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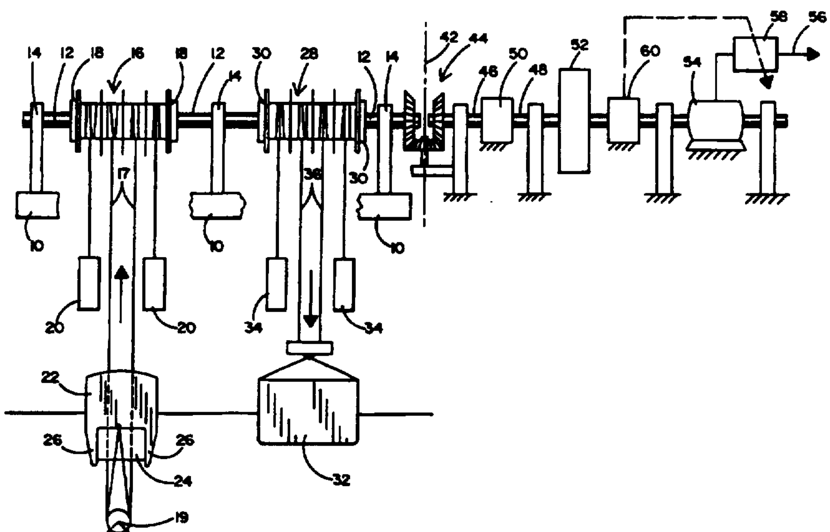

(57) Abstract

A wave power generator is substantially continuously driven by a pair of floats (22, 32) connected to a common drive shaft (12) and positioned side by side along a line perpendicular to the direction of wave motion (40), one float being specifically designed to efficiently drive the shaft during the rising portion of a wave, the other to efficiently drive the shaft during the falling portion of a wave. A flywheel (52) is maintained at a constant speed by an automatic load control throughout a range of wave patterns sufficient to encompass over 70% of the statistically expected wave patterns at the generator (54) location. An inclined-bottom float (22) is used for the rising wave drive, and a bottom-weighted float (32) is used for the falling wave drive. The floats (94, 96) may be disposed one above the other and may have mating conical surfaces (90, 92) for cushioning occasional contact between the floats.

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CUSHIONED DUAL-ACTION CONSTANT SPEED WAVE POWER GENERATOR

Field of the Invention

This invention relates to wave power generators, and more particularly to a double-action, constant-speed system which utilizes a maximum of the wave energy for power generation.

Statement of Related Cases

This case is a continuation-in-part of application Serial No. 590,121 filed 28 September 1990, which is itself a continuation-in-part of application Serial No. 453,049 filed 13 December 1989, now abandoned, which is itself a continuation-in-part of application Serial No. 885,864 filed 15 July 1986, entitled "Dual-Action Constant Speed Wave Power Generator", now abandoned, which in turn is a continuation-in-part of application Serial No. 614,459, filed 24 May 1984 and entitled "Wave Power Generator With Weighted Float", now abandoned.

Background of the Invention

Copending application Serial No. 590,121 and U.S. Patents Nos. 4,379,235 and 4,469,955 disclose two types of float systems specifically adapted to efficiently generate power during the fall of a wave and the rise of a wave, respectively. The drawback of both systems is that in each case, one half of the wave period is not used to drive the flywheel. As a result, not only does half the wave energy remain unutilized, but the flywheel has to be quite sizable to avoid excessive speed variations within long wave periods. Also, neither system is equally efficient with all types of waves, the system of copending application Ser. No. 590,121 being more efficient with shorter period waves, and the system of U.S. Patent No. 4,379,235 being more efficient with longer period waves.

The prior art has proposed using generator drive mechanisms which utilize both directions of movement of a float to generate power. This is not a good solution, however, because the drag produced by the power-generating load slows the travel of the float and prevents it from making a full stroke in either direction.

Another problem of the prior art was the inability of wave power generating systems to adequately accommodate the wide variety of wave heights and periods which occur in practice on both a daily and a seasonal basis.

Summary of the Invention

In one aspect of the invention, a float for falling-wave power is provided which has a lower, normally immersed portion filled with a relatively heavy substance such as water, or lead, and a normally floating portion filled, for example, with air. The combination of these two portions results in a float which is very stable yet responds very quickly to a rising wave front and remains essentially on top of the wave during its rapid rise. Then, when the wave recedes, the weight of the float does the work as the drag caused by the power generating load causes the float to rise at least partially out of the water.

In another aspect, the present invention makes full use of both the rising and falling movement of the wave by providing separate rising-wave and falling-wave drives for the generator flywheel. Each drive is idle during its return motion and is therefore capable of returning to the full extent of its stroke. In accordance with one embodiment of the invention, the system is adapted to be positioned so that the two floats are disposed along a line perpendicular to the wave front for maximum regularity of drive power.

In accordance with a further aspect of the invention, the flywheel transmission is so arranged that the wave heights and period necessary to produce rated flywheel rpm at full load (long-period, high waves) and rated flywheel rpm at minimum load (short-period, shallow waves) lie within a range encompassing the vast majority of the wave conditions statistically expected to be encountered at the location of the apparatus. Within this range, the invention provides automatic power output adjusting means to maintain the flywheel rpm essentially constant with varying wave patterns.

It is therefore the object of the invention to provide a highly efficient wave power generating system capable of effectively utilizing a wide range of wave patterns to produce alternating-current power at an essentially constant frequency.

In still another aspect of the invention, the efficiency of the float drive is enhanced by providing a mechanism which latches the descending float against descending movement when it reaches the crest of the wave, and then releases it when its weight reaches a predetermined amount as the wave recedes from beneath it. This arrangement makes it possible to utilize a greater portion of the static energy gathered by the float, because the float is not coupled to the flywheel drive below a certain minimum speed of descent, and the static energy released by any float movement below that speed is lost for power generation purposes.

Brief Description of the Drawings

Fig. 1 is a schematic front elevation of a wave power system constructed in accordance with the invention;

Fig. 2 is a plan view of the float arrangement of the system of Fig. 1;

Fig. 3 is a block diagram of the flywheel speed control used in the invention;

Fig. 4 is a vertical section of the preferred falling-wave float of Fig. 1;

Figs. 5a, b and c are vertical sections illustrating the operation of the float of Fig. 4;

Fig. 6 is a fragmentary, partially schematic elevational view of another embodiment of the invention; and

Fig. 7 is a fragmentary elevational view showing a specific float construction particularly adapted for use in the embodiment of Fig. 6.

Figs. 8a through 8c are schematic views illustrating the operation of an efficiency-enhancing addition to the system of Fig. 1; and

Fig. 9 is a time-amplitude diagram showing the effect of the apparatus of Figs. 8a-c.

Description of the Preferred Embodiments

Fig. 1 shows a wave power generating system according to this invention in somewhat schematic form. A platform 10 supports a drive shaft 12 in bearings 14. A drum 16 coaxial with the shaft 12 is connected to the shaft 12 by overrunning clutches 18 in such a way that the drum 16 drives the shaft whenever the drum 16 rotates under the influence of the pull of cable 17 which is looped over a sheave 19 attached to the ocean floor. The rising of float 22 pulls the cable 17. During the descent of float 22 on a falling wave, counterweights 20 keep the cable 17 taut.

The float 22 is preferably of the type described in my U.S. Patents No. 4,379,235 and 4,469,955, i.e. a body with a rearwardly inclined bottom surface 24 and guide flanges 26 which assist in maintaining the float 22 in a position facing the oncoming waves. The purpose of the inclined bottom surface 24 is to use the forward motion of the wave to increase the lift applied to the float 22.

A second drum 28 is coaxially mounted on drive shaft 12 and connected to it by overrunning clutches 30 in such a way as to drive the shaft 12 (in the same direction as drum 16) whenever the drum 28 is rotated by the descent of float 32. Counterweights 34 are provided on drum 28 to keep the cables 36 taut as float 32 rises.

It will be seen that the shaft 12 in this invention is driven essentially continuously: by float 22 during a rising wave, and by float 32 during a falling wave. The use of two floats with unidirectional drives rather than one float with a bidirectional drive has several advantages. For one, a float which must do work in both directions of movement never gets a chance to use the full height of the wave (for example, on a falling wave, the float, because of the drag of the drive shaft, will already encounter a new rise in the wave before it can reach the bottom of the wave trough); and for another, the use of separate rising and falling floats allows the use of the most efficient float construction for each of the rising and falling motions.

In order for floats 22 and 32 to drive the shaft 12 without overlap, it is necessary to dispose the two floats side by side along a line parallel to the wave fronts 38 (Fig. 2), i.e. perpendicular to the direction 40 of wave motion. For this purpose, it may be advantageous to journal the platform 10 for pivotal movement about an axis 42 (Fig. 1), or to pivot the entire system, so that varying directions of forward wave motion may be accommodated.

A bevel gear set 44 may be used to transmit rotation from the drive shaft 12 to a transmission shaft 46 which drives the flywheel shaft 48 through an appropriate transmission 50. A flywheel 52 fixedly mounted on shaft 48 is dimensioned to store sufficient energy to maintain the rotational speed of flywheel shaft 48 within a narrow tolerance of its rated speed as long as sufficient wave power is present.

Electrical power is produced in the system of this invention by an alternator 54 driven from flywheel shaft 48. In order to be compatible with a commercial power grid, the alternator 54 must run at a speed sufficiently constant to produce an output 56 at a frequency equal to the power grid frequency ±1 Hz.

Because wave power varies considerably from day to day and season to season, as hereinafter discussed in more detail, it is necessary to provide appropriate means for maintaining the speed of flywheel 52 constant regardless of the drive power produced by floats 22 and 32. This can be accomplished by slip clutches or other mechanical means, but those expedients are necessarily wasteful because the more energy is produced by the floats, the more is dissipated.

In accordance with the invention, a power output controller 58 is provided to regulate the amount of current (and hence power) which can be drawn by the commercial power grid from the alternator 54. The load controller 58 is itself controlled by a speed sensor 60 in an appropriate manner.

Fig. 3 shows one type of arrangement which may be used for load control. A timer 62 samples the output of speed sensor 60 at regular intervals (e.g. every 9 seconds) and loads the sample into a delay line 64 which is advanced one step by timer 62 at the same intervals. An accumulator 66 continuously provides an averaged value of a plurality of samples as the input signal to the load controller 58. The load controller 58 may limit the output current of alternator 54 continuously or in a stepped manner by any appropriate means well known to power engineers.

In accordance with the invention, the transmission 50 is so geared as to drive the flywheel 52 at at least the minimum acceptable speed with no electrical load under wave height and period conditions lying below the line 53 in Table I below. Wave conditions above the line 53 are too weak to produce usable power. The maximum power output of the alternator 54 is so chosen that the flywheel 52 will not exceed its maximum acceptable speed under the maximum reasonably expected wave height and period conditions.

Table I shows the statistical distribution of wave patterns by wave heights and periods at a typical offshore test location during a typical year.

TABLE I

Distribution of Occurrence

Wave Height In Feet	--------Wave Period in Seconds------------ 4-6	6-8	8-10	10-12	12-14	14-16	16-+
0- 1.64	.06%	.64%	.21%	.26%	1.43%	.41%	.06%
1.64- 3.28	10.59%	1.72%	.50%	1.43%	6.32%	1.78%	.24%
3.28- 4.92	17.82%	3.24%	.60%	.68%	3.12%	3.62%	.81%
4.92- 6.56	8.37%	9.89%	.58%	.20%	.56%	.96%	.84%
6.56- 8.20	.10%	11.39%	.32%	.04%	.10%	.26%	.44%
8.20- 9.84	Ø	5.74%	.07%	.07%	.03%	Ø	.09%
9.84-13.12	Ø	1.44%	2.27%	.01%	.04%	Ø	.03%
13.12-16.40	Ø	Ø	.51%	.01%	Ø	Ø	Ø
16.40-19.68	Ø	Ø	Ø	.06%	Ø	Ø	Ø
19.68-22.96	Ø	Ø	Ø	Ø	Ø	Ø	Ø
22.96- +	Ø	Ø	Ø	Ø	Ø	Ø	Ø

55 53

In a preferred embodiment, the system of this invention is designed to produce power in the wave conditions encompassed by the line 55 in Table I. It will be noted that approximately 70% of the wave patterns which can be statistically expected to occur in the course of a year can be used for power production, the remaining 30% being too weak to maintain the flywheel 52 within the rated speed range even with no electrical load. The small percentage of wave patterns in which the power output required to maintain the flywheel 52 is greater than the maximum power output of the alternator 54 is still usable for the production of power, but the excess power would then have to be dissipated by mechanical means. In the alternative, the system may be disconnected in the rare excessively high wave patterns.

The range of wave patterns capable of maintaining at least minimal rated flywheel speed with no load can be expanded by increasing the size of the floats or varying the transmission ratio; on the other hand, this causes overspeed conditions to occur earlier. The invention teaches that maximum efficiency with minimum equipment complexity can be obtained by proportioning the equipment to make use of the largest percentage of statistically expected wave patterns at the system location.

Fig. 4 shows the cross section of a preferred embodiment of the falling-wave float 32. The float 32 preferably includes a thick, corrosion-resistant water-tight casing 70 to which the cables 36 are attached by an appropriate securing device 72. The majority of the weight of the float is concentrated in its lower, normally submerged portion, and may consist, for example, of a layer of lead 74 and a volume 76 of liquid (preferably distilled water or oil to prevent internal corrosion). The weights 74 and 76 are so positioned within the body of the float 32 as to place its center of gravity below the water line in a position to provide maximum stability to the float 32. An air space 78 is provided within the float 32 above the weight layers 74, 76.

Figs. 5a through c illustrate the operation of the float 32 of this invention. In Fig. 5a, the float is shown in quiescent water. Because the weight of the float 32 is concentrated below the water line, it not only rides in a stable manner but its gross weight is also reduced by the volume of water it displaces.

In a rising wave front as shown in Fig. 5b, the float 32 rises with the wave, the submersion of the float 32 increasing only enough to provide the extra buoyancy necessary to accelerate the mass of the float 32 in an upward direction. Due to the action of overrunning clutches 30 (Fig. 1), the float 32 is operatively disconnected from the drive shaft 12 during its upward motion and therefore encounters no resistance therefrom. The wave is therefore able to freely lift the float 32 to its crest.

When the wave now recedes as shown in Fig. 5c, the float 32 begins to drop. As it does so, overrunning clutches 30 engage the drive shaft 12. It will be understood that the drive shaft 12 is loaded by the alternator 54 to rotate very slowly, i.e. at a speed slightly less than that dictated by the downward movement of the float 32 in synchronization with the receding wave of Fig. 5c. Consequently, the float 32 begins to rise out of the water as the wave recedes. As it does so, the weight portions of the float 32 are no longer supported by the wave, and the total weight of the float 32 pulls against the inertia of the drive shaft 12 and tries to accelerate it. By properly balancing the parameters of the apparatus, the float can be so adjusted as to utilize essentially the whole height of the wave, particularly if the wave has a sharp crest followed by a long trough.

Fig. 6 illustrates an alternative float arrangement which also provides the independent action of two opposing-direction floats detailed above in connection with Fig. 1. In the arrangement of Fig. 6, a gravity drive float 80 is disposed directly above a buoyancy float 82. The counterweighted drive cable 17 connects the buoyancy float 82 to the drum 16 of Fig. 1 after passing over cable guides 84, 86 mounted on a support structure 88 anchored on the ocean floor. Similarly, the counterweighted cable 36 connects the gravity drive float 80 to drive 28 as on Fig. 1.

