1=$

$$\frac{2{,}000{,}000 \times 1 \times 2 \times 9.81 \times 4}{2 \times 9.81} = 8{,}000{,}000 \text{ Kgm/sec}$$

$P_1=8{,}000{,}000\div102=78.43$ MW (Megawatts)

1 KW=101.94 Kilogrammeters per second

If sea water is used (d=1.025), $P_2=81.35$ MW

If the fluid is sea water from salt marshes (d=1.320), $P_3=136.66$ MW.

If the fluid is a concentrated solution of CO_3K_2 (d=1.500), $P_4=176.5$ MW.

II Turbines at the Extremities of the Hull

Example—FIGS. **5** and **6**

AB=100 m

AD=100 m

AG=25 m

GE=50 m

ED=25 m

The volume of the liquid in the compartment L is equal to the area $A'A_1'O\times AG=9375$ m^3.

The same value for the compartment N is

$$= \underline{9375\ m^3}$$
$$\text{Total} = 18750\ m^3$$

Wave length: 100 m

Trough: 5 m

Distance of fall $A'A_1'=h=15$ m

Period of 10 seconds, one fall every 5 seconds

Discharge per second 18750/5=3750 m^3

h'=15 m

$v=\sqrt{2\times 9.81\times 15}$

$v^2=2\times 9.81\times 15$

The fluid is water, d=1

$P_1=$

$$\frac{3{,}750{,}000\times 1\times 2\times 9.81\times 15}{2\times 9.81}=562.50\ \text{Kgm/sec}$$

With sea water (d=1.025), P_2=576.20 MW

With sea water from salt marshes (d=1.320), P_3=959.70 MW

With concentrated solution of CO_3K_2 (d=1.500), P_4=1239.54 MW

We claim:

1. Apparatus for utilizing the energy of sea swells and waves, characterized by the following combination:

(a) a vessel anchored at a place of anchorage and adapted to float on the surface of and to follow the undulations of the sea swells at the place of anchorage, said vessel having a bow, a stern, a hull, an upper deck disposed above the water internally of the hull and at least one intermediary deck located between the upper deck and the bottom of the hull;

(b) means positioning said vessel to face the sea swells so as to enable said vessel to pitch and not roll while anchored, said positioning means including anchoring means to anchor the vessel and maneuvering means to prevent the vessel from swinging at anchor;

(c) control means to modify the amplitude of the pitching of the vessel, said control means including at least one hollow, vertical air cylinder located at the bow and at the stern, respectively, of the vessel, said cylinders being closed at their upper ends;

(d) plural water-tight compartments disposed on at least one of the decks of the vessel and extending longitudinally of the vessel, each compartment comprising a conduit for containment and flow of a drive liquid which moves back and forth internally of the hull along the length of the vessel with the frequency of the pitching thereof;

(e) at least one prime mover located in the path of the moving liquid and adapted to harness the energy from the moving liquid and convert it to mechanical energy which can be utilized to drive at least one electric generator, said prime mover including a rotatable power output shaft;

(f) deflectors located at the extremities of the water-tight compartments and adapted to reduce the impact of the moving liquid when the liquid reaches the end of a compartment during completion of its downstroke as the result of the pitching of the vessel; and

(g) longitudinal bulkheads defining and separating parallel water-tight compartments to prevent lateral flow of the drive liquid, thereby minimizing listing of the vessel.

2. Apparatus as defined in claim 1, further including laterally disposed paddle wheels for maneuvering the vessel into a position of anchorage facing the sea swells.

3. Apparatus as defined in claim 1, further including at least one stern propeller for maneuvering the stern of the vessel toward the port side or the starboard side as required in order to position the vessel to face the sea swells.

4. Apparatus as defined in claim 1, wherein the lower ends of the air cylinders are submerged in the water and are open at their bottoms, whereby the descent of the cylinders into the water, as the result of the down pitching of the vessel, increases the air pressure in the cylinders to thereby moderate the amplitude of the pitching of the vessel.

5. Apparatus as defined in claim 1, further including:

(a) at least one water-tight compartment disposed in the front of the vessel and at least one water-tight compartment disposed in the rear of the vessel;

(b) at least one machine compartment disposed intermediate the front and rear water-tight compartments;

(c) a prime mover, such as a turbine, located in each machine compartment; and

(d) a plurality of flap-valves associated with each machine compartment permitting the moving liquid to flow into and discharge out of each machine compartment, at least two of said flap-valves being disposed upstream of each turbine and at least two of said flap-valves being disposed downstream of each turbine whereby the moving liquid always flows in the same direction relative to each turbine irrespective of the direction of flow of the moving liquid relative to the vessel.

6. Apparatus as defined in claim 1, further including:

(a) at least one water-tight compartment disposed in the front of the vessel and at least one water-tight compartment disposed in the rear of the vessel; and

(b) at least one turbine-generator unit disposed intermediate of the compartments, each said unit including blades adapted to change their orientation with each tilting of the vessel.

7. Apparatus as defined in claim 1, further including:

(a) at least two longitudinal transfer passages, at least one of said passages permitting the moving liquid to flow from the bow of the vessel to its stern, and at least one of said passages permitting the moving liquid to flow from the stern to the bow;

(b) at least one tank disposed at the bow of the vessel and at least one tank disposed at the stern of the vessel;

(c) each tank being connected to one of the passages by a liquid inlet defined by a flap-valve, each said flap-valve being adapted to permit moving liquid to flow at a controlled rate from its passage into the tank;

(d) each tank having an exit for the liquid whereby the moving liquid flows from the tank to one of the passageways; and

(e) at least one turbine positioned at the exit of each tank and adapted to be driven by the moving liquid as it flows from the tank to the passageway;

(f) said flap-valves being controllable to ensure continual flow of the moving liquid in the same direction at the controlled rate to the turbines to produce continuous rotation of the turbines.

8. Apparatus as defined in claim 1, wherein said hull is characterized by

(a) a bottom of arcuate cross section in the form of a large diameter cylinderical element and

(b) a finely streamlined bow.

9. Apparatus as defined in claim 1, further including storage tanks located in the bottom of the hold of the vessel to store the liquid in the event of interruption of the operation of the apparatus.

10. Apparatus as defined in claim 1, further including cushioning means located at each end of the vessel to

modify the amplitude of the pitching of the vessel, said cushioning means comprising a plurality of hollow, vertical air cylinders open at their bottoms.

11. Apparatus as defined in claim **10**, wherein the air cylinders are elongated and have a length sufficient for their open bottoms to remain immersed in the water during pitching of the vessel.

12. Apparatus as defined in claim **11**, wherein the air cylinders are closed to the atmosphere at their upper ends, and are provided with air valves for regulating the air pressure therein.

13. Apparatus as defined in claim **1**, wherein the vessel has a hull, the length of which at the water line is substantially equal to the wave length of the sea swells.

* * * * *

United States Patent [19]

Griffith

[11] **4,256,971**

[45] **Mar. 17, 1981**

[54] **WAVE AND WIND MOTION ENERGY TRANSDUCER**

[76] Inventor: **Rodney Griffith,** 6905 E. Ocean Blvd., Long Beach, Calif. 90803

[21] Appl. No.: **95,509**

[22] Filed: **Nov. 16, 1979**

[51] **Int. Cl.**³ **F03B 13/12**

[52] **U.S. Cl.** **290/53;** 290/42; 417/332

[58] **Field of Search** 290/53, 42, 43; 114/39; 115/4; 417/330, 331, 332, 333

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,682,176	8/1928	Hegenbarth	115/4
3,231,749	4/1963	Hinck	290/53
3,774,048	11/1973	Hardingham	290/42

Primary Examiner—J. V. Truhe

Assistant Examiner—D. L. Rebsch

Attorney, Agent, or Firm—Fulwider, Patton, Rieber, Lee & Utecht

[57] **ABSTRACT**

At least two spaced apart eccentric weights are rotatably mounted about vertical axles. The weights are coupled to advance a drive mechanism in a single direction when the weights move about their respective axles in either direction of rotation. The drive mechanism is coupled to a flywheel mounted upon a vertical axle and rotatable therewith. The transducer may be mounted athwartship in a floating vessel or supported on a mast or other support which is subjected to wind or wave motion. The eccentric weights oscillate irregularly about their axles under the influence of the rolling and pitching motion imparted by wind or waves. The motion of the eccentric weights thereby drives the flywheel in a single direction to provide useful power.