The operation of the floats in the embodiment of Fig. 6 is as follows: During the rising part of the wave, the gravity drive float 80 moves rapidly upward because it is not doing any work during its upward motion. At the same time, the buoyancy float 82 rises slowly because of the load imposed upon it by the flywheel 52 (Fig. 1). During this period, the vertical separation between the floats 80, 82 increases.

As the wave crests and begins to fall, the gravity drive float 80 goes into the working mode and descends slowly. As the buoyancy float 82 is still submerged, it continues to rise, and for a short time, the floats 80, 82 move toward each other. However, because the gravity drive float 80 is unable to follow the rapid fall of the wave, it comes out of the water. When the wave level reaches and passes the level of the buoyancy float so that it surfaces, the buoyancy float 82 ceases doing work and descends rapidly with the wave, again increasing the distance between the floats. The reverse situation occurs as the wave once again starts to rise.

Because ocean waves are not of uniform height and usually come in sets of a large wave followed by several smaller ones, the floats 80, 82 will occasionally move in such a way as to contact each other. However, as best shown in Fig. 7, the hydraulic action of the water between them can be utilized to cushion such a contact, and the frequency and duration of the contacts is usually small enough not to interfere with the operation of the floats 80, 82.

Where contacts are a problem, the float construction of Fig. 7 is advantageous. The flat mating surfaces of floats 80, 82 as shown in Fig. 6 are susceptible to meet without adequate cushioning if the floats 80, 82 become slightly tilted with respect to each other. By contrast, the concavo-convex shape of the mating surfaces 90, 92 of floats 94, 96 in Fig. 7 tend to move them into alignment due to the hydraulic action of the water as it exits from between the surfaces 90, 92 as the floats 94, 96 approach each other. The surfaces 90, 92 may be conical or pyramidal in shape without departing from the invention.

In practice, the arrangement of Fig. 6 may be advantageous in some situations because it requires a smaller platform than the embodiment of Fig. 1 and is not sensitive to wave direction.

Figs. 8 and 9 illustrate a way in which the structures of Figs. 1, 2 and 4 through 7 (or, for that matter, any gravity float) can be enhanced to provide substantially more drive power by increasing their efficiency. In accordance with the invention, this is accomplished by holding the gravity float after the cresting of the wave, in its topmost position until it is almost completely out of the water, and then allowing it to free-fall into its normal floating position.

The mathematical rationale for this is as follows: If the float shaft 12 in Fig. 1 rotates at a speed w, and the wave motion is sinusoidal (which it typically is), then there will be a certain distance h_F through which the gravity float has to drop before the wave is dropping fast enough for the overrunning clutch 30 to engage anbd deliver drive power to the shaft 12.

The motion of the float 32 can bve expressed by the equation

$$h_w = h_F + h_D + h_{drop}$$

in which h_w is the wave height;

h_D is the draft of the float;

h_F is the distance the float drops slower than w; and

h_{drop} is the distance the float tries to drop faster than w.

Inasmuch as h_w and h_d are constants, h drop (the distance through which the fall of the float 32 does usable work) can be maximized only by minimizing h_F.

In accordance with the invention, h_F is minimized by latching the float 32 against downward movement, once it has reached the crest of the wave, until its weight, no longer reduced by buoyancy, becomes sufficient to release the latch.

A suitable mechanism for accomplishing this purpose is schematically shown in Figs. 8a-c. A ratchet gear 100 is carried by the drum 28 and rotates therewith. A lever 102 pivoted at 104 on a support 106 is biased into a generally horizontal position in Fig. 8a by a spring 108. An electromagnet 110 connected to a power source 112 through a switch 114 operated by a motion sensor 116 is provided for a purpose hereinafter described.

The strength of the spring 108 is such that it holds the lever 102 in a position to normally prevent rotation of the drum 28 in a counterclockwise direction. However, as the wave level drops while the drum 28 prevents the float 32 from falling with it, the weight of the float 32 increases, and the teeth of the drum 28 start pushing the lever 102 downward against the bias of spring 108. Eventually, the lever 102 is pushed far enough toward the electromagnet 110 for its magnetic field to capture the lever 102 and draw it against the armature 118 of electromagnet 110 (Fig. 8b). The drum 28 is thereby released and can turn freely. The float 32, being now essentially suspended in air, almost instantly accelerates to a free-fall velocity great enough to positively drive the shaft 12. By the time the float 32 resumes its normal floating position, the wave level is falling rapidly enough to maintain the driving relationship of shaft 12 until the float 32 reaches the trough of the wave.

The motion sensor 116, which may be any of a number of devices commercially available for that purpose, detects the direction of motion of the drum 28. As soon as the wave starts rising again, and the motion of the drum 28 becomes clockwise, the motion sensor 116 operates switch 114 to de-energize electromagnet 110 and release lever 102 until the next fall of the wave causes the drum 28 to resume counterclockwise movement. During the clockwise movement of drum 28, the lever 102 simply ratchets on the teeth of drum 28 (Fig. 8c).

Fig. 9 illustrates the operation of the invention. If the float 32 simply follows the sinusoidal movement of the wave120, and if the shaft 12 speed w is such that the float 32 can do work only when its rate of fall is steeper than the slope 122, the only usable static energy of the float usable for power production is the mass of the float 32 times h_{dr1}. On the other hand, if the float 32 is held until time t_r when it is essentially out of the water, the usable energy is the float mass times h_{dr2}. The percentage of energy utilization improvement achieved by the invention depends upon the shaft speed w and the periodicity of the wave (i.e. the steepness of its sides), but in a typical ocean installation for the generation of commercial power, the improvement would be on the order of 20%.

It will be seen that the present invention provides a highly effective wave power generating system which affords maximum utilization of the statistically expected wave patterns at any given location.

CLAIMS

1. A wave power generating system, comprising:

a) a platform positioned over a body of water exhibiting wave motion;

b) a drive shaft mounted on said platform;

c) first float means for driving said draft shaft only during the rising portion of a wave;

d) second float means for driving said drive shaft only during the falling portion of a wave;

e) a flywheel operatively connected to said drive shaft to be driven thereby; and

f) generating means operatively connected to said flywheel for generating electrical power when driven by said flywheel;

g) said first and second float means being positioned side by side along a line substantially perpendicular to the motion of the waves so as to drive said flywheel with maximum regularity and without overlap in order to achieve a substantially constant operating speed for said generating means;

h) whereby the constancy of speed necessary for commercially usable power generation is achieved with a substantially less massive flywheel.

2. The system of Claim 1, in which said first float means include an inclined bottom surface so oriented as to derive life from the forward motion of said wave, and said second float means has a substantial majority of its weight concentrated in its lower half.

3. The system of Claim 1, further comprising:

i) load controller means for controlling the amount of electrical power generated by said generating means;

j) speed sensing means operatively connected to said flywheel for sensing its speed; and

k) control means connected to said speed sensing means and said load controller means for varying the power output of said generating means in such a manner as to maintain the speed of said flywheel substantially constant.

4. The system of Claim 3, in which said generating means is an alternator, and said flywheel maintains the output of said alternator at a substantially constant frequency.

5. A wave power generating system, comprising:

a) a platform positioned over a body of water exhibiting wave motion, said wave motion exhibiting variable wave heights and wave periods forming a plurality of wave patterns, each of said patterns having a statistical probability of occurrence in said body of water;

b) a drive shaft mounted on said platform;

c) first float means for driving said drive shaft only during the rising portion of a wave;

d) second float means for driving said drive shaft only during the falling portion of a wave, said first and second float means being positioned side by side along a line substantially perpendicular to the motion of the waves;

e) a flywheel operatively connected to said drive shaft to be driven thereby;

f) generating means operatively connected to said flywheel for generating electrical power when driven by said flywheel;

g) load controller means for controlling the amount of electrical power generated by said generating means;

h) speed sensing means operatively connected to said flywheel for sensing its speed; and

i) control means connected to said speed sensing means and said load controller means for varying the power output of said generating means in such a manner as to maintain the speed of said flywheel substantially constant;

j) said generating means being an alternator, and said flywheel maintaining the output of said alternator at a substantially constant frequency;

k) said flywheel having a narrow allowable speed range, the speed of said flywheel being a function of wave height, wave period, and alternator load; and

l) the range of wave heights and periods lying between the minimum height and maximum period required to drive said flywheel at the minimum allowable speed with no load, and the maximum heights and minimum period required to drive said flywheel at the maximum allowable speed with maximum load, encompassing in excess of 70% of the statistically expected wave patterns at the location of the system.

6. The system of Claim 1, in which said second float means include:

a) a body having an upper portion and a lower portion;

b) weight means in said lower portion sufficient to concentrate the bulk of the weight of said float in said lower portion; and

c) suspension means attached to said upper portion for floatingly suspending said float in a body of water.

7. The system of Claim 6, in which said suspension means are operatively connected to power generating apparatus in such a manner as to allow said float to rise freely during the rising portion of a wave, but to drive said power generating apparatus by virtue of its weight during the falling portion of a wave.

8. A wave power generating system, comprising:

a) a platform positioned over a body of water exhibiting wave motion;

b) a drive shaft mounted on said platform;

c) first float means for driving said drive shaft only during the rising portion of a wave;

d) second float means independent ofsaid first float means for driving said drive shaft only during the falling portion of a wave;

e) a flywheel operatively connected to said drive shaft to be driven thereby; and

f) generating means operatively connected to said flywheel for generating electrical power when driven by said flywheel;

g) said first and second float means being positioned in substantially vertical alignment with each other so as to drive said flywheel with maximum regularity in order to achieve a substantially constant operating speed for said generating means;

h) whereby the constancy of speed necessary for commercially usable power generation is achieved with a substantially less massive flywheel.

9. The wave power generating system of Claim 8, in which said first and second float means have mating

concavo-convex surfaces facing each other, whereby the water entrapped therebetween cushions contacts between said first and second float means.

10. The wave power generating means of Claim 9, in which said mating surfaces are conical in shape.

11. The wave power generating means of Claim 10, in which the mating surface of the upper float is convex and the mating surface of the lower float is concave.

12. A float arrangement for converting wave motion into work, comprising:

a) a pair of floats disposed substantially coaxially with each other, said floats being disposed for movement toward and away from each other in a fluid in response to wave motion in said fluid, said floats being capable of contacting each other at times during said movement;

b) said floats having mating surfaces facing each other, one of said mating surfaces being concave and the other convex,

c) whereby the fluid between said surfaces tends to cushion said contact while tending to coaxially align said floats with each other as they enter into contact with each other.

13. A method of enhancing the efficiency of a generating system powered by a float riding on substantially sinusoidal waves, in which said float drives

a continuously rotating shaft during a portion of its descending motion, comprising the steps of:

a) preventing said float from descending after reaching the crest of the wave, and

b) releasing said float for descent when its weight reaches a predetermined amount due to its reduced submergence.

14. The method of Claim 13, in which said float is released into a substantially free-fall condition.

15. Apparatus for enhancing the efficiency of a generating system powered by a float riding on substantially sinusoidal waves, in which said float drives a continuously rotating shaft during a portion of its descending motion, comprising:

a) a coupling mechanism arranged to couple said float to said shaft in driving relationship when, and only when, the speed and direction of movement of said float is sufficient to enable said float to increase the speed of rotation of said shaft;

b) a latching mechanism responsive to said float reaching its highest position at the crest of a wave for latching said float against descending movement; and

c) a release mechanism responsive to said float attaining a predetermined weight as a result of the wave falling away from it for releasing said float for descending movement.

16. The apparatus of Claim 15, in which said release mechanism releases said float for substantially free-fall movement.

AMENDED CLAIMS

[received by the International Bureau on 24 July 1995 (24.07.95); original claims 13-18 cancelled; remaining claims unchanged (1 page)]

concavo-convex surfaces facing each other, whereby the water entrapped therebetween cushions contacts between said first and second float means.

10. The wave power generating means of Claim 9, in which said mating surfaces are conical in shape.

11. The wave power generating means of Claim 10, in which the mating surface of the upper float is convex and the mating surface of the lower float is concave.

12. A float arrangement for converting wave motion into work, comprising:

a) a pair of floats disposed substantially coaxially with each other, said floats being disposed for movement toward and away from each other in a fluid in response to wave motion in said fluid, said floats being capable of contacting each other at times during said movement;

b) said floats having mating surfaces facing each other, one of said mating surfaces being concave and the other convex,

c) whereby the fluid between said surfaces tends to cushion said contact while tending to coaxially align said floats with each other as they enter into contact with each other.

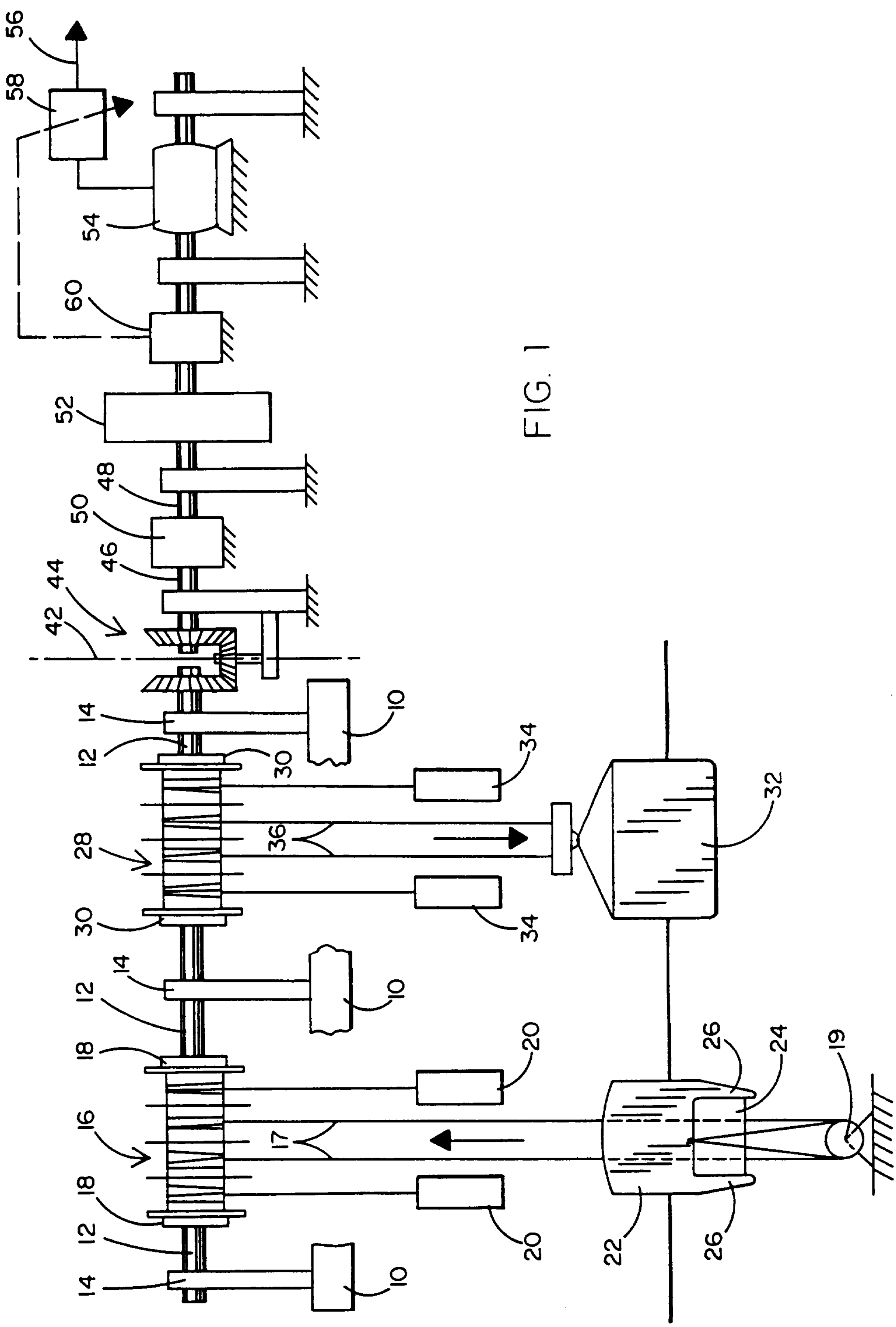
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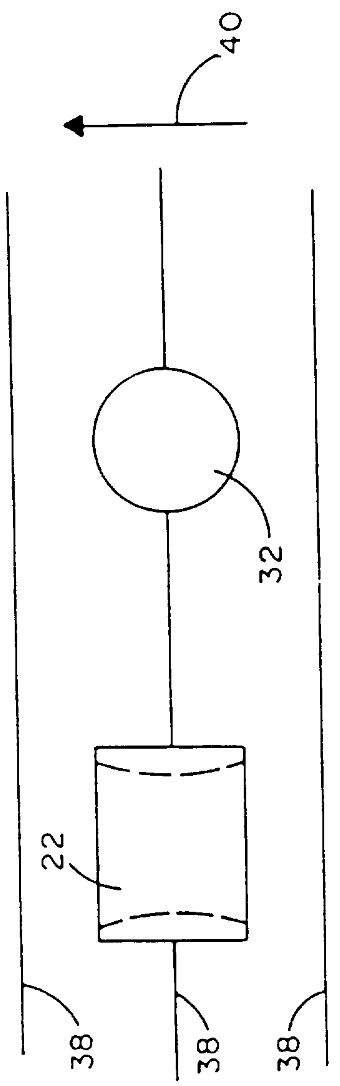
FIG. 1

FIG. 2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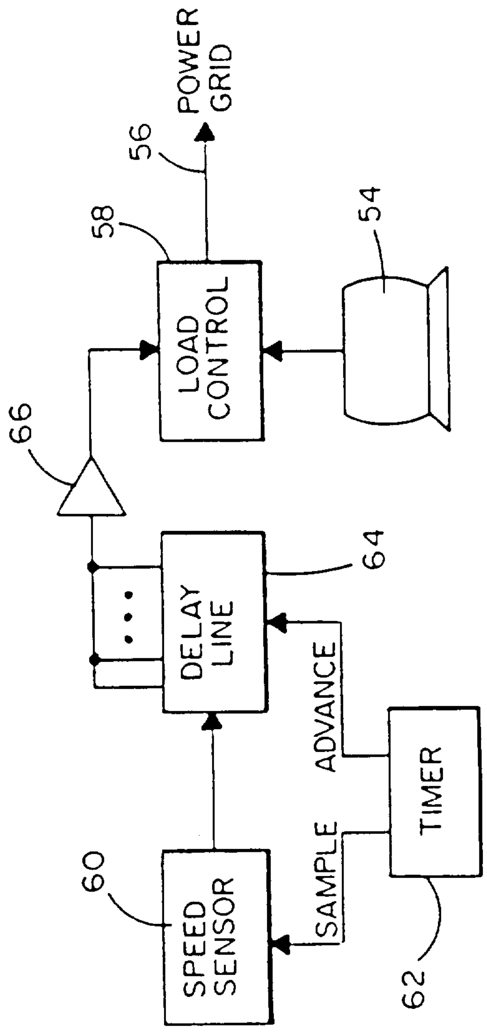
38

FIG. 3


POWER GRID
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58
54
LOAD CONTROL
66
DELAY LINE
64
ADVANCE
TIMER
SAMPLE
60
SPEED SENSOR
62