7 Claims, 5 Drawing Figures

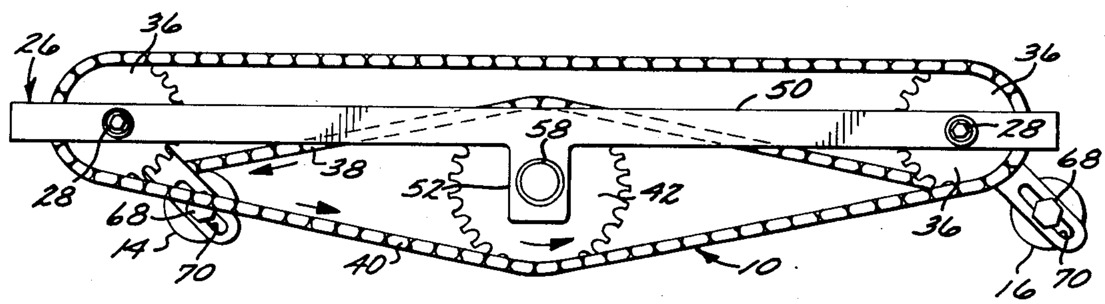


FIG. 1

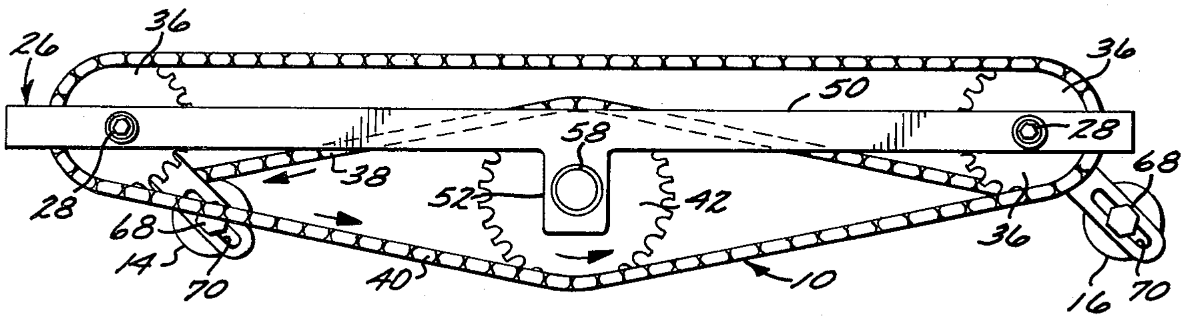
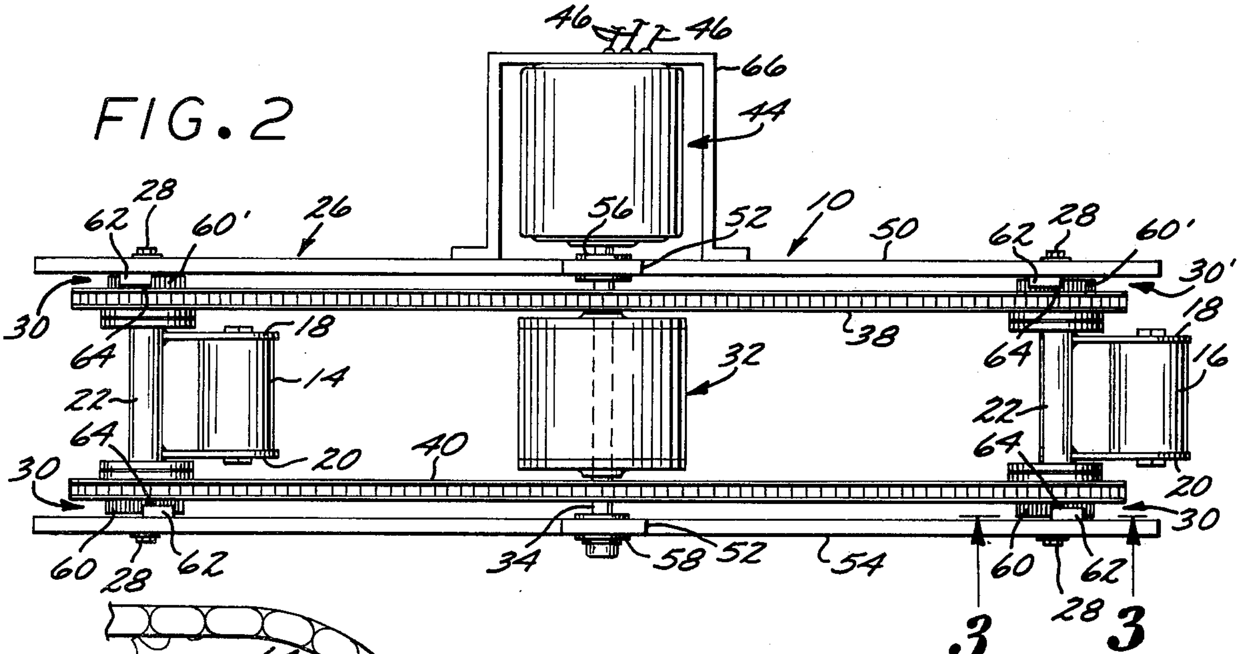


FIG. 2



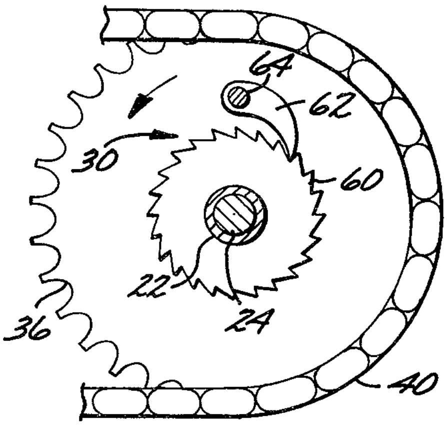


FIG. 3

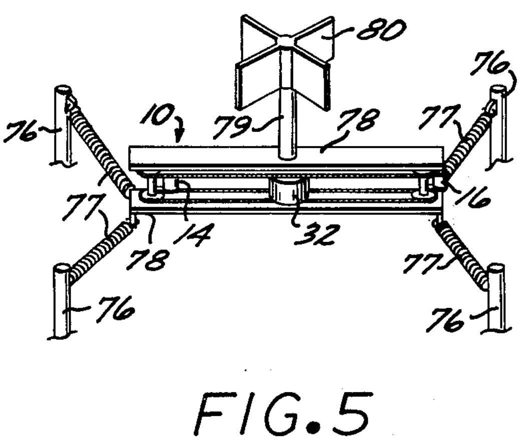


FIG. 5

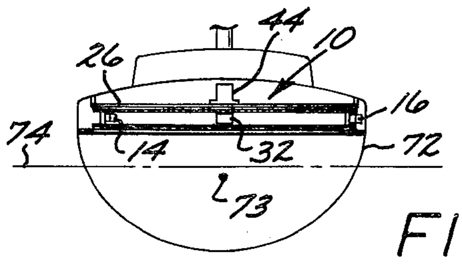


FIG. 4

WAVE AND WIND MOTION ENERGY TRANSDUCER

FIELD OF THE INVENTION

The present invention relates to devices for extracting useful power from wind and wave energy.

DESCRIPTION OF THE PRIOR ART

In the past, various mechanisms have been employed to harness the power of wind and waves which ceaselessly expend energy, but with very little transformation of that power to a form useful for performing the tasks desired by humanity. The development of devices for extraction of energy from wind and wave motion has lagged far behind the development of other energy resources, even though wind and wave energy is, for all intents and purposes, a renewable and unceasing energy source.

Some work has been done in the field of wave motion energy extraction, but the devices developed to data have had only a minor commercial significance. Most wind energy transducers that have been developed respond directly to the velocity of the wind. As a consequence, when wind velocity is quite low, the conventional devices are of very little use. The present invention, on the other hand, responds to changes in fluid velocity. As a consequence, the present invention is able to extract wind energy from wind of only a slight velocity, if, as is usually the case, the velocity of the wind varies moment by moment.

Attempts have been made to extract wave energy in water through mechanisms which are responsive to the shifting disposition of a floating vessel that is subjected to wave action. For example, U.S. Pat. No. 3,774,048 is directed to a device for transforming the pitching and rolling motion of a marine structure into useful energy. This device involves a single eccentrically weighted driving device mounted about a vertical axle and geared to an energy takeoff mechanism. The driving force is applied in a single direction although the eccentrically weighted driving device rotates in alternate directions. The entire mechanism is positioned at a single location near the center of the vessel. U.S. Pat. No. 1,682,176 describes another system in which an eccentrically weighted rotor travels upon a circular track extending transversely across a vessel to drive a vertical shaft passing through the center of the vessel. Both of these devices, although responding to the pitching and rolling motion of a boat, fail to extract a significant amount of the available energy from this motion.

SUMMARY OF THE INVENTION

The present invention employs a plurality of laterally spaced apart eccentric weights which are mounted for rotation upon vertical drive axles. Although the eccentric weights move upon their associated vertical drive axles in both clockwise and counterclockwise rotation, they are coupled to rotate a flywheel and flywheel shaft in a single direction of rotation. When used as a wave motion transducer, eccentric weights of the invention are located at laterally spaced apart positions near the periphery of a vessel or floating structure on opposite sides of the center of gravity thereof. When so positioned, the eccentric weights of the invention extract a considerable amount of energy from the pitching and rolling motion of the floating structure in the water. By positioning the eccentric weights opposite each other

near the periphery of the floating device, the eccentric weights are subjected to far greater rates of change of motion then are similar eccentric weights which are rotated about an axle located near the center of a vessel. This is because the vessel, as it pitches and rolls, tends to rotate about its own center of gravity. The locations on the vessel which are furthest from the center of gravity experience the greatest angular momentum, and hence the greatest change in angular momentum with the rolling and pitching movement. By positioning the eccentric weights about axles located near the periphery, the present invention is able to extract considerably more energy from wave motion as contrasted with prior art devices of the type described.

A further advantage of the present invention is that the movement of the plurality of eccentric weights creates a condition in which the movement of the weights is accentuated by the moment of the other weights. This increases rotation of all of the weights about their respective drive axles. For example, when the transducer of the invention is mounted upon a pole or mast and held aloft exposed to the wind with the rotatable eccentric weights spaced laterally apart, the action of wind upon vanes affixed to the pole tends to flex the pole. With the flexing movement, the weights rotate about their associated axles. The device thus extracts useful energy from the change in position of the eccentric weights. Moreover, as the weights move, they further flex the pole or mast to accentuate the movement thereof. This increases the rotation of the weights, and hence the amount of energy extracted.

The transducer of the invention may be used as a major source of commercial electrical power in both urban and rural environments. The invention may also be used as a transportable power supply in both large and small boats, on off shore oil drilling platforms, and also in campers and other recreational vehicles. The transducer of the invention may be utilized as either a primary power source, or as an auxiliary power source to supply supplemental power.

The invention may be explained with greater clarity and facility by reference to the accompanying drawings.

DESCRIPTION OF THE DRAWINGS

FIG. **1** is a bottom plan view of a motion transducer according to the invention.

FIG. **2** is a side elevational view of the motion transducer of FIG. **1**.

FIG. **3** is a sectional detail taken along the lines **3—3** of FIG. **2**.

FIG. **4** illustrates diagrammatically the installation of the motion transducer in a floating vessel.

FIG. **5** illustrates diagrammatically the invention mounted on a mast and exposed to the wind.

DESCRIPTION OF THE EMBODIMENT

FIGS. **1** and **2** illustrate an energy transducer **10** constructed according to the present invention. The transducer **10** includes two laterally spaced apart generally cylindrical shaped lead weights **14** and **16**, each carried at a distance from an associated drive axle between laterally disposed upper and lower flat steel bars **18** and **20**. The bars **18** and **20** are suspended in cantilever fashion from generally vertical steel sleeves **22**, and are welded thereto at their inboard ends. The sleeves **22** are rotatable and coaxial about generally vertical drive axles 24, one of which is depicted in section in FIG. 3. The axles 24 are held in position in a steel framework 26 by means of hexagon headed fastening machine screws 28.