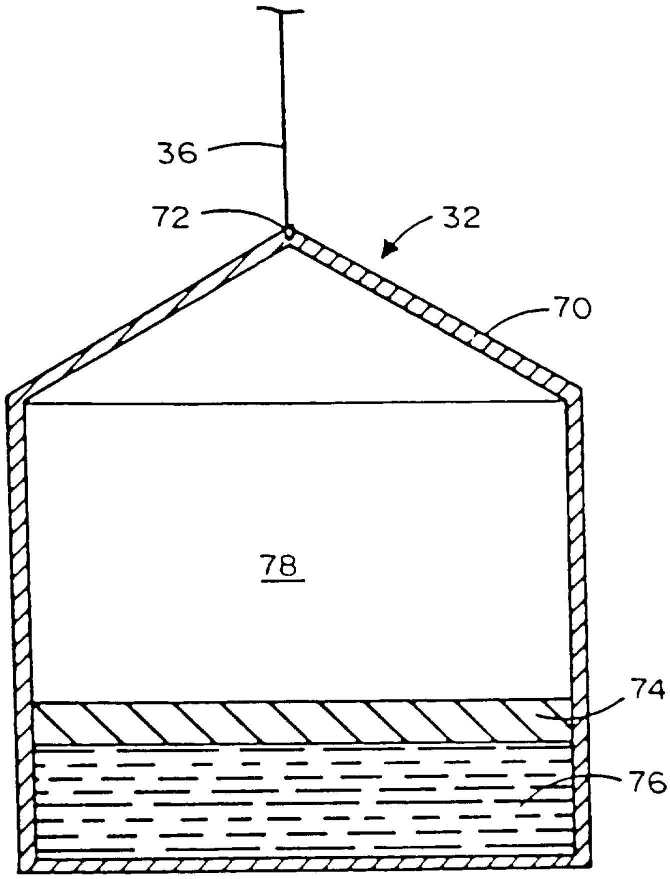


FIG. 4

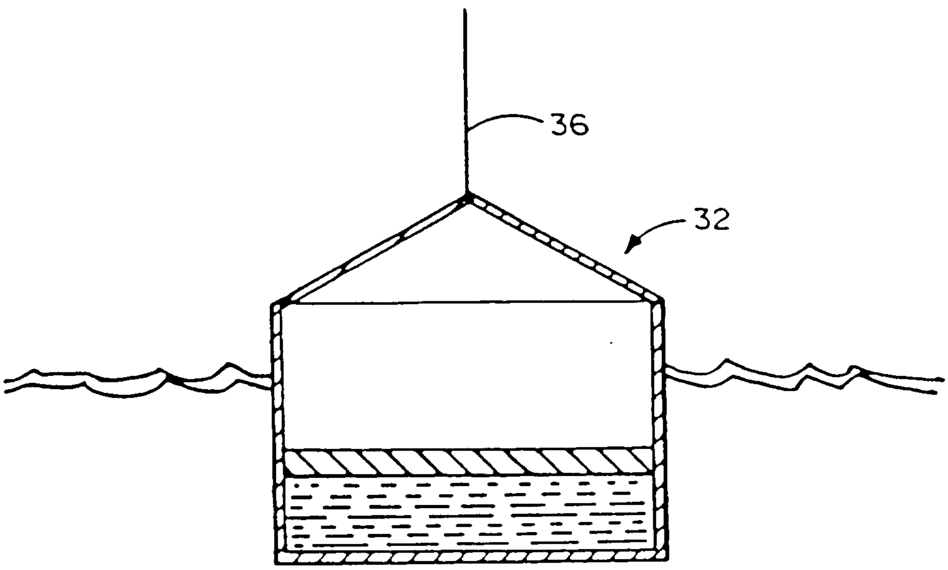


FIG. 5a

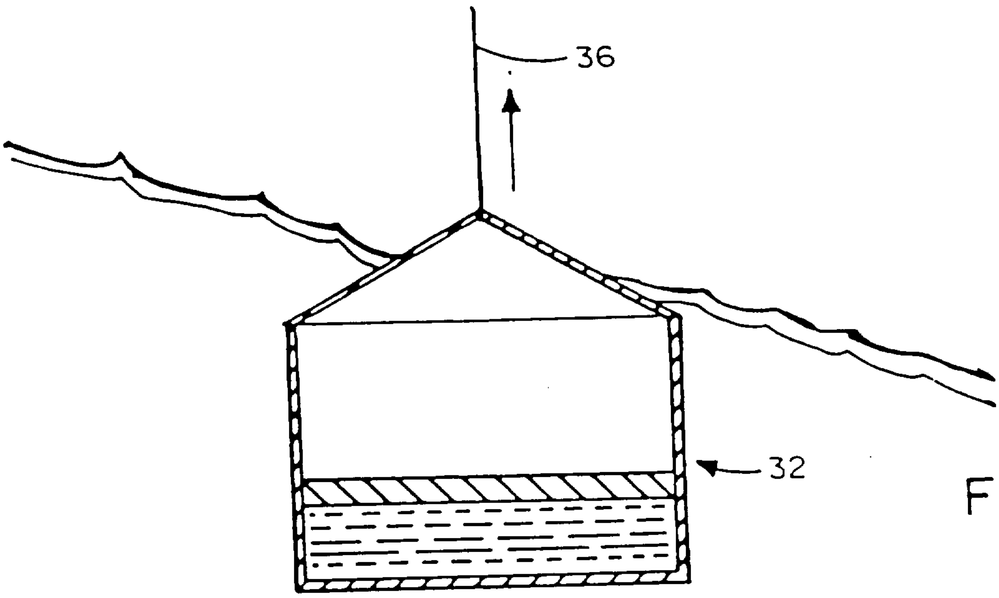


FIG. 5b

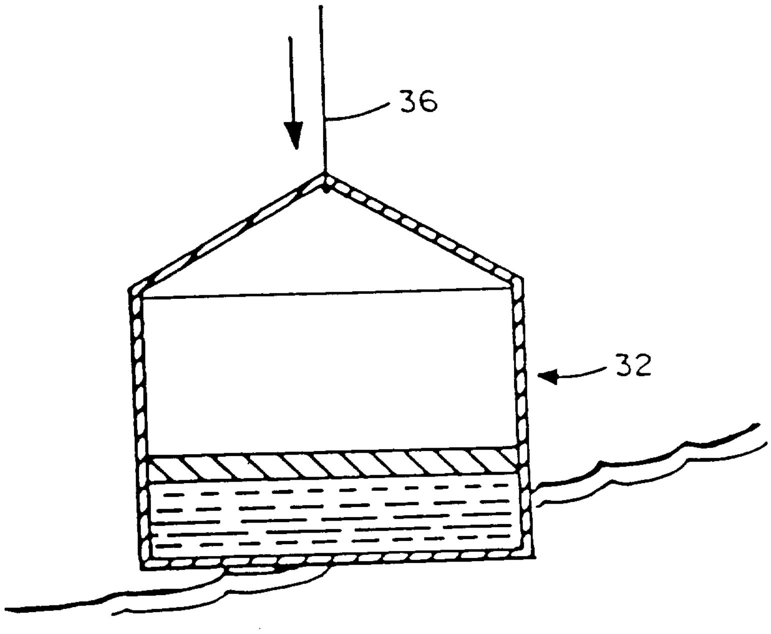


FIG. 5c

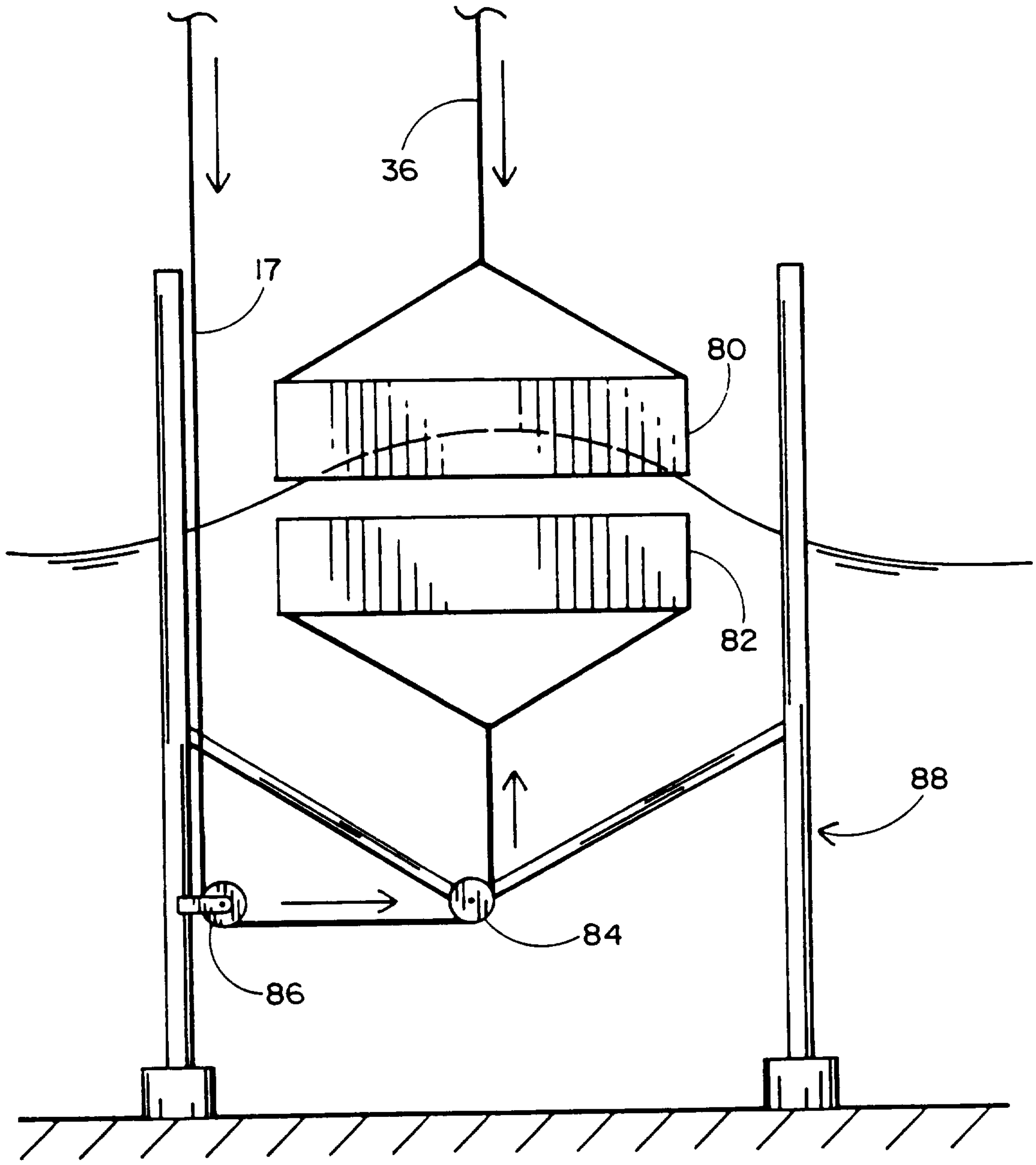


FIG. 6

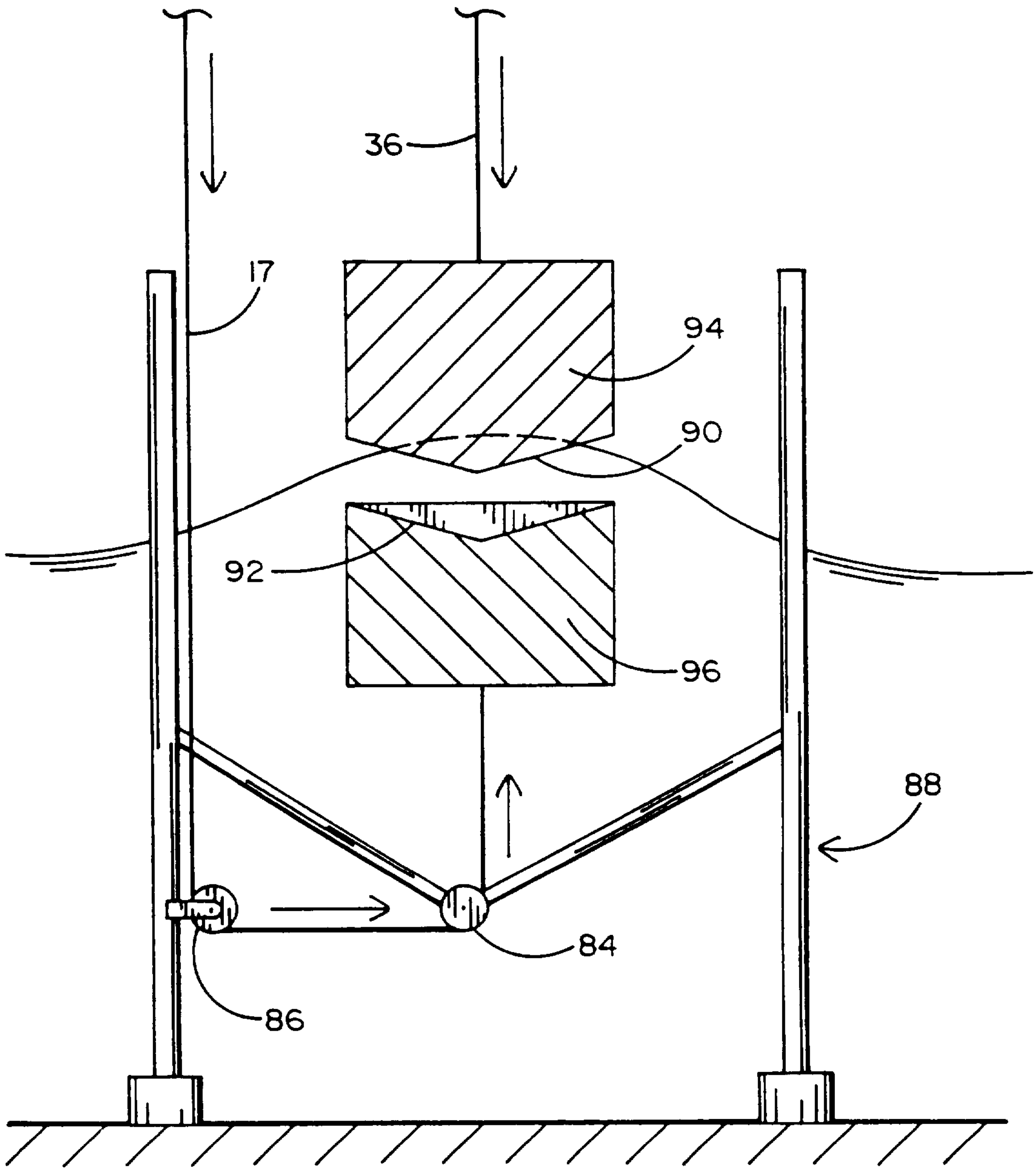


FIG. 7

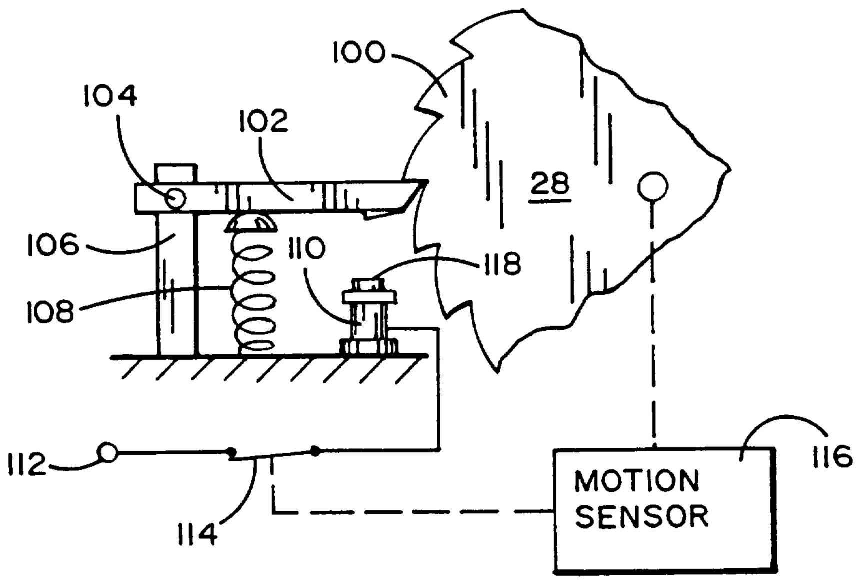
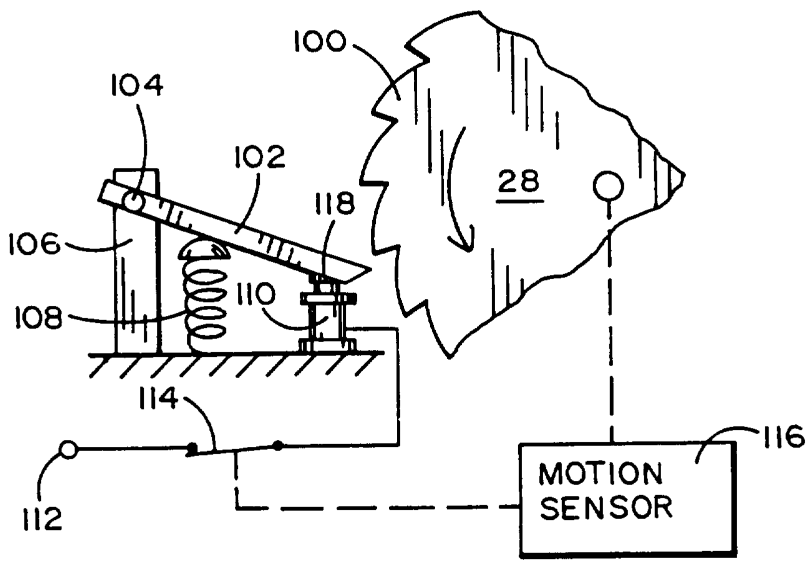

100
104
102
28
106
110
118
108
112
114
MOTION SENSOR
116

FIG. 8a


100
104
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28
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108
114
112
MOTION SENSOR
116

FIG. 8b

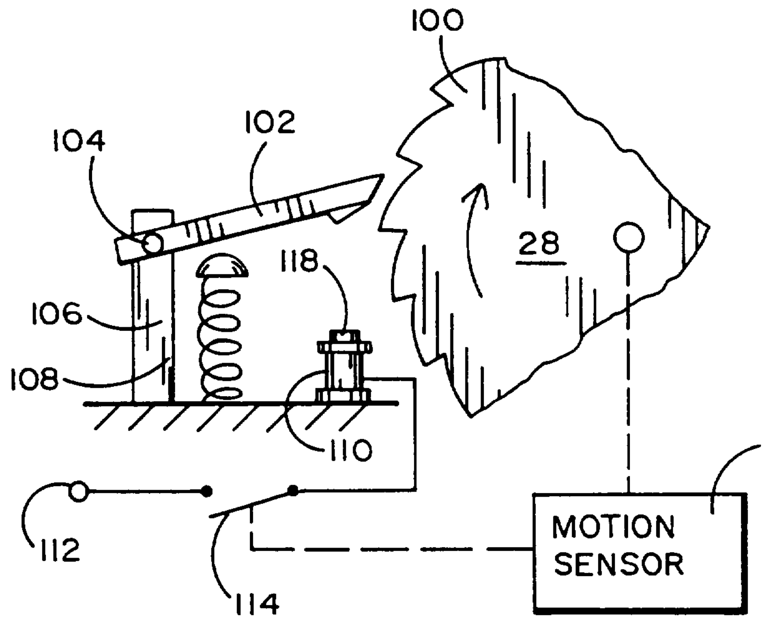
100
102
104
28
118
106
108
110
116
MOTION
SENSOR
112
114

FIG. 8c

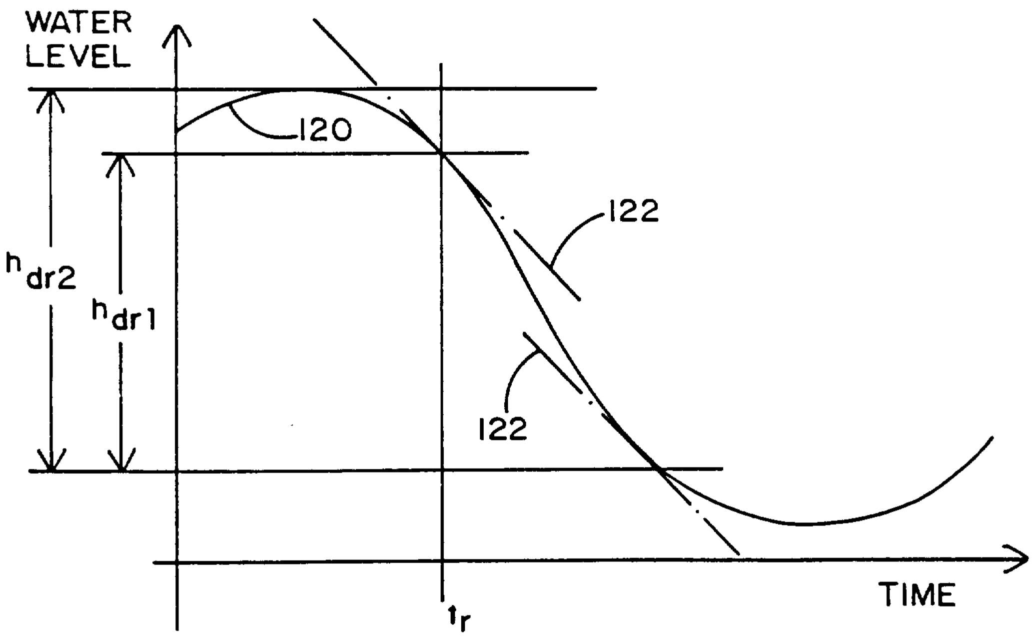
WATER
LEVEL
120
122
h_{dr2}
h_{dr1}
122
t_r
TIME

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/03693

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :F03B 13/12, 13/14
US CL : 60/503, 507; 290/53
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 60/503, 507; 290/53

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 366,768, (Elias), 19 July 1887 See entire document	1-16
Y	US, A, 3,668,412, (Vrana et al), 06 June 1972 See entire document	14-16
A	US, A, 4,145,885, (Solell), 27 March 1979 See entire document	1-16
A	US, A, 4,379,235, (Trepl, II), 05 April 1983 See entire document	1-16

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
08 MAY 1995	01 JUN 1995
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer STEVEN STEPHAN Telephone No. (703) 308-2826

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US95/03693

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4,469,955, (Trepl, II), 04 September 1984 See entire document	1-16
X --- Y	US, A, 4599,858, (La Stella et al), 15 July 1986 See entire document	13 --- 14-16
A	US, A, 4,718,231, (Vides), 12 January 1988 See entire document	1-16
A	FR, A, 2,339,071, (Comte), 23 September 1977 See entire document	1-16
A	Nature Magazine, Volume 249, issued 21 June 1974, S.H. Salter, "Wave Power," pages 720-724. See entire article.	1-16

(12) UK Patent Application (19) GB (11) 2 440 154 (13) A

(43) Date of A Publication 23.01.2008

(21) Application No: **0616692.0**

(22) Date of Filing: **23.08.2006**

(30) Priority Data:
(31) **0614210** (32) **18.07.2006** (33) **GB**

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RM3 9YU, United Kingdom

(51) INT CL:
F03B 13/18 (2006.01)

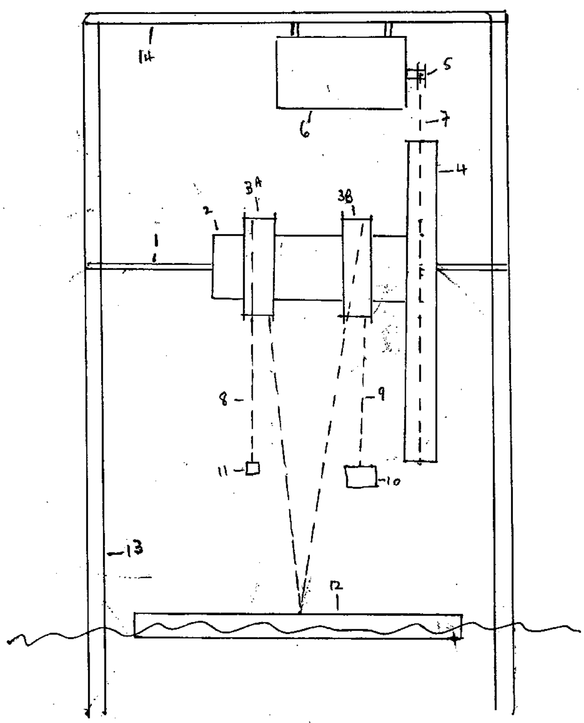
(52) UK CL (Edition X):
F1S S28B1

(56) Documents Cited:
GB 2408075 A
GB 0202709 A
DE 003409325 A1
GB 0244418 A
WO 1996/030646 A1

(58) Field of Search:
INT CL **F03B**
Other:

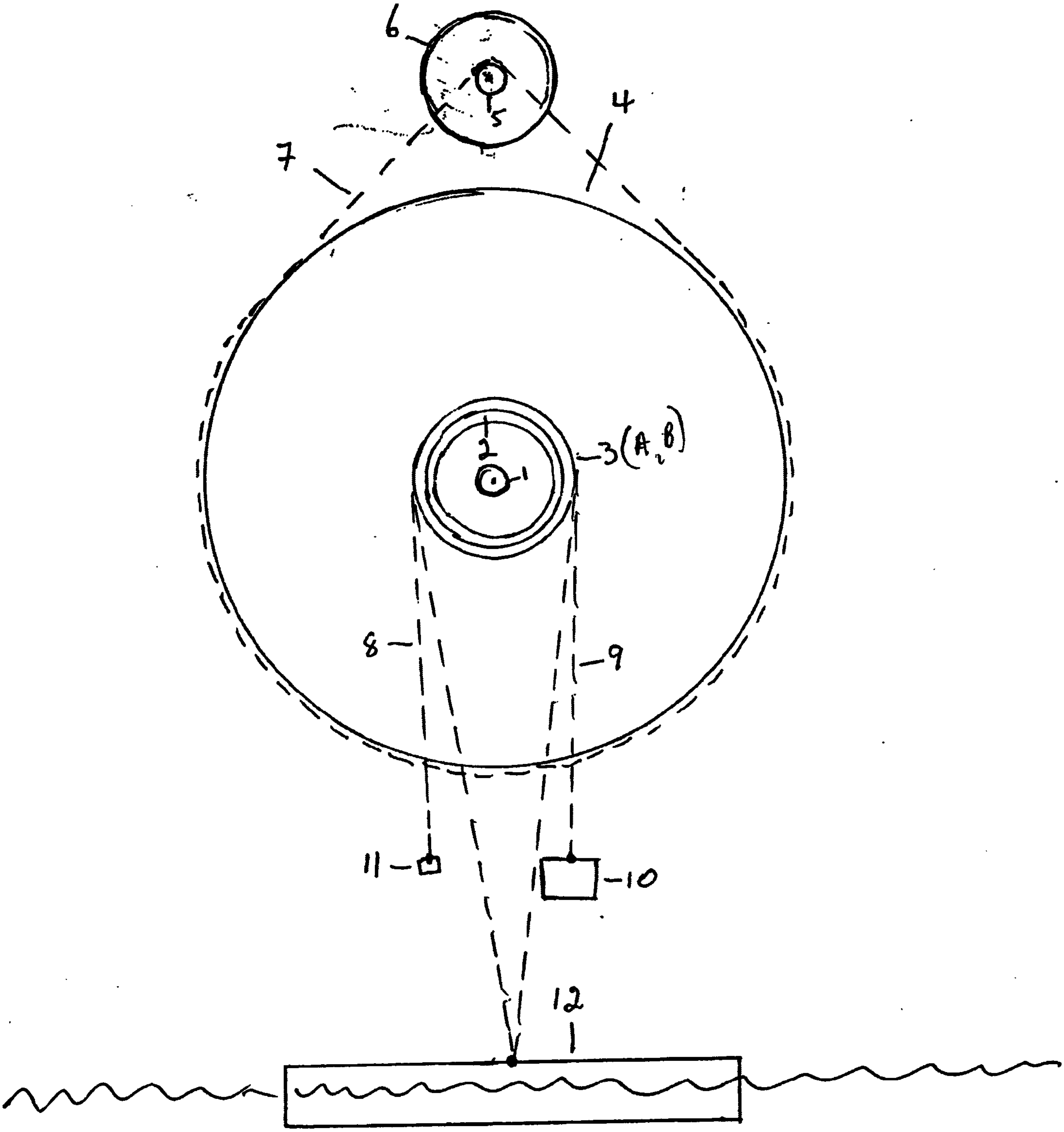
(54) Abstract Title**: Wave generator with ratchet to convert wave motion to unidirectional rotation**

(57) A wave powered energy conversion device has a float 12 and converts the wave motion to unidirectional rotary motion by pulling up weights 10 and 11, attached to cords 9 and 8 over ratcheted wheels 3B and 3A respectively. Wheel 2, 4 is therefore turned clockwise by both upwards and downwards movement of the float, and drives generator 6 with belt 7. The axle 1 is supported on vertical posts 13 fixed to sea bed, and permanent magnet generator 6 is fixed on a cross member 14 supported on top of posts 13 (figure 1).

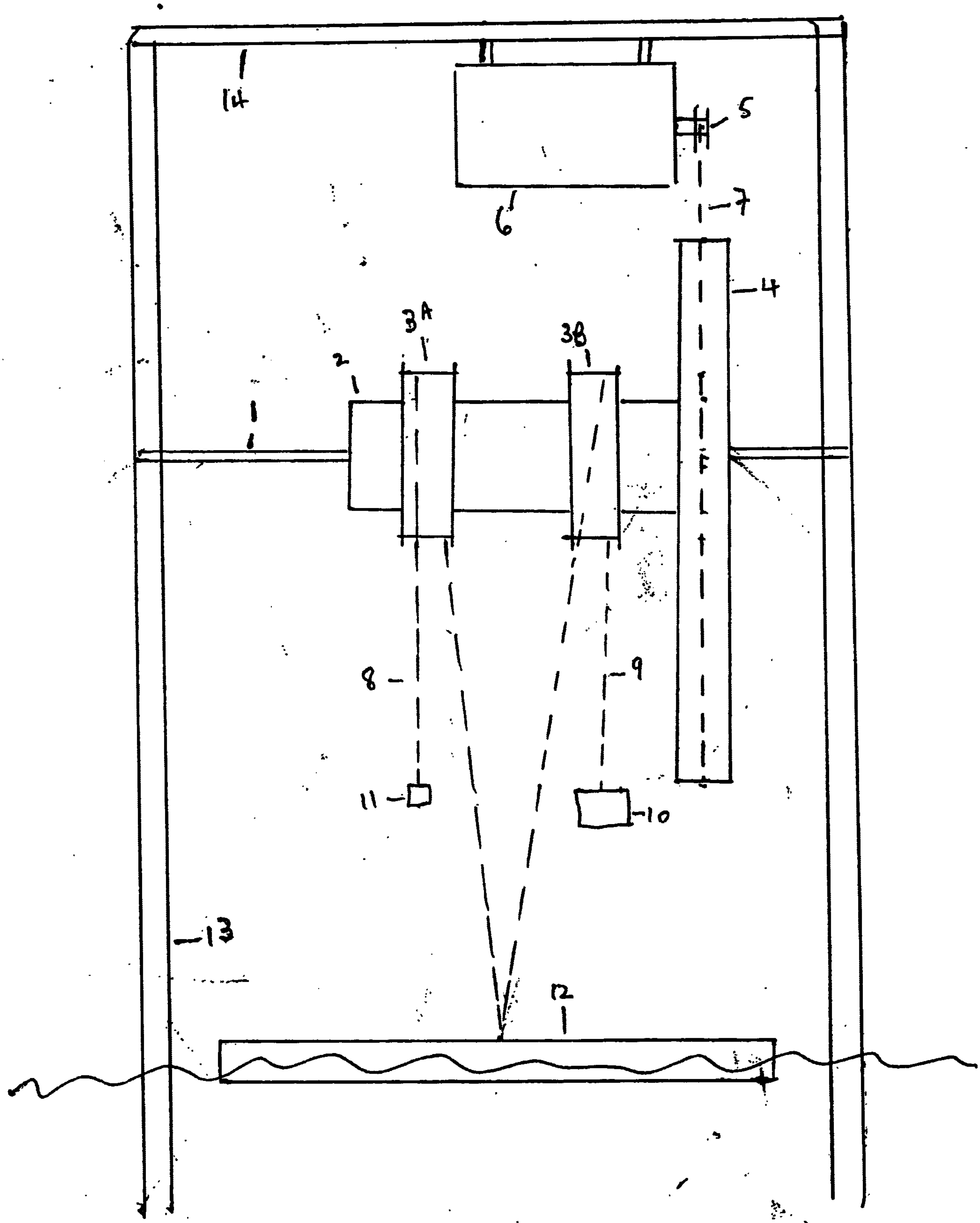


GB 2 440 154 A

DRAWING 1/2



DRAWING 2/2



DESCRIPTION

TIDES AND WAVES POWERED ELECTRICITY GENERATOR

The invention relates to a tides and waves powered electricity generator, which includes a generator, sea tides, waves and weights mounted on posts fixed anywhere convenient, to sea bed.

Tides and waves powered electricity generators are known, but suffer from the disadvantage of complicated and expensive energy conversion process, that can be installed at only few selected sites.

An object of this invention is to provide a unique Energy Conversion Device for converting tides and waves motion directly to rotary motion to turn a generator.

Accordingly, this invention provides a tides and waves powered electricity generator including two posts fixed to sea bed , an energy conversion device, using wheels with weights, float and cords, mounted on the posts.

A preferred embodiment of the invention will now be described with reference to the two accompanying drawings in which:

I. DRAWING 1/2 shows a front view of the tides and waves powered electricity generator.

II. DRAWING 2/2 shows a lateral view of the tides and waves powered electricity generator.

III. As shown in Drawing 2/2, the tides and waves powered electricity generator comprises two vertical posts (13) and a transverse post (14) fixed to the vertical posts. A permanent magnet, direct current generator (6) is fixed to the transverse post, with the pulley (5) directly above the large wheel (4) of the Energy Conversion Device.

IV. As shown in Drawings 1/2 and 2/2 the Energy Conversion Device comprises of wheel (2) and wheel (4) forming one wheel with axle (1) fixed to the vertical posts (13).

V. Wheel (3A) and wheel (3B) are identical ratcheted wheels fixed on wheel (2) such that each always rotates with wheel (2) and wheel (4) clockwise but each can rotate freely anti-clockwise

VI. Cord (8) with one end attached to the centre of weight (12) and the other end attached to weight (11) passes over wheel (3A) acting as a pulley, such that weight (12) acts a clockwise pull on wheel (3A) going down.

DESCRIPTION

VII. Cord (9) with one end attached to the centre of weight (12) and the other end attached to weight (10) passes over wheel (3B) acting as a pulley, such that weight (10) acts a clockwise pull on wheel (3B) going down.

VIII. Belt (7) acts on wheel (4) and pulley (5)

IX. Weight (10) is heavy enough to turn wheel (2), wheel (3B), wheel (4) and pulley (5) clockwise, going down, due to gravity.

X. Weight (11) is heavy enough to turn wheel (3A) anti-clockwise and keep cord (8) taut, going down, due to gravity.

XI. Weight (12) floats on the sea surface, and is heavy enough to pull up both weight (10) and weight (11),turn wheel (3B) anticlockwise and turn wheel (2), wheel (3A), wheel (4) and pulley (5) clockwise, all at the same time, going down.

XII. Once the installation of the tides and waves powered electricity generator and the Energy Conversion Device is complete, the motion of the tides and waves falling downward, will make the floating weight (12) go downward with them which will turn the generator clockwise(XI). And when the motion of the tides and waves rise upward, weight (10) will turn the generator clockwise(IX)

However the motions of the tides and waves, the Energy Conversion Device will continue to turn the generator, which will continue to produce electricity.

CLAIMS

1. A tides and waves powered electricity generator comprising two vertical posts fixed to seabed, supporting a transverse post holding a permanent magnet generator driven by a belt passing around a large wheel joint to a smaller wheel on the same axle, part of an energy conversion device having two ratcheted wheels rotating around the smaller wheel, mounted on the vertical posts and cords wrapped over the ratcheted wheels attached to hanging weights at one end and to a float on sea surface at the other end, to turn the generator to produce electricity.

2. A tides and waves powered electricity generator as claimed in Claim 1 wherein an energy conversion device means is provided, with its axle supported on the vertical posts fixed to sea bed, to convert the motion of the tides and waves into unidirectional rotary motion and transmit the tides and waves energy to turn the generator and produce electricity.

3. A tides and waves powered electricity generator as claimed in Claim 1 or Claim 2 wherein ratcheted wheel means is provided, as part of the energy conversion device to turn the generator in a unidirection.

4. A tides and waves powered electricity generator as claimed in Claim 2 or Claim 3 wherein cords means is provided, as part of the energy conversion device, wrapped over the ratcheted wheels for turning the ratcheted wheels and the generator.

5. A tides and waves powered electricity generator as claimed in Claim 2 or Claim 3 or Claim 4 wherein weights means is provided, as part of the energy conversion device, attached to the cords for turning the ratcheted wheels and the generator.

6. A tides and waves powered electricity generator as claimed in Claim 3 or Claim 4 or Claim 5 wherein float means is provided, as part of the energy conversion device, on the tides and waves attached to the cords for turning the ratcheted wheels and the generator.

7. A tides and waves powered electricity generator substantially as herein described above and illustrated in the accompanying drawings.

The Patent Office

For innovation

Application No: GB0616692.0 **Examiner:** Peter Middleton

Claims searched: 1-7 **Date of search:** 20 February 2007

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	1-6	WO96/30646 A1 (WORLD ENERGY) see abstract and figures: arrangement of wave energy device to turn shaft on rising and falling movements
X	1-6	DE3409325 A1 (GRAVEMEYER) see figures and WPI abstract accession number 1985-237586 [39]: weight connected to shaft by several cables and freewheels
X	1-6	GB244418 A (VODENITCHAROFF) see figures: different sized weights to generate power and to merely keep rope taut
X	1-6	GB2408075 A (UNIVERSITY OF MANCHESTER) see figures: float and counterweight drive shaft via freewheel connection
X	1-6	GB202709 A (GIACCHI) see figures: float and counterweight drive shaft via freewheel connection

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

F03B

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

Online: WPI, EPODOC

(12) UK Patent Application (19) GB (11) 2 408 075 (13) A

(43) Date of A Publication 18.05.2005

(21) Application No: **0324183.3**

(22) Date of Filing: **16.10.2003**

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Alan Charles Williamson
Nicholas Jenkins

(74) Agent and/or Address for Service:
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STOCKPORT, Cheshire, SK3 0ET,
United Kingdom

(51) INT CL^7:
F03B 13/18

(52) UK CL (Edition X):
F1S S28B1

(56) Documents Cited:
GB 1522661 A **WO 1989/007197 A**
JP 2000154774 A **US 4599858 A**

(58) Field of Search:
UK CL (Edition X) **F1S**
INT CL^7 **F03B**
Other: **EPODOC, WPI**

(54) Abstract Title: **Device for utilising wave energy**

(57) Apparatus for extracting energy from waves comprises a float device 10 coupled to a shaft 16 such that vertical movement of the float devices drives the shaft. Movement of the float device 10 is generated by the wave motion, and the mass of the float device is such that its natural frequency of vertical oscillation is substantially resonant with the frequency of a sea wave. The mass of the float device can be adjustable to achieve this.

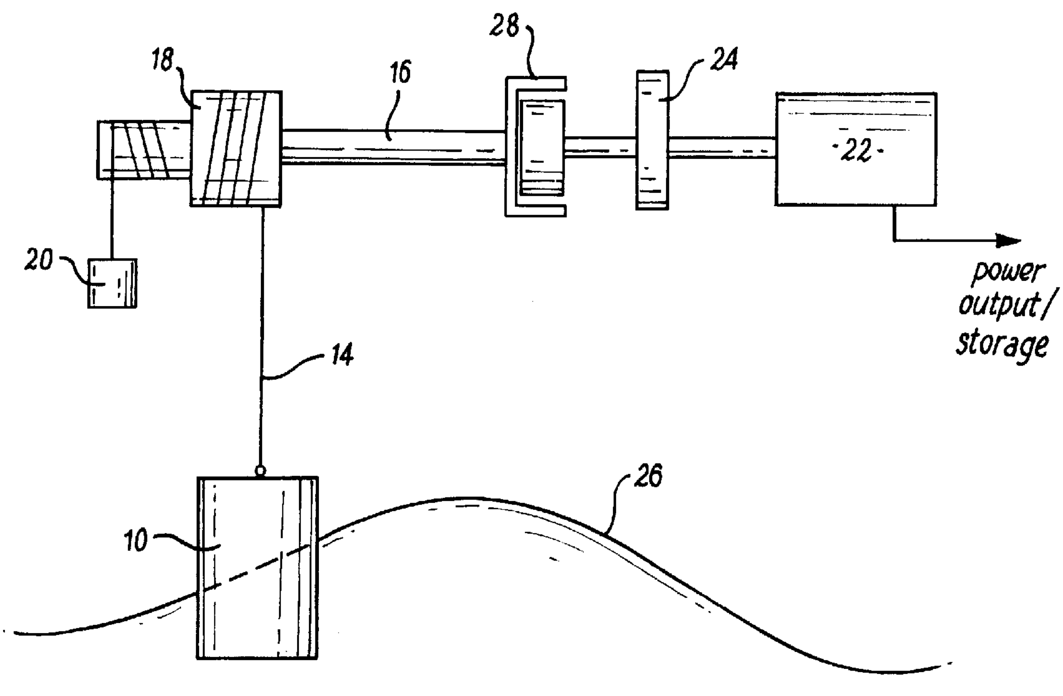

FIG. 1

GB 2 408 075 A

The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.