Clutch mechanisms 30 and 30', one of which is depicted in detail in FIG. 3, are engageable by the eccentric weights 14 and 16 through the sleeves 22 as the weights rotate in either a counterclockwise or clockwise direction. A generally cylindrical lead flywheel 32 is coupled for rotation with a vertical flywheel axle or shaft 34, also carried in the framework 26 at its center. Drive linkage, including sprockets 36 mounted at both ends of the vertical drive axles 24 and chain loops 38 and 40 drive upper and lower sprockets 42 that are secured upon the flywheel axle 34. The clutch mechanisms 30 and 30' operate to engage the sprockets 36 only to advance each of the chain loops 38 and 40 in a single direction, as indicated by the directional indicia associated therewith in FIGS. 1 and 3. The chain loops 38 and 40 transfer the unidirectional motion imparted thereto to the flywheel axle 34. This rotates the flywheel 32 and the flywheel axle 34 in a single direction of rotation. A power takeoff in the form of an electrical generator 44 is provided to convert the mechanical rotational movement of the axle 34 to the electrical power at the electrical leads 46.

The steel frame 26 includes an elongated flat sheet metal bar 50 with a laterally extending perpendicular tab 52 at its center. The bar 50 forms the upper framework support, and an identical bar 54, illustrated in FIG. 1 and congruent therewith and spaced vertically therebelow forms a lower support. The bars 50 and 54 are spaced from each other by the vertical drive axles 24 which are secured thereto and fixed therebetween as depicted in FIG. 2. The vertical drive axles 24 are solid cylindrical steel rods tapped at both ends to receive the threaded shanks of the hexagonal headed screws 28. The vertical flywheel axle 34 is rotatable relative to the frame 26 and is carried within annular bearings 56 and 58.

The sleeves 22 to which the eccentrically mounted weights 14 and 16 are attached are carried by bearings for rotation about the vertical drive axles 24. Each of the sleeves 22 carries a pair of annular ratchet wheels 60 and 60' one of which is depicted in a plan view in FIG. 3. Each ratchet wheel interacts with a restraining pawl or tooth 62 which is spring biased inwardly toward the vertical drive axle 24 associated therewith. Together, the ratchet wheels 60 and 60' and the pawls 62 form the clutch mechanisms 30 and 30'. Each of the clutch mechanisms 30 and 30' is similar in design and construction to clutch mechanisms as conventionally utilized in bicycles. The vertical drive sleeves 22 and sprockets 36 may likewise be constructed of bicycle parts.

A single clutch mechanism 30 is depicted in FIG. 3. The ratchet wheel 60 is keyed, splined or otherwise securely attached to the sleeve 22 to rotate therewith. The sprocket 36 on the other hand, is journaled for rotation about the sleeve 22, unless engaged by the pawl 62 for rotation therewith. The pawl 62 is mounted for rotation relative to the sprocket 36 upon a mounting pin 64 extending from the face of the sprocket 36 parallel to the axial alignment of the sleeve 22 and in co-planar arrangement with a ratchet wheel 60 or 60'. The pawl 62 is biased toward the ratchet wheel 60 or 60' by a spring mechanism, not shown.

The arrangement of the teeth on the ratchet wheel 60 of the clutch mechanism 30 depicted in FIG. 3 is such that the teeth are directed radially outwardly with a counterclockwise inclination. Accordingly, the pawl 62 will engage the sprocket 36 to rotate with the sleeve 22 only when the sleeve 22 carries the ratchet wheel 60 in a counterclockwise direction. This will occur only when the eccentric weight 16 rotates in a counterclockwise direction as viewed in FIG. 1. Counterclockwise rotation of either sprocket 36 in either clutch mechanism 30 will advance the chain loop 40 in a counterclockwise direction as viewed in FIG. 1. When the weight 16 rotates in clockwise fashion about the vertical drive axle 24, it carries the sleeve 22 and ratchet wheel 60 therewith. When the ratchet wheel 60 is rotated in this fashion, the pawl 62 ratchets over the teeth thereof and the sprocket 36 is disengaged from the sleeve 22.

The clutch mechanism 30 depicted in FIG. 3 is the clutch mechanism that is located adjacent to and disposed inwardly from the bottom bar 54 of the support frame 26 at both of the vertical drive axles 24 associated with both of the eccentric weights 14 and 16. A clutch mechanism 30' with a ratchet wheel having teeth of opposite disposition is located at the other end of each vertical drive axle 24 near the top bar 50 of the frame 26. That is, instead of the radially outwardly and counterclockwise inclined teeth of the ratchet wheel 60 as depicted in FIG. 3, the clutch mechanism 30' (FIG. 2) includes a ratchet wheel with teeth that are disposed radially outwardly and inclined clockwise in opposite disposition to the teeth of the ratchet wheel 60. Accordingly, the clutch mechanisms 30' will engage sleeves 22 and sprockets 36 at the upper ends of the vertical drive axles 24 to advance the chain loop 38 in a clockwise direction of rotation, as viewed in FIG. 1 only when one or both of the eccentric weights 14 or 16 rotate clockwise about an associated vertical drive axle 24.

When the eccentric weight 16 moves in rotation about its vertical drive axle 24, it will at any point in time, engage one and only one of the sprockets 36 located at opposite ends of the axle 24. When the eccentric weight 16 moves in counterclockwise fashion about the vertical drive axle 24, it will carry the sprocket 36 at the lower end of the vertical drive axle 24 adjacent the bar 54 to advance the chain loop 40 in a counterclockwise direction. Conversely, when the weight 16 moves in clockwise fashion about the vertical drive axle 24, it will engage only the sprocket 36 located adjacent to the upper bar 50 to advance the chain loop 38 in a clockwise direction, as viewed in FIG. 1. With reference to FIG. 1, it is apparent that whether either of the flywheel sprockets 42 are driven by the chain loop 38 or by the chain loop 40, the flywheel axle 34 and flywheel 32 will in both cases be driven in counterclockwise rotation. This unidirectional driving arrangement is effectuated by the tangential engagement of the chain loops 38 and 40 on opposite sides of the flywheel axle 34 with a sprocket 42 associated therewith.

The driving engagement of the eccentric weight 14 is identical to that of the eccentric weight 16, and the clutch mechanisms 30 and 30' associated therewith are as previously described in association with the vertical drive axle 24 of the eccentric weight 16.

The chain loops 38 and 40 are constructed of sequentially connected steel links with interstitial spaces between links designed to receive the teeth of the sprockets 38 and 42. Such endless chains are typically used in bicycle drive mechanisms.

The flywheel 32 need not necessarily by cylindrical, but is constructed with a heavy weight which is not eccentric, but is balanced evenly about the flywheel axle 34. A protective cage 66 houses the generator 44 and the generator casing is rigidly secured to the cage 66. The generator 44 includes a rotor which is mounted upon an extension of the flywheel axle 34 and driven by rotation of the flywheel axle 34 and flywheel 32. The flywheel 32 is rigidly coupled to rotate with the flywheel axle 34. The purpose of the flywheel 32 is to make the rotation of the flywheel axle 34 as uniform as possible. The rotor of the generator 44 rotates within stator windings so that electrical power is generated and is drawn off for use by the generator outlet leads 46, as depicted in FIG. 2.

The ideal mass and the optimum position of the eccentric weights 14 and 16 from the vertical drive axles 24 will vary according to the size of the structure upon which the transducer 10 is mounted, the wave period or steadiness of the wind, and the height of the waves or wind strength. Accordingly, the weights 14 and 16 are not permanently secured to the laterally extending bars 18 and 20, but rather are mounted on releasable fasteners, such as the machine bolts 68 depicted in FIGS. 1 and 2. The bars 18 and 20 include longitudinal slots 70 so that the weights 14 and 16 can be adjusted radially relative to the vertical drive axles 24 to alter the angular moment of the rotation of the eccentric weights 14 and 16 thereabout. The machine screws 68 need merely be loosened to allow the weights 14 and 16 to be moved radially within the slots 70 to a desired location. The screws 68 are then tightened at a distance from the vertical drive axles 24 to achieve the desired moment of the eccentric weight thereabout. In this fashion the degree of eccentricity of the weights 14 and 16 is adjustable. The distance at which the weights 14 and 16 are positioned along the longitudinal slots 70 is governed by the height of the swells to which the transducer is subjected, and the mass of the weights 14 and 16. For large power installations it is advantageous to include a servo drive mechanism for moving the weights 14 and 16 along the slots 70. This servo mechanism may be either manually controlled or computer controlled so that with changing swell conditions the radial positions of the weights 14 and 16 may be adjusted automatically.

FIG. 4 illustrates the positioning of the energy transducer 10 in a floating structure, illustrated as the hull 72 of a boat. The vertical drive axles carry the eccentric weights 14 and 16 within the framework 26 near the lateral periphery of the port and starboard sides of the boat hull 72 on opposite sides of the center of gravity 73 of the hull 12. As waves progress through the water 74, the boat hull 72 will heel to the port or starboard side, and will also pitch and yaw from bow to stern. The framework 26 is rigidly secured to the structure of the hull 72. The eccentric weights 14 and 16 will move in arcuate paths, not necessarily in the same direction at the same time, and typically in irregular oscillating patterns with the wave motion. As the eccentric weights 14 and 16 move, they drive one or the other of the sprockets 36 associated therewith to advance either the chain loop 38 or the chain loop 40 in the directions indicated by the directional arrows in FIG. 1. This rotates the upper or lower sprocket 42 coupled to the flywheel axle 34 to generate electricity in the generator 44. Since the rolling motion and pitching of the boat hull 72 is virtually continuous as long as the hull 72 floats in the water 74, a continuous source of useable power is provided.

The transducer 10 of the invention may well dictate an alternative manner of anchoring the vessel upon which it is mounted. In conventional practice, a boat or other vessel is anchored by chains or other lines that are cleated to the deck of the vessel. To increase the rocking action of the vessel in order to maximize the power output from the transducer 10 it may well be preferable to attach the anchor lines to the keel of the vessel at swivel connections. With the swell action this will increase the rolling and pitching movement of the vessel considerably so as to increase the power output of the invention. Additional anchor lines can be attached to the deck of the vessel to control the rolling and pitching motion as desired.

FIG. 5 illustrates the transducer 10 of the invention mounted at some arbitrary elevation suspended between poles or masts 76. The poles 76 are upright and are located diagonally outward from the corners of the transducer 10. Coil springs 77 extend laterally diagonally to each corner of the transducer 10 from the poles 76 and are attached to the transducer 10 by means of brackets 78. Atop the transducer 10 there is an upright stanchion 79 with a plurality of flat, solid, sheet-like vanes 80, mounted in perpendicular alignment to extend outwardly at 90° intervals. When the wind blows, regardless of direction, it will impinge upon at least some of the vanes 80. This causes the transducer 10 to flex and rock elastically in the wind, relative to the poles 76 as restrained by the coil springs 77 so that the eccentric weights 14 and 16 rotate about their axles and turn the flywheel 32 in the manner previously described. As with the utilization of the device in a structure floating in water, the oscillatory movement of the eccentric weights 14 and 16 may be irregular. The eccentric weights 14 and 16 may even turn in complete circles for a time, although more typically they irregularly advance in first one direction of rotation, and then in the opposite direction.

It is to be understood that numerous forms of a power takeoff may be employed. That is, in place of the generator 44, the energy developed by rotation of the flywheel shaft 34 may be transmitted as mechanical rotorary motion to any type of power takeoff, such as a propellor shaft, for example. Any conventional type of power takeoff may be utilized.

It should further be understood that the orientation of the vertical drive axles 24 and the flywheel axle 34 deviates from a true vertical direction by the extent to which the transducer 10 is rocked or tilted. The description of the axles as being vertically aligned is intended to refer to a generally upright orientation and should not be limited to strict vertical alignment. Indeed, it is necessary to the operation of the device for the alignment to vary back and forth from the vertical.

Undoubtedly, numerous other modifications of the invention and various implementations thereof beyond those depicted and described in detail in connection herewith will occur to those familiar with wind and wave energy extraction devices. Accordingly, the scope of the invention should not be construed as limited to the specific embodiment depicted, nor to the mounting arrangements depicted and described. Rather, the necessary features and scope of the invention are as set forth in claims appended hereto.

I claim:

1. An energy transducer comprising a plurality of laterally spaced apart eccentric weights mounted for rotation upon vertical drive axles, a flywheel coupled

for rotation with a vertical flywheel shaft, interconnecting drive linkage means, for driving said flywheel in response to movement of said eccentric weights, and clutch means engageable by said eccentric weights as said weights rotate in either direction to advance said drive linkage means to rotate said flywheel and said flywheel shaft in a single direction of rotation.

2. An energy transducer according to claim 1 mounted in a floating structure.

3. An energy transducer according to claim 2 further characterized in that said vertical drive axles are located near the lateral periphery of said floating structure and on opposite sides of the center of gravity thereof.

4. An energy transducer according to claim 1 further characterized in that said flywheel axle is coupled to drive an electrical generator.

5. An energy transducer according to claim 1 further characterized in that the degree of eccentricity of the mass of said eccentric weights relative to said vertical drive axles is adjustable.

6. An energy transducer according to claim 1 further characterized in that said drive axles and said flywheel axle are carried in a rigid framework which is supported in a flowing fluid upon an upright support which responds elastically to changes in fluid motion.

7. An energy transducer according to claim 6 further characterized in that said transducer is pole mounted in the air and exposed to the wind.

* * * * *

United States Patent [19]

Hardingham

[11] **3,774,048**

[45] **Nov. 20, 1973**

[54] **ENERGY GENERATING AND STORING ASSEMBLY FOR MARINE STRUCTURE**

[76] Inventor: **Derek D. Hardingham,** 1030 Crest View Dr., Seal Beach, Calif. 90740

[22] Filed: **Feb. 22, 1972**

[21] Appl. No.: **228,037**

[52] **U.S. Cl.** **290/42,** 290/53, 115/4, 114/39

[51] **Int. Cl.** **F03b 13/12**

[58] **Field of Search** 9/8; 115/4; 240/42, 240/43; 114/53, 54, 39; 417/330, 331, 332, 333

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[57] **ABSTRACT**

A device and method of using same for transforming the pitch and roll motion of a buoyant marine structure into storable energy that is available for future use.