Original Printed on Recycled Paper

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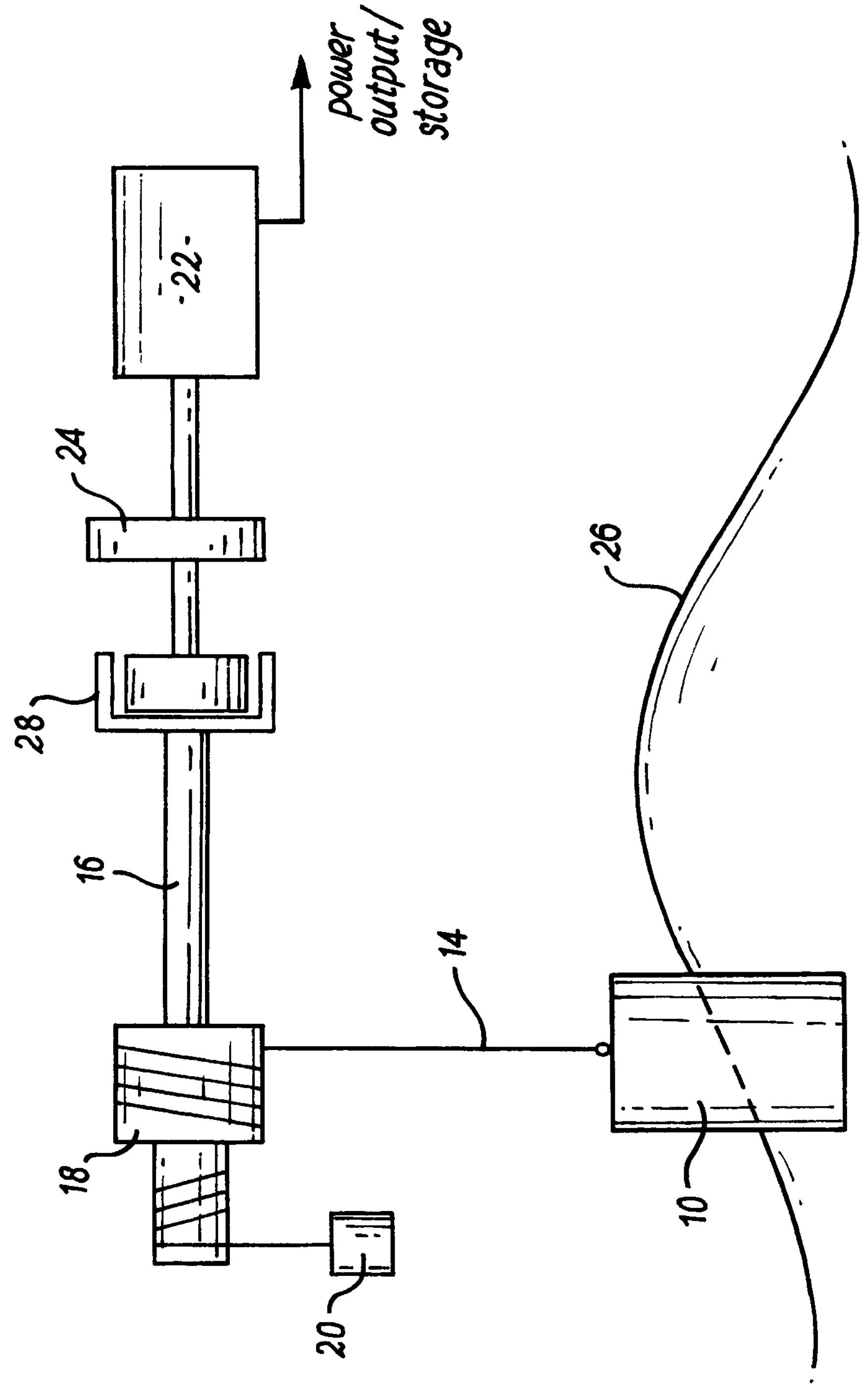

Fig. 1

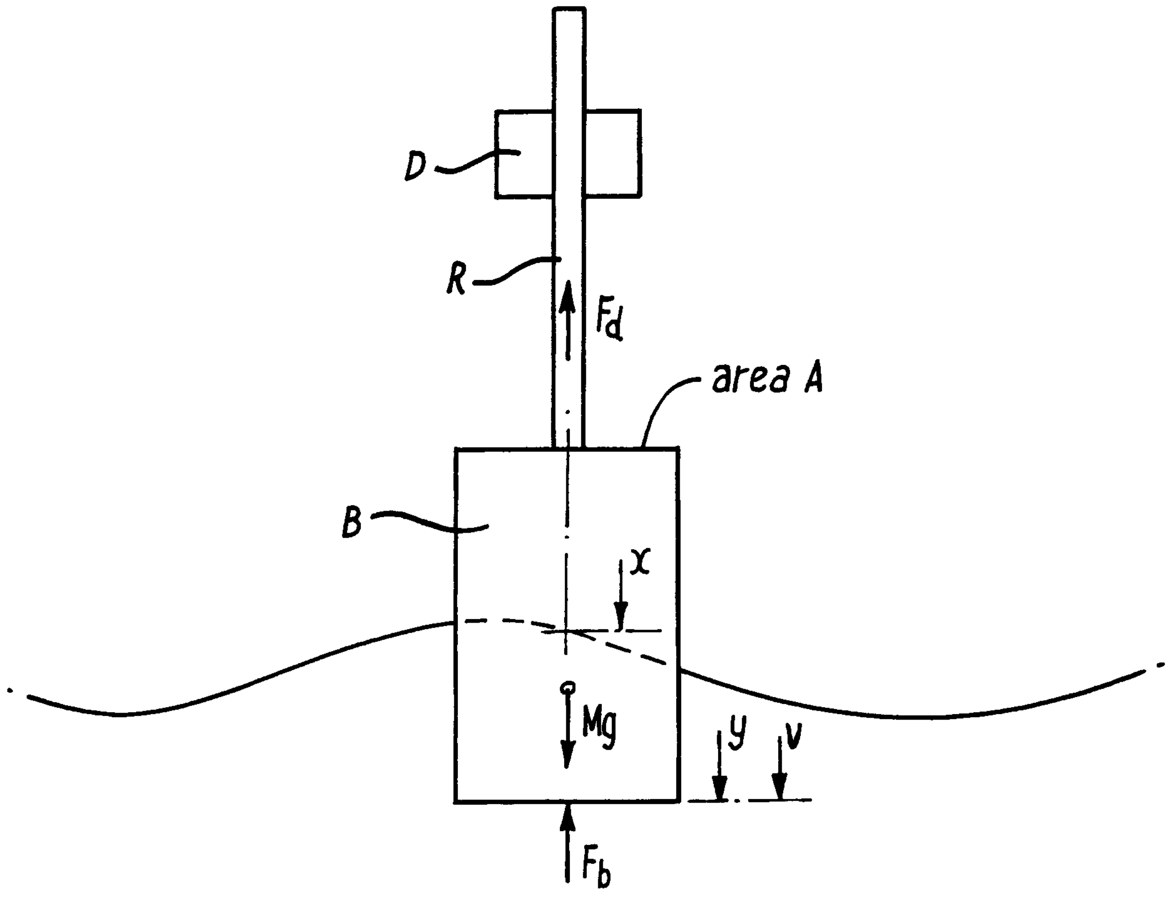

FIG. 2

22 11 04

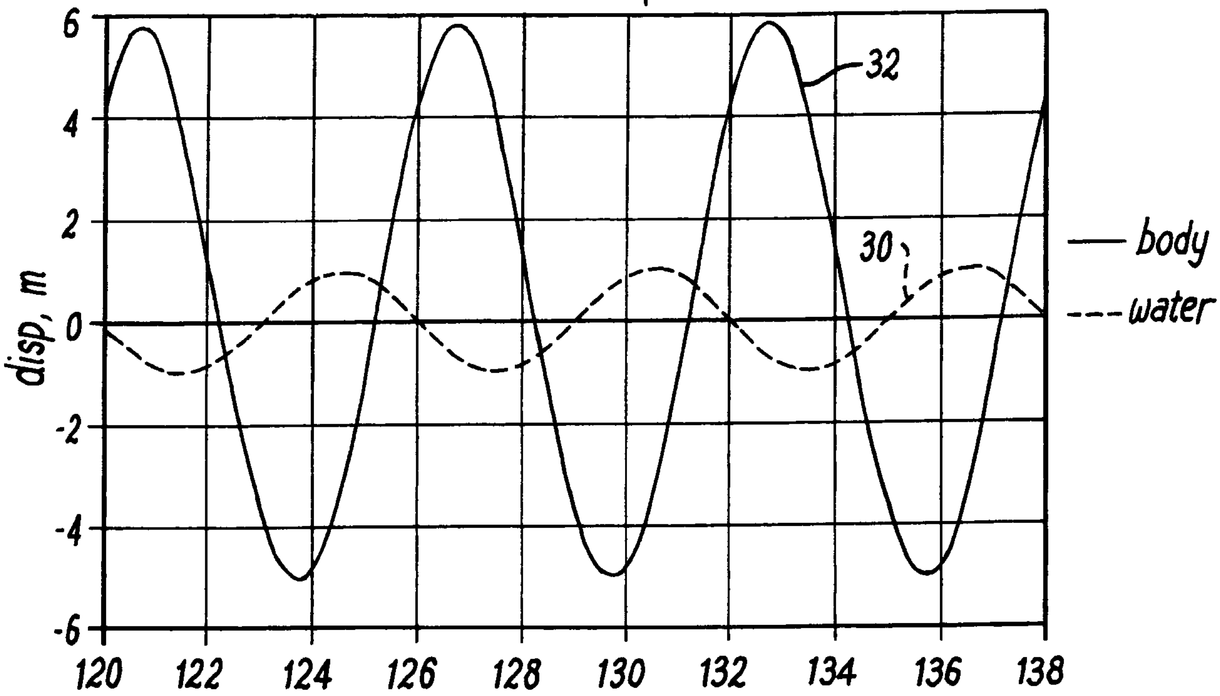

FIG. 3(a)

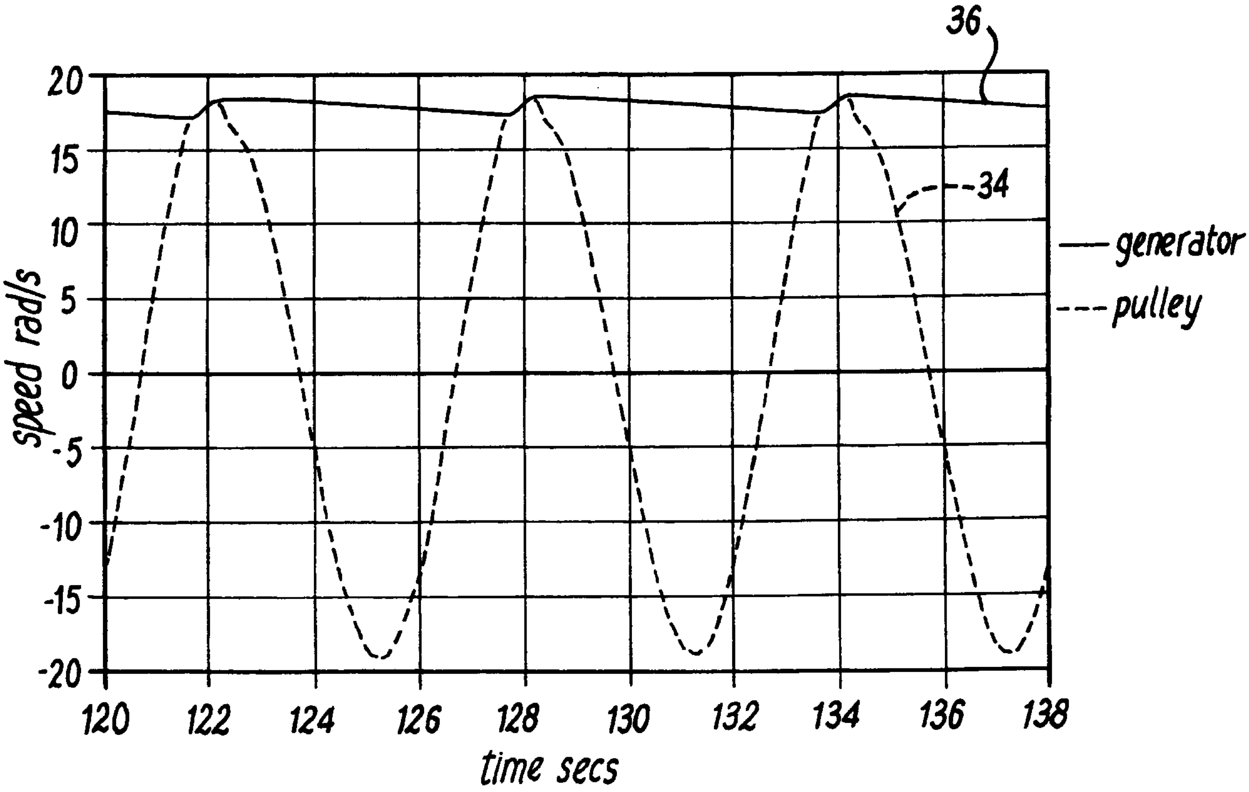

FIG. 3(b)

22 11 04

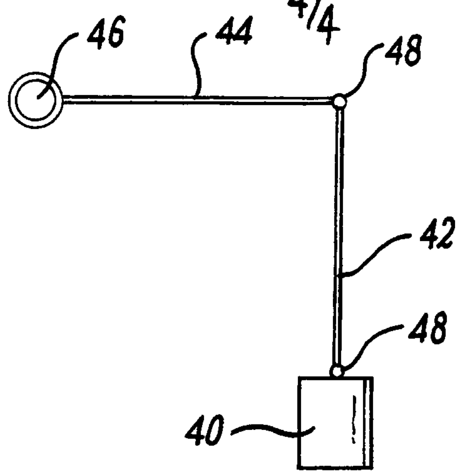

FIG. 4(a)

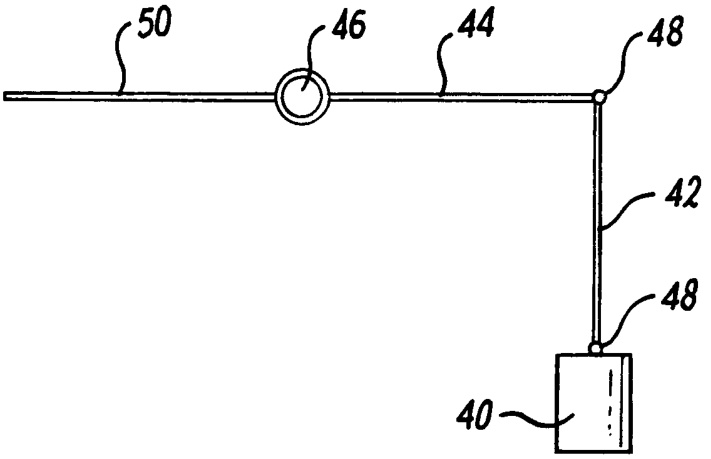

FIG. 4(b)

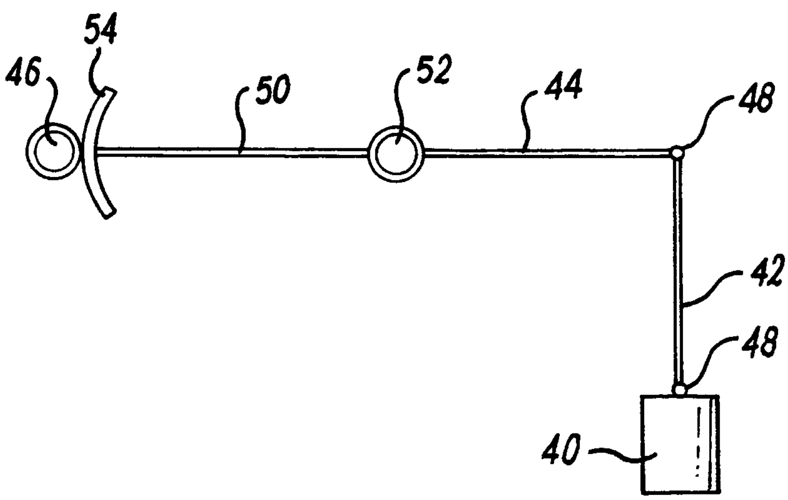

FIG. 4(c)

2408075

Method and Device for Utilising Wave Energy

This invention relates to methods and devices for utilising wave energy, in particular for converting the motion of sea waves into a source of useful power output.