13 Claims, 10 Drawing Figures

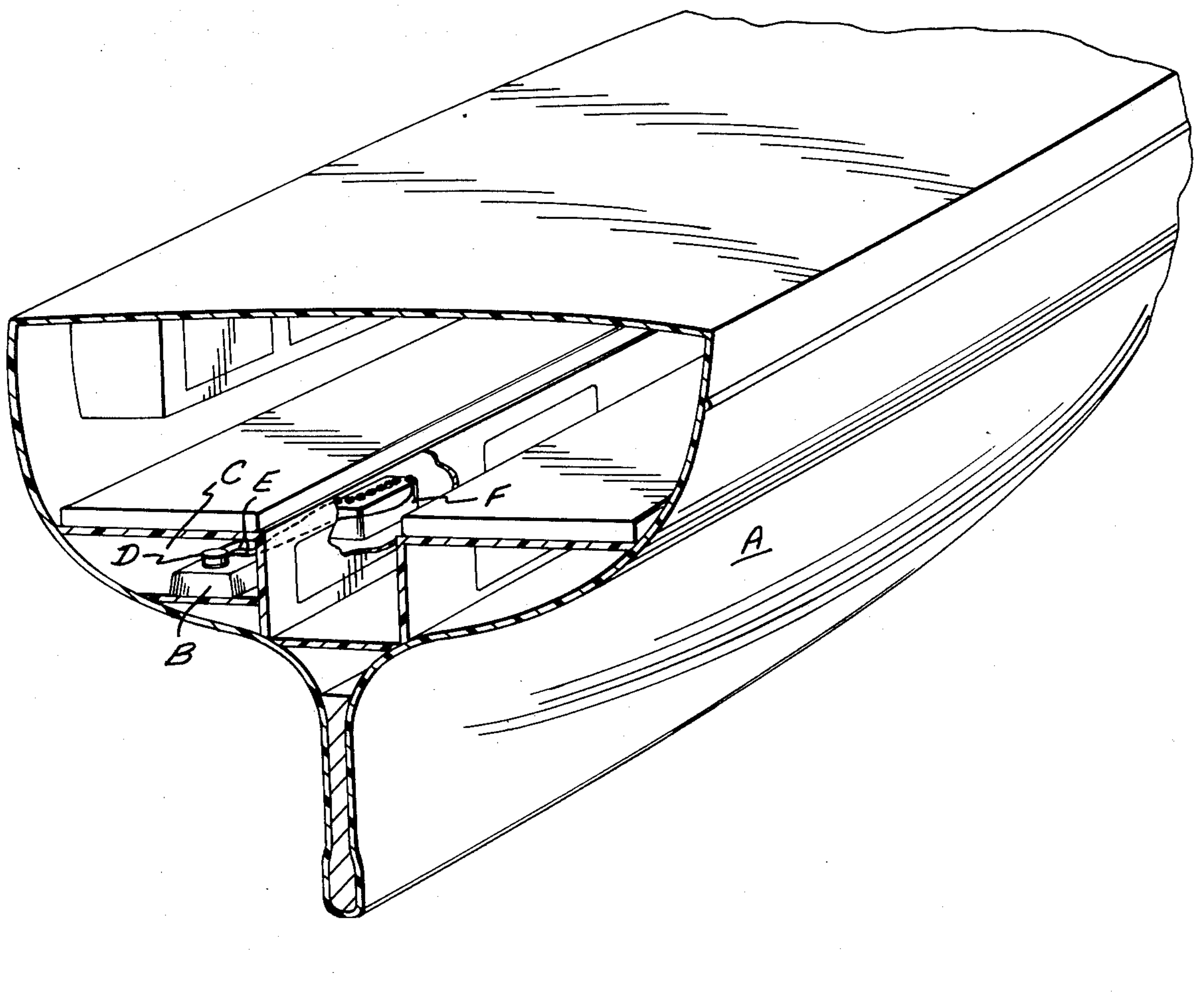


FIG. 1

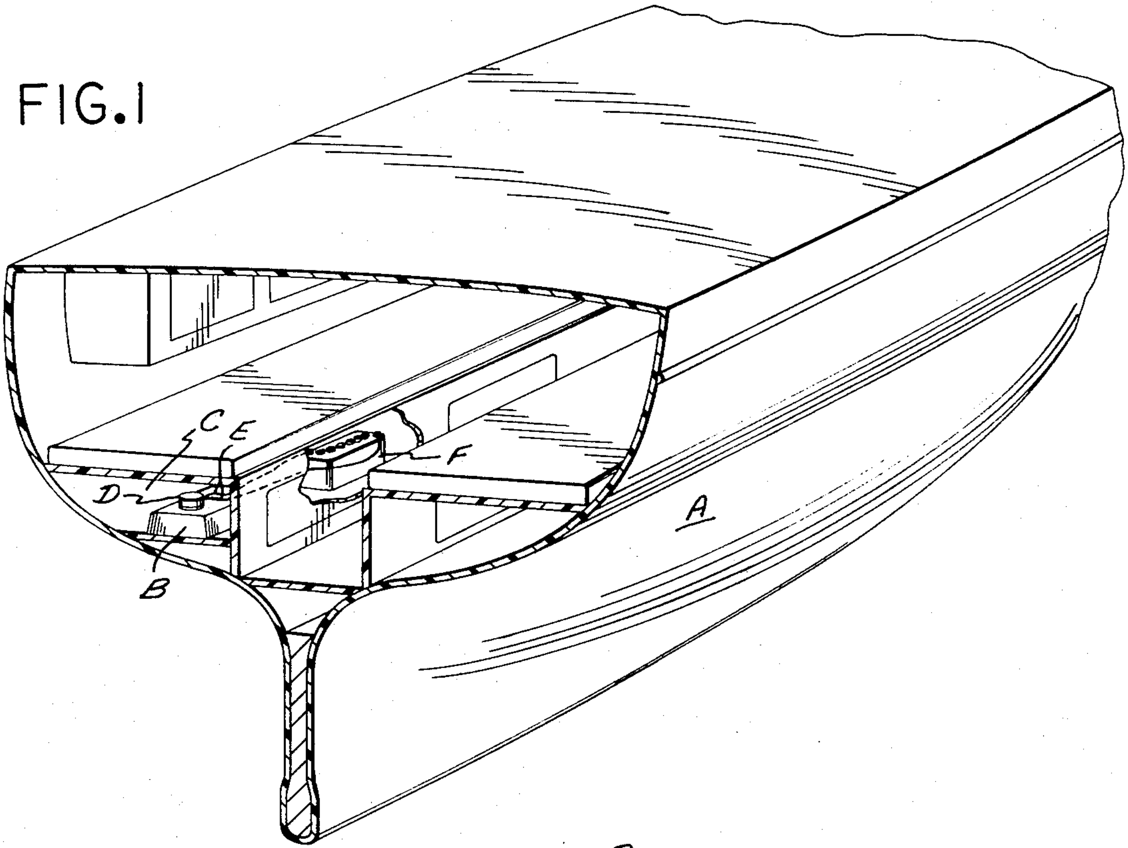
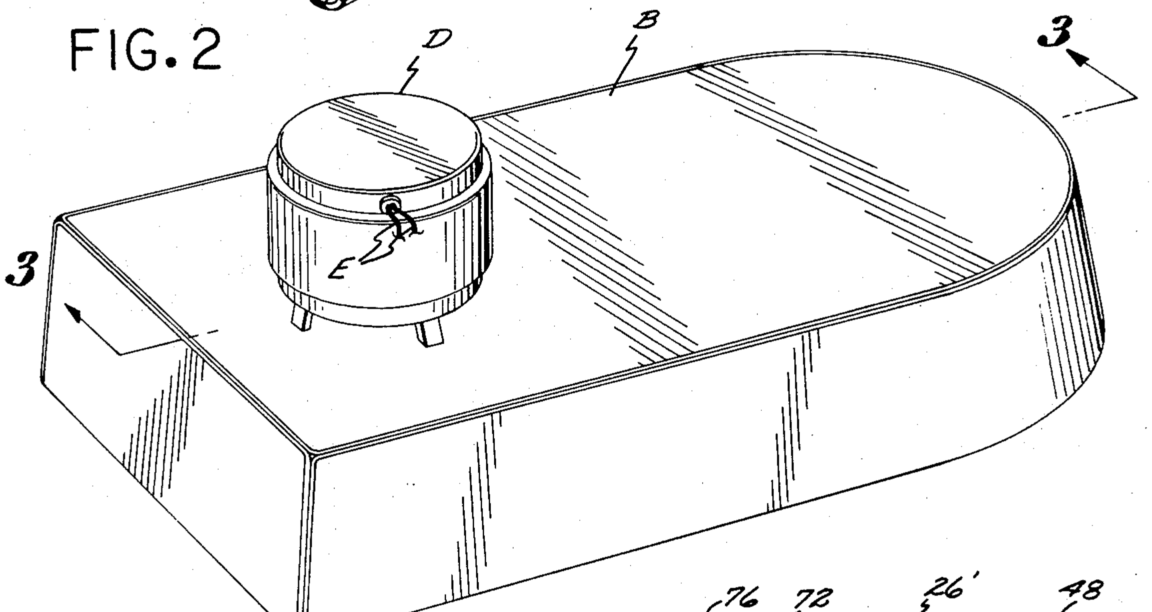


FIG. 2



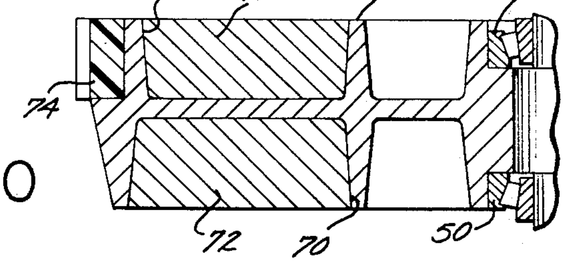


FIG. 10

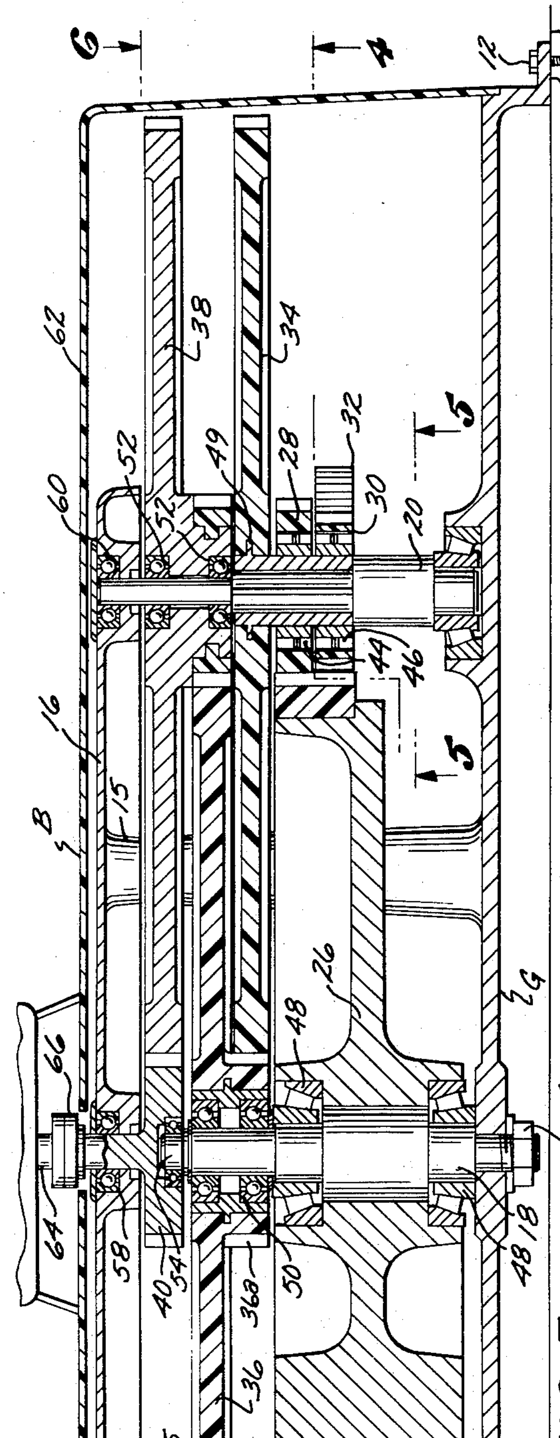


FIG.3

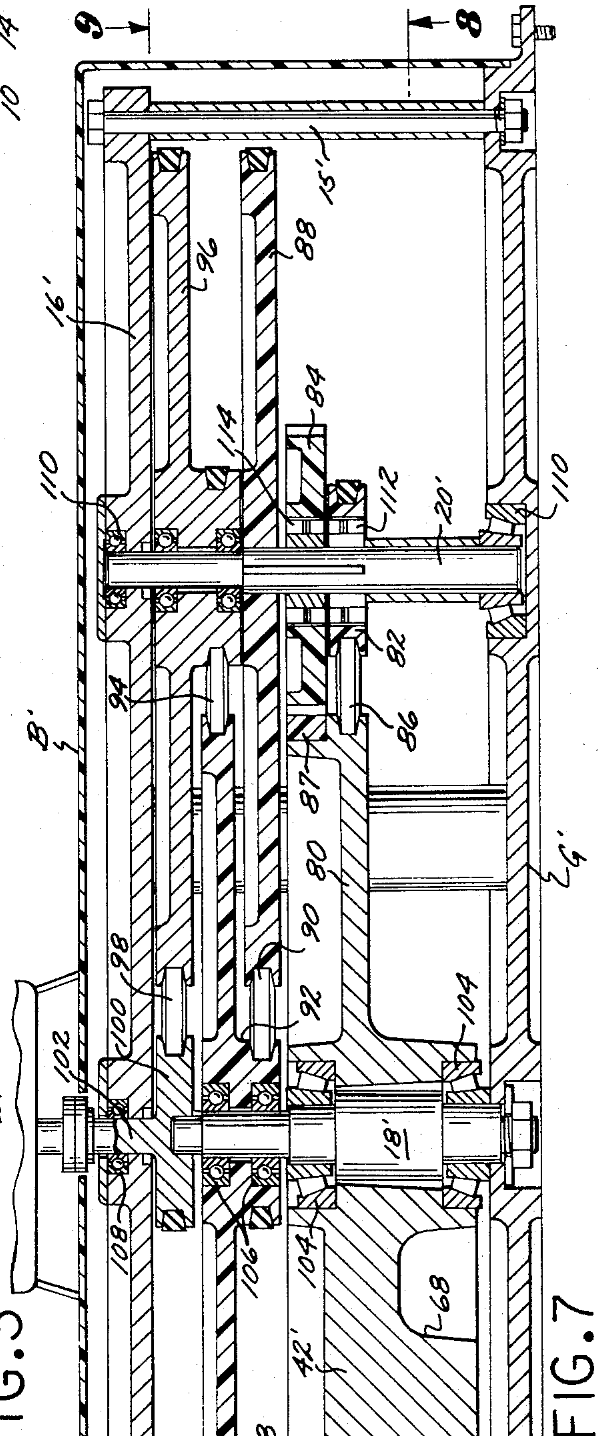


FIG.7

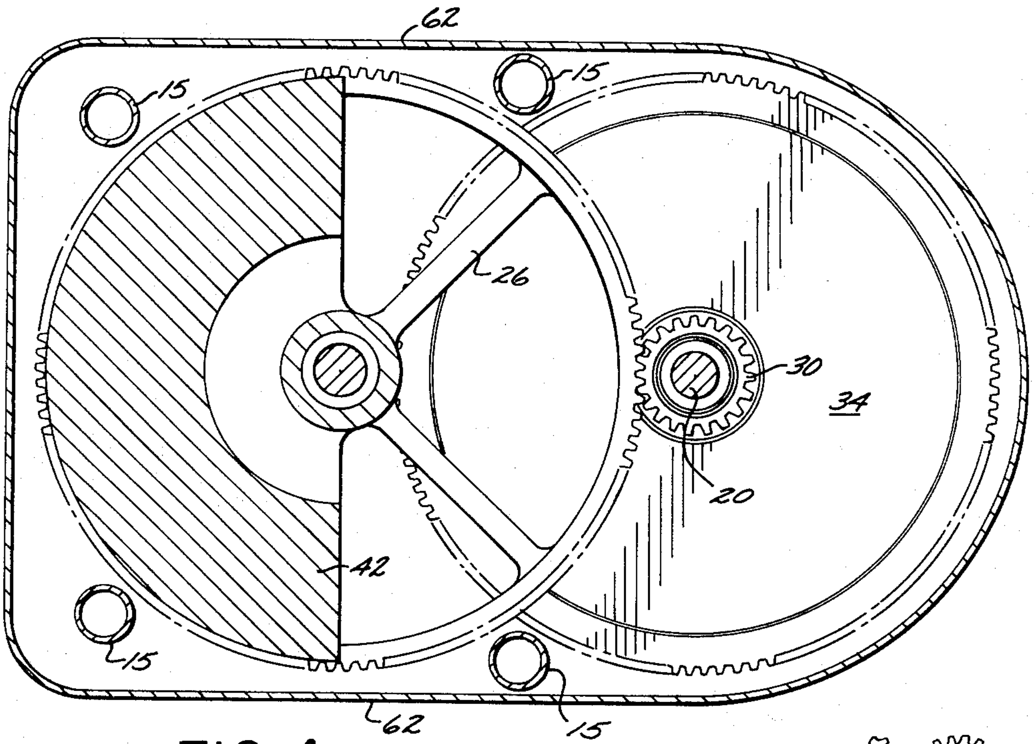


FIG.4

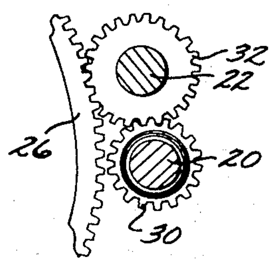
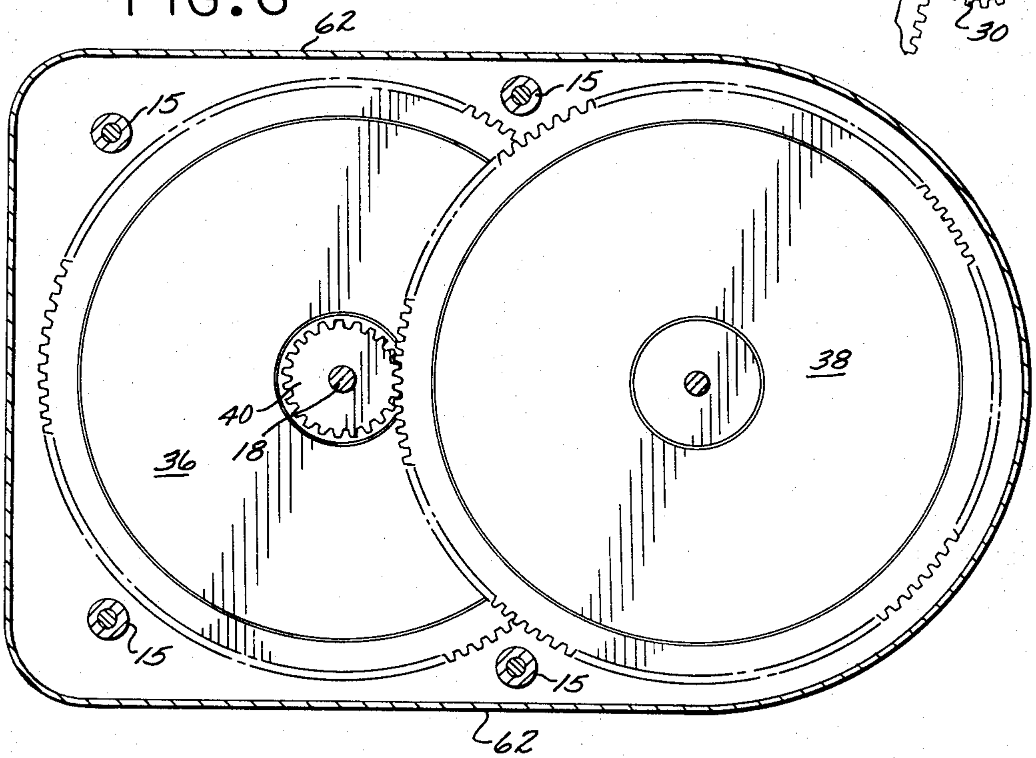


FIG.5

FIG.6



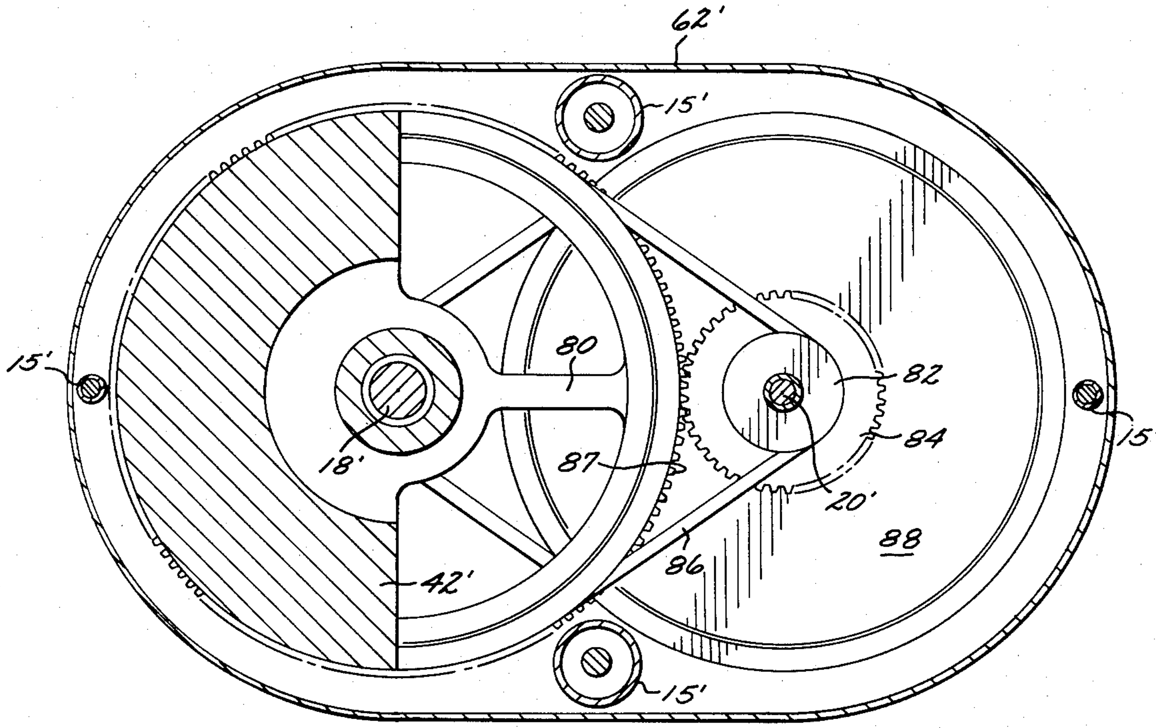
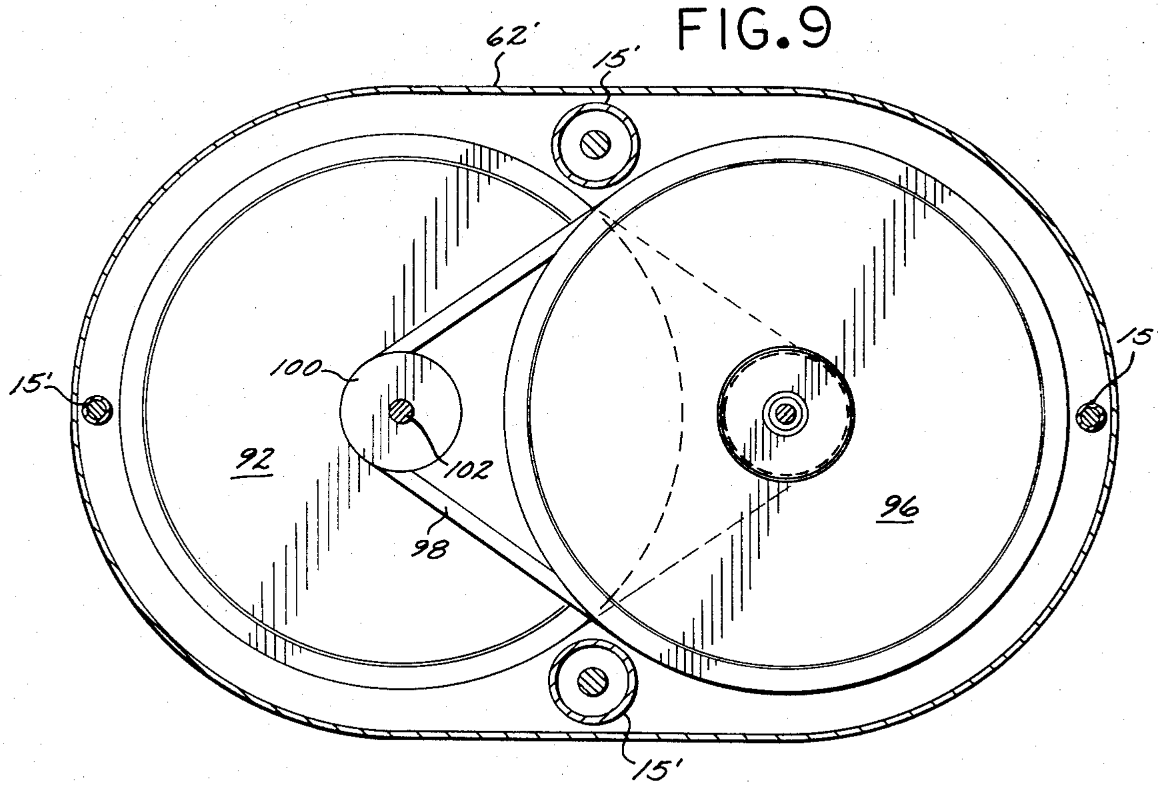

62'
15'
15'
15'
15'
80
82
84
87
18'
20'
88
86
42'

FIG.8

FIG.9


62'
15'
15'
15'
15'
100
102
92
96
98

ENERGY GENERATING AND STORING ASSEMBLY FOR MARINE STRUCTURE

BACKGROUND OF THE INVENTION

1. Field of the Invention

An energy generating and storing assembly for a buoyant marine structure that is actuated by the pitch and roll motion of the latter.