There have been many attempts to harness the energy involved in wave motion of water. Usually, the object of such systems is to convert the wave motion of water into electricity. Many prior art systems are structurally complicated in nature and characterised by operating efficiencies which are somewhat less than would be desirable. Probably of most relevance to the present invention are US 4379235 and US 5424582, the contents of which are hereby incorporated herein by reference, which describe wave power generators which comprise a flywheel in operative connection to electricity generating means, the flywheel being driven by the motion of a float which follows the rising and falling portions of passing waves.

The present invention provides improved methods and devices for utilising wave energy which may be structurally quite simple in nature and which can operate with relatively high efficiency.

For the avoidance of doubt, the term "sea waves" refers to any naturally occurring waves present on a body of water such as a sea, ocean or even a tidal wave or bore occurring on a river.

According to a first aspect of the invention there is provided a device for converting the motion of sea waves into a source of useful power output, the device comprising:

a structure having a drive shaft mounted thereon;

a float device connected to said structure and in operative connection with the drive shaft so that vertical motion of the float device drives the drive shaft; and

a rotatable device in operative connection with the drive shaft so that rotation of the drive shaft rotates the rotatable device;

in which the float device has a natural frequency of vertical oscillation which is substantially resonant with the frequency of a sea wave.

The mass of the float device may be adjustable so as to tune the natural frequency of vertical oscillation of the float device to be substantially resonant with the frequency of a sea wave. Operational adjustment of the mass of the float device may be achieved by providing the float device with an interior chamber and means for admitting water into the chamber and/or expelling water from the chamber. Alternatively, the natural frequency may be tuned by adding or removing other weights from the float device, or by changing the shape of the float device. In this way, the operation of the device can be optimised with respect to the current - or predicted - wave conditions.

The device may further comprise a counterweight in operative connection with the float device.

Advantageously, the rotatable device comprises electricity generating means. Additionally, a flywheel can be employed to provide further inertia. Alternatively, it is possible to use a simple flywheel as the rotatable device to act as a store of energy available to perform other operations, such as mechanical operations.

In a preferred embodiment, the device further comprises clutch means, said clutch means being disposed with respect to the rotatable device so that the rotatable device is rotated by the drive shaft only when the drive shaft is rotating in a predetermined direction. The predetermined direction may correspond to the rising portion of a wave or the falling portion of a wave.

The device may further comprise constraining means adapted to restrict side to side motion of the float device. The constraining means may comprise tethers, or any other suitable means.

Advantageously, the device further comprises at least one gearing system for controlling the transmission of rotational motion to or from the rotatable device. The gearing system may be disposed between the drive shaft and the rotatable device and/or after the rotatable device. In embodiments comprising clutch means, the gearing system may be disposed between the drive shaft and the clutch means and/or between the clutch means and the rotatable device.

The float device may be connected to said structure via a device disposed below the level of the float device so that the float device drives the drive shaft during the rising portion of a wave. The device may comprise a pulley, spindle or like device.

The float device may have a natural frequency which is substantially resonant with the frequency of a sea wave of wave height in the range 0.5 to 10m, preferably in the range 1.0 to 4.0m, most preferably about 2.0m. The wave height is defined as being the vertical distance between the peak and trough of a wave.

The natural frequency of oscillation of the float device may be in the range 0.05 to 0.33 Hz, corresponding to dominant periods in the range 3 to 20s.

The mass of the float device may be in the range 50 to 10,000 tonnes.

The device may be adapted so that, when the natural frequency of vertical oscillation of the float device is substantially resonant with the frequency of a sea wave, the amplitude of oscillation of the float device is magnified due to resonance. The amplitude of oscillation of the float device may exceed the amplitude of oscillation of the sea wave, preferably exceeding the amplitude of oscillation of the sea wave by a factor of two or more. By amplitude of oscillation is meant the extent of the motion (of a wave or of the float device) from the origin of the oscillatory motion. In other words, the amplitude of oscillation of a sea wave is one half of the corresponding sea wave height.

The device may comprise a substantially rigid connecting rod coupled to the float device and permitting the float device to be connected to said structure. This arrangement avoids problems associated with flexing of the component used to suspend the float device. In related embodiments, the device further comprises a crank arm, the connecting rod being in operative connection with the drive shaft via the crank arm. The device may further comprise a counterbalance arm. The device may still further comprise a pivot, in which: the crank arm and the counterbalance are in connection with the pivot so that movement of the connecting rod causes rotational motion of the counterbalance arm about the pivot; and the counterbalance arm is in operative connection with the drive shaft so that rotational motion of the counterbalance arm about the pivot rotates the rotatable device. This enables the connecting rod to be always in tension and hence in a known state. Additionally, this arrangement permits the addition of inertia to the system which can be used to modify the natural frequency. In any of the embodiments comprising a substantially rigid connecting rod, at least one gearing system may be used to control the transmission of rotational motion to or from the rotatable device. The gearing system may be disposed between the connecting rod and the drive shaft.

According to a second aspect of the invention there is provided a method of converting the motion of sea waves into a source of useful power output comprising the steps of:

disposing a float device on a body of water so that the float device floats thereon;

allowing the motion of sea waves across the body of water to vertically displace the float device; and

transmitting power associated with vertical displacement of the float device to a rotatable device so that the vertical displacement of the float device caused by the motion of the sea waves rotates the rotatable device;

in which the natural frequency of vertical oscillation of the float device is substantially resonant with the frequency of the sea waves.

The wave height of the sea waves may be in the range 0.5 to 10m, preferably in the range 1.0 to 4.0m, most preferably about 2.0m.

The natural frequency of vertical oscillation of the float device may be in the range 0.05 to 0.33Hz.

The amplitude of oscillation of the float device may exceed the amplitude of oscillation of the sea wave, preferably exceeding the amplitude of oscillation of the sea wave by a factor of two or more.

The method may further comprise the step of generating electricity from the rotation of the rotating device. In this instance power associated with vertical displacement of the float device may be transmitted also to a flywheel. In this way, the moment of inertia of the rotatable device can be augmented.

In other embodiments, the rotatable device may comprise a flywheel.

The method may comprise the further step of adjusting the mass of the float device so as to tune the natural frequency of vertical oscillation of the float device to be substantially resonant with the frequency of the sea waves.

Power may be transmitted to the rotatable device through clutch means so that the rotatable device is rotated only when the float device is vertically displaced in a predetermined direction.

Methods and devices in accordance with the invention will now be described with reference to the accompanying drawings, in which:

Figure 1	shows a first embodiment of a device for converting the motion of sea waves into a source of electricity;
Figure 2	shows a system including a float device used for mathematical modelling;
Figure 3	shows (a) displacement of water and float device and (b) speeds of the pulley and generator obtained by simulation of the behaviour of the system described by Figures 1 and 2; and

Figure 4 shows (a) a second embodiment, (b) a third embodiment and (c) a fourth embodiment of portions of a device for converting the motion of sea waves into a source of electricity.

The present invention provides a means of harnessing the energy involved in wave motion of water. The invention can utilise a comparatively simple arrangement which minimises the structure and hardware needed to couple the motion of the water to a rotating shaft to produce continuous generation of electricity or, if preferred, mechanical power output. The device is suited to offshore conditions where the availability of wave power is high, as well as nearshore conditions where conditions are less extreme.

The present invention is based around a body which has sufficient buoyancy to follow the rise and fall of the surface of the water. An important feature of this device is that advantage is taken of the natural frequency of such a buoyant body in amplifying the vertical motion of the body when the wave frequency is close to the natural frequency of the body. The device may thus be tuned to the most probable wave frequency. Typically, but not exclusively, the device is tuned so that its natural frequency coincides with relatively small wave heights for which amplification is most desirable. The body may be connected to a structure which is fixed to the ground (as in shore-based, or nearshore-based implementations) or to a platform which is supported either from the seabed or by floats (as in offshore implementations).

In a first embodiment of the invention, depicted in Figure 1, the body 10 is suspended from a structure (not shown) by a suspending component 14 such as a cable, wire, rope or similarly flexible component. The structure can be any suitable body, such as a platform. The suspending component 14 is taken over and transmits motion to a drive shaft 16 via a pulley 18. As the body 10 rises a counterweight 20 takes in the slack in the suspending component 14 by rotating the pulley 18. A drive mechanism might be employed instead for this purpose. The drive shaft 16 is connected to an electricity generator 22 through a clutch/freewheel device 28. The clutch 28 is caused to engage and disengage the connection of the drive shaft 16 with an electricity generator 22. Thus, the clutch/freewheel 28 allows the electricity generator 22 to rotate in the direction opposite to that of the pulley 18 as the body 10 rises. The first embodiment also comprises a separate flywheel 24, which flywheel provides extra inertia coupled to the generator 22. At the peak of a wave, the body 10 starts to descend under the action of gravity, and the pulley 18 begins to rotate in the same direction as the electricity generator 22. At some time during the fall of the body 10 the speed of the pulley 18, which is enhanced by resonance, becomes equal to that of the electricity generator 22 and, under these conditions, the freewheel device 28 engages so that the increasing downwards velocity of the body 10 causes the speed of the electricity generator 22 to increase. When the body 10 ceases its downward acceleration as a result of interaction with the water surface 26 the freewheel device 28 is disengaged, allowing the flywheel 24 and electricity generator 22 to continue their rotation as the pulley 18 decelerates to zero speed. The cycle then commences to repeat as the water surface 26 rises and starts to lift the body 10. If the electricity generator 22 and the flywheel 24 are together designed with sufficient moment of inertia, then useful power may be extracted during the entire cycle with the speed of the electricity generator 22 falling during the interludes between the acceleration periods, but remaining high enough to keep the generating capability through the cycle.

Other embodiments of the invention may place a gearbox between the pulley 18 and the generator 22 and flywheel 24 to increase the speeds of the generator 22 and flywheel 24, thus reducing the size of both generator 22 and flywheel 24 for a given energy extraction per cycle. The freewheel device can be placed either between pulley and gearbox, or between gearbox and generator and flywheel. Although not essential for the operation of the system, a preferred refinement involves the attachment of tethers to th body 10 to restrict motion within a horizontal plane. The tethers, preferably at least th in number, allow the body 10 to rise and fall under the action of the largest waves, yet constrain its position sufficiently to permit optimal operation of the pulley 18. Other motion constraining systems might be envisaged.

In a second embodiment of the invention the flywheel is dispensed with. Thus, the drive shaft solely drives the electricity generator and not an additional flywheel. Again, appropriate gearing can be employed.

An important aspect of the invention concerns resonance. To illustrate the effects of resonance the system will be reduced in complexity by making certain assumptions. The reduced system is shown in Figure 2. Here a floating body B is shown, for the purpose of illustration, as a right cylinder of cross-sectional area A, and is attached, for the purpose of illustration, to a rigid rod R which passes through an energy absorbing device D. The device D extracts energy by the production of a force F_d which opposes the motion of the rod R. Again, for the purpose of illustration the force is assumed to be proportional to the velocity v of the rod and body.

The buoyancy force acting will depend upon the immersion. For the assumptions made in this illustration, the force is given by

$$F_b = A\sigma g(y-x)$$

Where σ is the density of the water, g is the acceleration of gravity, x is the fall of the water surface from a datum and y is the fall of the buoy from the same datum. It will be noted that this can be written as:

$F_b = k_b(y-x)$ where $k_b = A\sigma g$ is a constant.

The force F_d can be written as

$F_d = k_d v$ where k_d is also a constant under the assumptions made here.

In this simplification, k_d accounts for the energy extraction by the device D but there is also energy extraction due to the motion of the body B relative to the water body causing damping. This takes the form of frictional resistance and also radiation damping due to waves being radiated from the body. The former may be minimised by streamlining the body and the latter tends to zero as the body cross-sectional area tends to zero. The shape of the body can be optimised for energy extraction in resonant conditions.

The buoy is thus acted upon by three forces in the vertical direction, the weight Mg and the two forces F_d and F_b

Under static conditions with $x = 0$ and $v = 0$, the value of $y = y_o$ and $Mg = k_b y_o$.

If a quantity z is defined as $(y - y_o)$ then the motion of the buoy as a function of time t is defined by the differential equation:

$$M \frac{d^2 z}{dt^2} + k_d \frac{dz}{dt} + k_b z = k_b x$$

If the water surface fall is defined by

$x = W \sin(\omega t)$ where W = half the wave height and the wave period $T = 2\pi/\omega$

then the solution to the equation is: $z = A \sin(\omega t - \phi)$

where

$$A = \frac{\omega_0^2 W}{\sqrt{(\omega_0^2 - \omega^2)^2 + (k_d \omega / M)^2}}$$

$$\tan(\phi) = \frac{k_d \omega / M}{(\omega_0^2 - \omega^2)}$$

and $\omega_0^2 = k_b / M$.

The parameter ω_o is the undamped natural frequency of the system.

The rate of extraction of energy from the system is given by the product F_d and v and it can be shown that the average power extracted over a cycle is given by:

$P = 0.5\ k_d \omega^2 A^2$

Resonance occurs when the exciting frequency ω is the same as the undamped natural frequency ω_o. In this case, for a given wave height, the amplitude of the oscillation of the buoy is a maximum and could even be greater than W, the amplitude of the wave.

One aspect of the invention lies in the adjustment of the system parameters to satisfy conditions for resonance. The values of k_b and M can be adjusted in the design of the system to make the system resonant frequency suit a chosen value of wave period to achieve large values of oscillation amplitude.

The above is somewhat of a simplification for the purposes of demonstration. In practice, a system is nonlinear in at least two respects. One has been mentioned above in relation to hydrodynamic damping due to relative motion between the body and the water body. As the body oscillates in the water the damping force will only be proportional to velocity for small amplitudes. In general for larger amplitudes nonlinearities in many physical systems reduce this effect. Another aspect is that, by the nature of the device, useful energy may only be extracted during parts of the cycle of oscillation. The latter factor in particular makes it impossible to solve for the motion of the system analytically. However, it is possible to simulate numerically, and this has been done for one particular set of conditions, while maintaining the linear friction assumption.

Figure 3 shows the steady state behaviour of a floating body of the type shown in Figure 2 when excited by a wave motion of period 6s and wave height 2m. These are considered to represent relatively calm conditions in most large seas or oceans. The body, of mass 300 Tonnes, is supported by a cable pulling over a pulley of diameter 0.6m. The pulley is connected through a ratcheting freewheel to a generator having an efficiency of 80% which provides a smooth unvarying output of 0.3MW. A friction coefficient of 0.02 is assumed on the body surface and the body is assumed to be of sufficiently small cross section for negligible radiation damping.