2. Description of the Prior Art

Owners of power bolts as well as sailing vessels that are provided with auxilliary engines, must periodically operate the latter to drive generators to maintain storage batteries on the boat or vessel in a charged condition. If the batteries are used as a source of electrical energy for lights, engine starting purposes, and the like, it will be apparent that the engines must be operated relatively frequently, which is not only annoying and an inconvenience to the owner, but is relatively expensive if the engine is of substantial horsepower.

The primary purpose in devising the present invention is to provide a device in which the pitch and roll motion of the buoyant marine structure is utilized to oscillate a pivotally supported, off-centered weight, with the oscillating motion of the weight being transformed into relatively high speed motion in a single direction that is used to drive an electric generator, air or gas compressor, pump, or the like, whereby electric energy or gas under pressure may be stored for future use. Operation of the device occurs automatically as the marine structure on which it is installed pitches and rolls, and with no expense to the owner.

The device is particularly adapted for installation in hollow buoys that are located in remote and hard-to-reach locations, with the device, as the buoy pitches and rolls, generating electricity to charge storage batteries in the buoy and the charged batteries serving as a source of electrical energy to operate lights mounted on the buoys. From experience, it has been found that the device operates satisfactorily even when the marine structure on which it is installed is subjected to but slight pitch and roll motion.

SUMMARY OF THE INVENTION

A device that is secured in a fixed position relative to a buoyant marine structure that is subjected to pitch and roll motion. The device includes a pivotally supported, off-centered weight that oscillates as a result of said motion, and this oscillating motion, by gear means, being transformed into rotary motion in a single direction. The rotary motion in a single direction is used to drive a generator, compressor, pump, or the like to store energy that may subsequently be used for desired electrical or mechanical purposes. The gear means, in addition to transforming the oscillatory motion into rotary motion in a single direction, also provides this rotary motion at a substantially greater angular velocity than that at which said weight oscillates.

A major object of the invention is to provide a power-generating device that is automatically actuated by the pitch and roll of a buoyant marine structure on which the device is installed, and the power so generated being used to store electrical or pneumatic energy for future use on the structure.

Another object of this invention is to furnish a light-weight, compact device of relatively simple mechanical structure that is easily and conveniently installed on a marine structure, and after installation will automatically maintain storage batteries on the structure in a charged condition due to the pitch and roll motion to which the structure is subjected.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view of a portion of a marine vessel that is cut away to show a possible positioning of the power generating device within the interior thereof;

FIG. **2** is a perspective view of the device;

FIG. **3** is a longitudinal cross-sectional view of a first form of the device;

FIG. **4** is a fragmentary, longitudinal cross-sectional view of the first form of the device taken on the line **4—4** of FIG. **3**;

FIG. **5** is a fragmentary, longitudinal cross-sectional view of the first form of the device taken on the line **5—5** of FIG. **3**;

FIG. **6** is a longitudinal cross-sectional view of the first form of the device taken on the line **6—6** of FIG. **3**;

FIG. **7** is a longitudinal cross-sectional view of a second form of the device;

FIG. **8** and FIG. **9** are longitudinal cross-sectional views of the second form of the device taken on the lines **8—8** and **9—9**, respectively, of FIG. **7**; and

FIG. **10** is a fragmentary transverse cross-sectional view of an alternate form of eccentrically weighted oscillating gear.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A conventional buoyant marine vessel A is shown in FIG. **1** that is subjected to pitch and roll movement when subjected to wave action. The invention B that is illustrated as mounted in a compartment C in the vessel A, when vessel A is subjected to pitch and roll motion, is actuated to drive an alternator D to discharge electric current through conductors E to charge storage batteries F. The first form B-**1** of the invention, as illustrated in FIGS. **3** to **6** inclusive, includes an elongate base G that has lugs or a flange **10** projecting outwardly therefrom through which bolts **12** extend to engage a flat, horizontal surface portion **14** of the vessel A, as shown in FIG. **3**.

A number of spaced uprights **15** are secured to base G and serve to support a plate **16** on the upper ends thereof. Plate **16**, as shown in FIG. **3**, occupies an elevated position relative to base G and is substantially parallel thereto.

First, second and third shafts **18, 20** and **22** are provided. The first and third shafts **18** and **22** are stub shafts of the same structure. The first and third shafts **18** and **22** have lower, externally threaded portions of smaller diameter that extend downwardly through openings in the base G to be engaged by nuts **24**.

First, second, third, fourth, fifth, sixth, seventh and eighth gears **26, 28, 30, 32, 34, 36, 38** and **40**, respectively, are provided as shown in FIGS. **3** and **5**. First, sixth and eighth gears **26 36** and **40** are mounted on first shaft **18**. Second, third, fifth and seventh gears, **28, 30, 34** and **38** are mounted on second shaft **20**. Fourth gear **32** that is an idler gear is rotatably supported on third shaft **22**, as shown in FIG. **5**.

First gear **26** has a weight **42** of substantial magnitude eccentrically mounted thereon as shown in FIGS. **3** and **4**. First and second ratchet mechanisms **44** and **46** are interposed between second shaft **20** and second and third gears 28 and 30 that allow these gears to rotate in both first and second directions, but to drive second shaft 20 only when gears 28 or 30 rotate in a first direction.

First gear 26 is rotatably supported on first shaft 18 by first and second bearings 48 and 50, as shown in FIG. 3. First bearing 48 is preferably a thrust bearing whereby the eccentrically weighted first gear 26 is rotatably supported on first shaft 18 in a manner to have a minimum of friction as it oscillates thereon, as will later be explained. First gear 26, as may be seen in FIG. 3, is of far greater diameter than that of second gear 28. First and second gears 26 and 28 are in toothed engagement. Third and fourth gears 30 and 32 may be of substantially the same diameter. Fourth gear 32 is in toothed engagement with both first gear 26 and third gear 30. When first gear 26 rotates in a second direction, this motion is transferred through fourth gear 32 to rotate third gear 30 in a first direction. Rotation of either second gear 28 or third gear 30 in a first direction serves to impart like movement to second shaft 20 due to first and second ratchet mechanisms 44 and 46.

Fifth gear 34 is, by a conventional key 49 or other fastening means, rigidly secured to second shaft 20. The fifth gear 34 is of substantially greater diameter than second gear 28. Fifth gear 34 is in engagement with an externally toothed hub 36*a* that forms a part of sixth gear 36, as shown in FIG. 3. Sixth gear 36 is rotatably supported on first shaft 18 by a bearing assembly 50 as shown in FIG. 3. The sixth gear 36 that is of substantially the same diameter as fifth gear 34 is in engagement with an externally toothed hub 38*a* that forms a part of seventh gear 38. The seventh gear 38 that is of substantially the same diameter as sixth gear 36 is in toothed engagement with eighth gear 40. Seventh gear 38 is rotatably supported on second shaft 20 by two bearing assemblies 52.

The eighth gear 40 that is in toothed engagement with seventh gear 38 is rotatably supported on first shaft 18 by a bearing assembly 54. A fourth shaft 56 extends upwardly from eighth gear 40. Fourth shaft 56 is rotatably supported in a fixed position by a bearing assembly 58 supported by plate 16. The upper end portion of second shaft 20 is rotatably supported by a bearing assembly 60 supported from plate 16.

An inverted cover or housing 62 is removably secured to base G by conventional means (not shown). The housing 62 serves to enclose first, second and third shafts 18, 20 and 22, first to eighth gears 26 to 40 inclusive, and plate 16. Housing 62 serves as a support for alternator D, which alternator has a driving shaft 64 extending therefrom that is rigidly connected to eighth gear 40 by a coupling 66, as shown in FIG. 3. First gear 26 is preferably formed from a non-magnetic material, as is weight 42, to eliminate the possibility of the oscillating weight having an adverse effect on a compass that may be mounted on the vessel A. Weight 42 is preferably of semi-circular shape, as shown in FIG. 4. Weight 42 may have cavities 68 formed therein that have molten lead poured therein to increase the magnitude of the weight.

Second, third, fourth, fifth, sixth and eighth gears 28, 30, 32, 34, 36 and 40, respectively, are preferably formed from a tough polymerized resin such as nylon or the like to minimize the weight of the invention B. First gear 26 has a tooth-defining ring 26*a* formed of a polymerized resin bonded thereto and disposed in a circular recess formed in the body of the gear. Toothed ring 26*a* is in engagement with second and fourth gears 28 and 32 and, as a result, the wear on ring 26*a* and gears 28 and 32 will be uniform as they rotate.

Seventh gear 38 is preferably formed from steel or the like. The seventh gear 38, due to the weight thereof, acts as a flywheel to smooth out the rotary motion delivered by it to eighth gear 40. Eighth gear 40 is also formed from the same material as seventh gear 38 in order that there be uniform wear on the two gears as they rotate. An alternate first gear 26′ is shown in FIG. 10 that includes a hub 68 that has an eccentric compartment defining frame 70 extending outwardly therefrom, with the compartments being filled with lead 72 to increase the weight thereof. Gear 26′ has a tooth-defining ring 74 of a polymerized resin inserted in a circular recess 76 formed therein, with the ring being bonded to the body of the gear.

After the invention B is installed in a vessel A, as previously described, and the vessel A moves with pitch and roll motion due to wave or tide action, the eccentrically weighted first gear 26 oscillates. Rotary motion of first gear 26 in a first direction drives second gear 28 in the same direction to rotate second shaft 20 and fifth gear 34. Fifth gear 34, as it rotates in a first direction, drives sixth, seventh and eighth gears 36, 38 and 40 at increasing rates of rotation, with the fourth shaft 56 which is connected to eighth gear 40 being driven at a sufficiently high rate of rotation that the alternator D is actuated to generate an electric current that flows through conductors E to batteries F to charge the latter.

When the eccentrically weighted first gear 26 oscillates in a second direction, third gear 30 is driven by fourth gear 32 to rotate in a first direction and drive second shaft 20 in a first direction. Fifth gear 34 serves to transmit rotary motion to sixth gear 36 in a single direction irrespective of whether second shaft 20 is rotated in a first direction by second gear 28 or third gear 30.

An alternate form B′ of the invention is shown in FIG. 7 that serves the same purpose as the first form B previously described, and both forms include certain common elements. Elements in alternate form B′ that are common to the first form B of the invention are identified by the number or letter used in describing the first form but with a prime added thereto. The alternate form B′ of the invention differs from the first form B primarily in being of belt-driven construction rather than of the gear driven type.

The alternate form B′ includes a base G′ that has uprights 15′ secured thereto that support a plate 16′. A first stub shaft 18′ extends upwardly from base G′. The base G′ and plate 16′ rotatably support a second shaft 20′ therebetween.

A first sheave 80 that has a weight 42′ eccentrically mounted thereon is rotatably supported on first shaft 18′. A second sheave 82 and second gear 84 are mounted on second shaft 20′. A first endless belt 86 engages the first and second sheaves 80 and 82. The first sheave 80 has a first ring gear 87 rigidly secured thereto that is in toothed engagement with second gear 84. Second shaft 20′ has a third sheave 88 keyed thereto. Third sheave 88 is engaged by a second endless belt 90 that also engages a fourth double sheave 92 rotatably supported on first shaft 18′. A third endless belt 94 extends from fourth double sheave 92 to engage a fifth double sheave **96** rotatably supported on second shaft **20'**.

Fifth double sheave **96** is drivingly connected by a fourth endless belt **98** to a sixth shave **100** that is rotatably supported on first shaft **18'**. The sixth sheave **100** has a third shaft **102** extending upwardly therefrom that is drivingly connected to alternator D' in the same manner as shaft **64** in the first form B of the invention. Bearing assemblies **104, 106** and **109** rotatably support first, fourth and sixth sheaves **80, 92** and **100**, respectively, on first shaft **18'**. Second shaft **20'** is rotatably supported by bearing assemblies **110** between base G' and plate **16'**. Fifth sheave **96** is rotatably supported on second shaft **20'** by bearing assemblies **110**.

Second sheave **82** and second gear **84** have ratchet mechanisms **112** and **114** interposed between them and second shaft **20'** that permits the second sheave **82** and second gear **84** to drive the second shaft **20'** only when the second sheave **82** and second gear **84** rotate in a first direction. When first sheave **80** oscillates in a first direction, the first belt **86** drives second shaft **20'** in a first direction to rotate third sheave **88.** Rotation of third sheave **88** in a first direction results in the alternator D' being driven in a first direction due to rotation of second, third and fourth belts **90, 94** and **98,** and fourth, fifth and sixth sheaves **92, 96** and **100.**

Upon first sheave **80** oscillating in a second direction, the second gear **84** is driven in a second direction to rotate second shaft **20'** in a first direction. The second shaft **20'** now drives the alternator D' in the same direction and in the same direction as previously described when rotation of shaft **20'** was due to the action of second sheave **82.**

The use and operation of the two forms of the device B and B' has been previously described in detail and need not be repeated. In both the first and alternate forms of the device B and B' the motive power is furnished by the off-centered weights oscillating through an arcuate path as the vessel A on which either device is mounted is subjected to pitch and roll motion by wave action.

Although the invention has been described and illustrated as driving an alternator D to charge storage batteries F, it will be apparent that a conventional rotary pump (not shown) may be substituted for the alternator, and a conventional pressure vessel for the storage batteries. The pump, as it is rotated, will discharge a gaseous medium such as air to the pressure vessel where it is stored at a greater than ambient pressure for future use as a source of energy. The pump and pressure vessel are connected by conventional piping (not shown).

I claim:

1. A device for use in transforming the pitch and roll motion of a buoyant marine structure into storage battery contained electrical energy for future use, said device including:

a. a base;

b. first means for securing said base in a fixed position relative to said structure;

c. a rigid plate;

d. second means for holding said plate at a fixed elevated position above said base and substantially parallel thereto;

e. first, second and third spaced shafts normally disposed to said base and situated between said base and plate, said first and third shafts being stub shafts supported from said base, and said second shaft having the end portions thereof rotatably supported by said base and plate;

f. first, second, third, fourth, fifth, sixth, seventh, and eighth gears, said first, sixth and eighth gears being rotatably supported on said first shaft, said second, third, fifth and seventh gears mounted on said second shaft but only said seventh gear being rotatable in two opposite directions relative thereto, said fifth gear being keyed to said second shaft, said sixth and seventh gears including externally toothed hubs that are engaged by said fifth and sixth gears, said fourth gear being rotatably supported on said third shaft and in engagement with both said first gear and said third gear, said first gear being in engagement with said second gear and said seventh gear in engagement with said eighth gear, said first, fifth, sixth and seventh gears being of substantially greater diameter than said second gear;

g. third and fourth means interposed between said second shaft and said second and third gears for allowing said second and third gears to rotate in first and second opposite directions, but with said third and fourth means permitting said second and third gears to drive said second shaft and fifth gear only when said second or third gear rotates in a first direction, said second gear rotating in said first direction when said first gear so rotates, and said third gear rotating in said first direction when said first gear rotates in a second direction;

h. a weight eccentrically supported on said first gear that oscillates said first gear in first and second directions as said structure pitches and rolls, with said oscillating movement of said first gear being transformed into rotational movement of said second shaft in a single direction by said second and third gears and said third and fourth means, and said fifth gear transferring said rotary motion of said second shaft to said eighth gear through driving rotation of said sixth and seventh gears;

i. fifth means for generating an electric current when a shaft that forms a part thereof is rotated, said fifth means occupying a fixed position relative to said plate;

j. sixth means for connecting said shaft of said fifth means to said eighth gear to drive said shaft of said fifth means in a single direction as said first gear oscillates, with said seventh gear being of sufficient weight to act as a flywheel to minimize variations in the rate of rotation of said shaft of said fifth means; and

k. electrical conducting means through which an electrical current generated by said fifth means flows to charge storage battery means as a future source of stored electrical energy.

2. A device as defined in claim **4** that further includes:

1. a protective housing removably secured to said base to enclose said first to eighth gears inclusive and also serve as a support for said fifth means.

3. A define as defined in claim **4** in which said second means are a plurality of spaced uprights that occupy fixed positions relative to said base and secured thereto, with said plate removably secured to the ends of said upright most remote from said base.

4. A device as defined in claim 4 in which said weight is formed from a non-magnetic material to prevent the oscillation of said weight having an adverse effect on a compass that may be mounted on said structure.

5. A device as defined in claim 4 in which said third and fourth means are ratchet mechanisms.

6. A device as defined in claim 4 in which said fifth means is an alternator that includes a rotatable fourth shaft that is operatively connected to said eighth gear by said sixth means.

7. A device as defined in claim 4 in which said seventh gear is of sufficient size and weight to act as a flywheel and smooth out the rotational energy delivered by said seventh gear to said eighth gear due to the oscillation of said first gear.

8. A device for use in transforming the pitch and roll motion of a buoyant marine structure into storage battery contained electrical energy for future use, said device including:

a. a base;

b. first means for securing said base in a fixed position relative to said structure;

c. a rigid plate;

d. second means for holding said plate at a fixed elevation above said base and substantially parallel thereto;

e. first and second shafts normally disposed to said base and situated between said base and plate, said first shaft being a stub shaft supported from said base, and said second shaft having the end portions thereof rotatably supported by said base and plate;

f. first, second, third, fourth, fifth and sixth sheaves, said first, fourth and sixth sheaves rotatably supported on said first shaft and said second, third and fifth sheaves mounted on said second shaft, said third sheave keyed to said second shaft, and said fifth sheave being freely rotatable on said second shaft;

g. a ring gear supported from said first sheave;

h. a first gear mounted on said second shaft and in engagement with said ring gear; i. first, second, third and fourth endless belts, said first belt drivingly engaging said first and second sheaves, said second belt drivingly engaging said third and fourth sheaves, said third belt drivingly engaging said fourth and fifth sheaves, and said fourth belt drivingly engaging said fifth and sixth sheaves;

j. a non-magnetic weight eccentrically supported on said first sheave that oscillates said first sheave in opposite directions as said structure pitches and rolls;

k. third and fourth means interposed between said second shaft and said first gear and said second sheave for allowing said first gear and second sheave to rotate in first and second directions, but said third and fourth means permitting said first gear and second sheave to drive said second shaft only in a first direction when said second sheave and first gear rotate in said first direction, said second sheave rotating in said first direction when said first sheave so rotates, and said first gear rotating in said first direction when said first sheave rotates in a second direction due to the pitch and roll of said structure;

l. fifth means for generating an electric current when a shaft that forms a part thereof is rotated, said fifth means occupying a fixed position relative to said plate;

m. sixth means for connecting said shaft of said fifth means to said sixth sheave to drive said shaft of said fifth means in a single direction as the weight supporting first sheave oscillates and transmits rotary motion in a single direction through said second to fifth sheaves inclusive and said first gear to said sixth sheave;

n. storage battery means on said structure; and o. electrical conducting means through which electric energy generated by said fifth means flows to storage battery means on said structure for future use.

9. A device as defined in claim 8 that further includes:

p. a protective housing removably secured to said base to enclose said first and sixth sheaves inclusive, said first gear, and said first, second and third belts, and also serve as a support for said fifth means.

10. A device as defined in claim 8 in which said second means are a plurality of spaced uprights that occupy fixed positions relative to said base and secured thereto, with said plate removably secured to the ends of said uprights most remote from said base.

11. A device as defined in claim 8 in which said third and fourth means are ratchet mechanisms.

12. A device as defined in claim 8 in which said weight is formed from a non-magnetic material to prevent the oscillation of said weight having an adverse effect on a compass that may be mounted on said structure.

13. A device as defined in claim 8 in which said fifth means is an alternator that includes a rotatable shaft that is operatively connected to said sixth sheave by said sixth means.

* * * * *