Figure 3(a) shows the displacements of water 30 and body 32, and these clearly demonstrate the amplification of oscillation amplitude by resonance. Amplifications of nearly six times are shown in Figure 3(a). The height of the float device should be chosen so that the float device remains in contact with the sea wave over the entire oscillation if the full amplification is to be enjoyed. In Figure 3(b) the speeds of pulley 34 and generator 36 are shown. It can be seen how the oscillating speed of the pulley is mechanically rectified to give a unidirectional speed of the generator.

The parameters utilised in the system simulated for the purposes of Figure 3 are illustrative, and may be varied in a number of ways. For example, in the system above a right cylinder is convenient for demonstration because it gives a constant factor k_b. The minimisation of frictional resistance and radiation damping have been mentioned above, and indeed a right cylinder is not ideal in respect of the former consideration. However the shape of the body may also control the oscillation. Thus, the performance of the system can be varied by way of varying the shape of the floating body. The dimensions of the floating body can also be varied so as to control the performance of the system. For example it is possible to limit the amplitude of oscillation by choice of overall height of the body. In preferred, but non-limiting, examples, the natural frequency of oscillation of the float device is in the range 0.05 to 0.33Hz, and the mass of the float device is in the range 50 to 10,000 tonnes, preferably 100 to 100 tonnes. The float device may comprise reinforced concrete, although other materials might be employed.

Should wave conditions change, it may be desirable that the natural frequency of the body also be changed. In a preferred but not limiting example the mass of the body is conveniently increased by admitting water into its interior by releasing one-way hatches at the required level. These would admit water during immersion but retain water when emerging. To reverse the process and to reduce the mass, water could be shed by suitable reverse acting one-way hatches, or scuppers, which allow egress of water from the body on emerging but prevent ingress during immersion. Of course any other method of adding and shedding mass - not necessarily water - could achieve the same objective.

In one mode of operating devices of the present invention, the device is tuned so as to be resonant with relatively small waves of wave height around 2m. The device might be retuned so as to be resonant with slightly different waves should sea conditions change somewhat. However, the device is not tuned to be resonant with large waves if such waves (eg, waves of wave height around 10m or greater) are encountered, because such waves supply a great deal of power even to an untuned device.

A further alternative embodiment of the invention uses the same essential principles as discussed above, but also places a pulley, spindle or like device under the water surface. The suspending component, as well as passing over an upper pulley also passes under a lower pulley before being connected to the body. By such means the generator is accelerated during the upward motion of the body. The advantage of such a system is that it will be possible to produce, by means of buoyancy, increased accelerating forces at the pulley for a given mass of the body.

Figure 4 shows a number of alternative drive systems which are within the scope of the invention. For simplicity of presentation, Figure 4 depicts the mechanical linkages between the float device and the drive shaft only. It is understood that the motion of the drive shaft shown in Figure 4 will be utilised to rotate a rotatable device in the manner explained elsewhere within the present disclosure. Figure 4 (a) shows a float device 40 connected to a connecting rod 42. The connecting rod 42 can be manufactured from a metal or another suitable material so as to provide a substantially rigid structure. The connecting rod 42 is in connection with a crank arm 44 which in turn is in connection with drive shaft 46. The connecting rod 42 is attached to the float device 40 and crank arm 44 via hinged joints 48, thereby permitting a certain amount of lateral motion of the float device 40. This arrangement avoids problems associated with repeated flexure of suspending components such as ropes. Figure 4 (b) shows a related embodiment which utilises the same components depicted in Figure 4 (a) together with a counterbalance arm

50. Identical numerals to those used in Figure 4 (a) are used in Figure 4 (b) to depict identical components. The provision of the counterbalance arm 50 enables the suspending rod to always be in tension and hence be in a known state. Additionally, this arrangements permits the addition of inertia to the system which can be used to modify the natural frequency. Figure 4 (c) shows a further variant comprising a float device 40 suspended using a substantially rigid connecting rod 42 coupled via hinges 48 to a crank arm 44. The crank arm 44 is connected to a pivot 52 and to a counterbalance arm 50. The counterbalance arm is in connection with the drive shaft 46, optionally via gearing 54. This arrangement permits the possibility of mechanical magnification of linear motion of the suspending rod, for increased angular velocity of the drive shaft through transmission gearing.

The arrangements shown in US 5424582 might be incorporated into the present invention provided that the float means described therein are adjusted so as to have a natural resonant frequency which is substantially resonant with the frequency of the waves.

The invention can provide for acceleration of the generator during both upward and downward motion of the body. This can be arranged by using two freewheels and appropriate gearing. Further details concerning how two arrangements can be combined to provide acceleration during both upward and downward motion of the body can be found in US 5424582. Such an arrangement can be used in the context of the present invention provided that resonance of the float device with the waves is achieved.

The structure on which the drive shaft is mounted may be moored or otherwise secured to the sea bed, shore, or to a secured structure such as a rig or jetty. Alternatively, it is possible to use a floating structure on which the drive shaft is mounted.

Another alternative embodiment of the invention uses a rigid suspending component, constrained in a vertical attitude by sliding or rotating bearings during its upwards and downwards motions as the body attached below it rises and falls with the water surface. Upward and/or downward motions could then be utilised for acceleration of the flywheel and generator through a suitable linear to rotary motion converter. In another alternative embodiment still the drive shaft might not be disposed in the horizontal plane. Instead, the drive shaft might be disposed vertically, or intermediate between horizontal and vertical. Appropriate gearing, such as bevel gears, can be used to achieve these configurations.

CLAIMS

1. A device for converting the motion of sea waves into a source of useful power output, the device comprising:

a structure having a drive shaft mounted thereon;

a float device connected to said structure and in operative connection with the drive shaft so that vertical motion of the float device drives the drive shaft; and

a rotatable device in operative connection with the drive shaft so that rotation of the drive shaft rotates the rotatable device;

in which the float device has a natural frequency of vertical oscillation which is substantially resonant with the frequency of a sea wave.

2. A device according to claim 1 in which the mass of the float device is adjustable so as to tune the natural frequency of vertical oscillation of the float device to be substantially resonant with the frequency of a sea wave.

3. A device according to claim 2 in which the float device comprises an interior chamber and means for admitting water into the chamber and/or expelling water from the chamber.

4. A device according to any of claims 1 to 3 further comprising a counterweight in operative connection with the float device.

5. A device according to any previous claim in which the rotatable device comprises electricity generating means.

6. A device according to claim 5 further comprising a flywheel in operative connection with the drive shaft so that motion of the float device rotates the flywheel.

7. A device according to any previous claim further comprising clutch means, said clutch means being disposed with respect to the rotatable device so that the rotatable device is rotated by the drive shaft only when the drive shaft is rotating in a predetermined direction.

8. A device according to any previous claim further comprising constraining means adapted to restrict side to side motion of the float device.

9. A device according to any previous claim further comprising at least one gearing system for controlling the transmission of rotational motion to or from the rotatable device.

10. A device according to any previous claim in which the float device is connected to said structure via a device disposed below the level of the float device so that the float device drives the drive shaft during the rising portion of a wave.

11. A device according to any previous claim in which the float device has a natural frequency which is substantially resonant with the frequency of a sea wave of wave height in the range 0.5 to 10m, preferably in the range 1.0 to 4.0m, most preferably about 2.0m.

12. A device according to any previous claim in which the float device has a natural frequency in the range 0.05 to 0.33Hz.

13. A device according to any previous claim adapted so that, when the natural frequency of vertical oscillation of the float device is substantially resonant with the frequency of a sea wave, the amplitude of oscillation of the float device exceeds the amplitude of oscillation of the sea wave, preferably exceeding the amplitude of oscillation of the sea wave by a factor of two or more.

14. A device according to any previous claim comprising a substantially rigid connecting rod coupled to the float device and permitting the float device to be suspended from said structure.

15. A device according to claim 14 further comprising a crank arm, in which the connecting rod is in operative connection with the drive shaft via the crank arm.

16. A device according to claim 15 further comprising a counterbalance arm.

17. A device according to claim 16 further comprising a pivot, in which:

the crank arm and the counterbalance arm are in connection with the pivot so that movement of the connecting rod causes rotational motion of the counterbalance arm about the pivot; and

counterbalance arm is in operative connection with the drive shaft so that rotational motion of the counterbalance arm about the pivot rotates the rotatable device.

18. A method of converting the motion of sea waves into a source of useful power output comprising the steps of:

disposing a float device on a body of water so that the float device floats thereon;

allowing the motion of sea waves across the body of water to vertically displace the float device; and

transmitting power associated with vertical displacement of the float device to a rotatable device so that the vertical displacement of the float device caused by the motion of the sea waves rotates the rotatable device;

in which the natural frequency of vertical oscillation of the float device is substantially resonant with the frequency of the sea waves.

19. A method according to claim 18 in which the wave height of the sea waves is in the range 0.5 to 10m, preferably in the range 1.0 to 4.0m, most preferably about 2.0m.

20. A method according to claim 18 or claim 19 in which the natural frequency of vertical oscillation of the float device is in the range of 0.05 to 0.33Hz.

21. A method according to any of claims 18 to 20 in which the amplitude of oscillation of the float device exceeds the wave height of the amplitude of oscillation, preferably exceeding the amplitude of oscillation of the sea wave by a factor of two or more.

22. A method according to any of claims 18 to 21 further comprising the step of generating electricity from the rotation of the rotatable device.

23. A method according to any of claims 18 to 22 comprising the further step of adjusting the mass of the float device so as to tune the natural frequency of vertical oscillation of the float device to be substantially resonant with the frequency of the sea waves.

24. A method according to any of claims 18 to 23 in which power is transmitted to the rotatable device through clutch means so that the rotatable device is rotated by the drive shaft only when the float device is vertically displaced in a predetermined direction.

Application No: GB0324183.3	**Examiner:** Mr Tom Roberts
Claims searched: 1-24	**Date of search:** 11 March 2005

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, 8, 11-14, 18-22	JP2000154774 A (WATABE) See abs, figs
X	1-5, 8, 11-14, 16, 18-23	WO89/07197 A (BURTON LAWRENCE) See whole doc esp. page 8 para 2.
X	1, 4, 5, 6, 10, 11-13, 18-20, 22	GB1522661 A (BUDAL K) See whole doc, esp abs, fig. 1
A	-	US4599858 A (STELLA JOSEPH) See abs, figs. 1 and 2

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 :

F1S

Worldwide search of patent documents classified in the following areas of the IPC^{07}

F03B

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

EPODOC, WPI

US005359229A

United States Patent [19]

Youngblood

[11] **Patent Number: 5,359,229**

[45] **Date of Patent: Oct. 25, 1994**

[54] **APPARATUS FOR CONVERTING WAVE MOTION INTO ELECTRICAL ENERGY**

[76] Inventor: **George M. Youngblood,** 12935 Wincrest Ct., Cypress, Tex. 77429

[21] Appl. No.: **218,838**

[22] Filed: **Mar. 28, 1994**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 102,891, Aug. 6, 1993, abandoned.

[51] **Int. Cl.**[5] **F03B 13/12;** F03B 13/18

[52] **U.S. Cl.** **290/53;** 60/502; 60/507; 290/42; 417/331; 417/333

[58] **Field of Search** 60/502, 507; 290/42, 290/53; 417/331, 333

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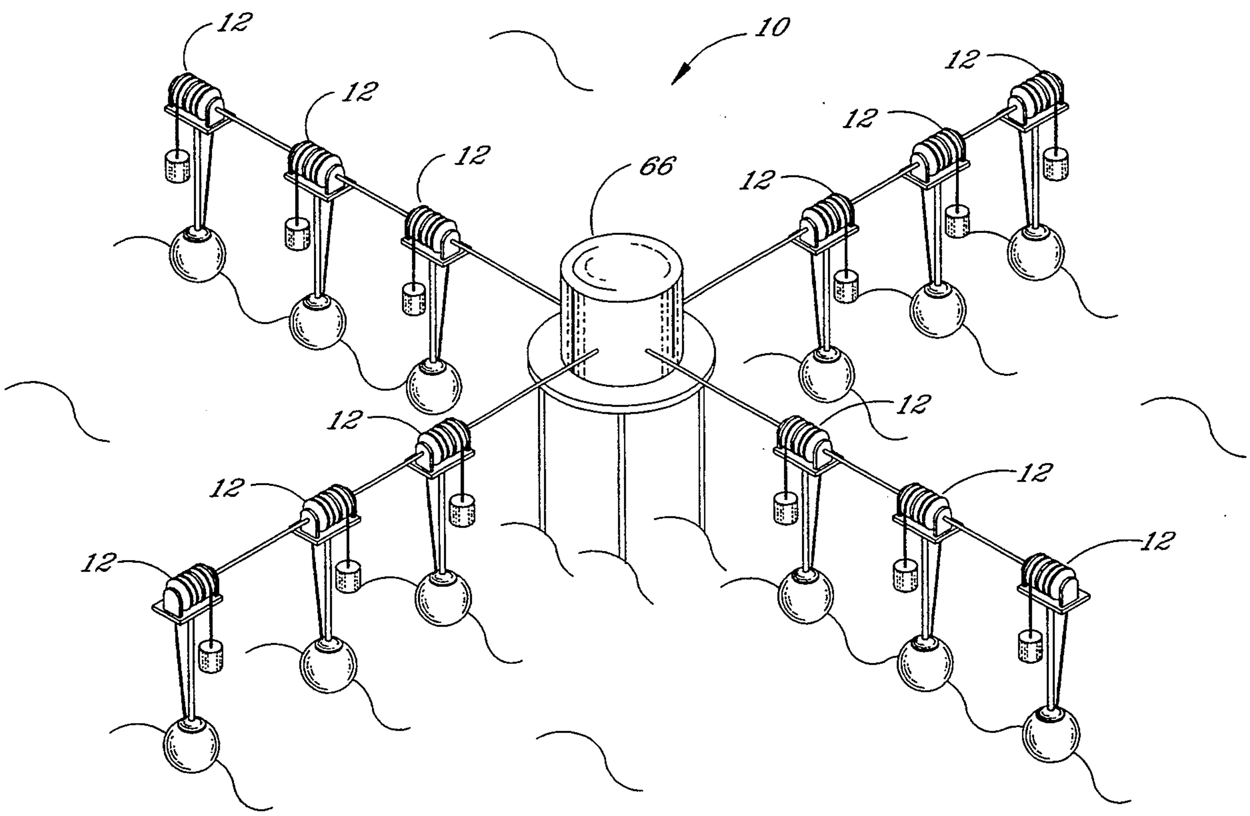
Primary Examiner—a. D. Pellinen
Assistant Examiner—Robert Lloyd Hoover

[57] **ABSTRACT**

Apparatus for producing electrical energy from the rise and fall of waves on a body of water. A vertical column is anchored to the floor of the body of water. A buoyant, spherical float is telescopically mounted to the vertical column in a manner that allows it to rise and fall with the waves, guided by the vertical column. A drive shaft is mounted to the vertical column and above the float. A downstroke drive transfer mechanism is mounted to the drive shaft. A first cable is attached to the float and to the downstroke drive transfer mechanism. A second cable is attached to a counter-weight and to the downstroke drive transfer mechanism. As the float falls as a wave trough passes, the downward motion of the float is transferred to the downstroke drive transfer mechanism through the first cable, causing the drive shaft to rotate. The drive shaft does not rotate as the float rises. The drive shaft is connected to an electrical energy generating system.

22 Claims, 12 Drawing Sheets



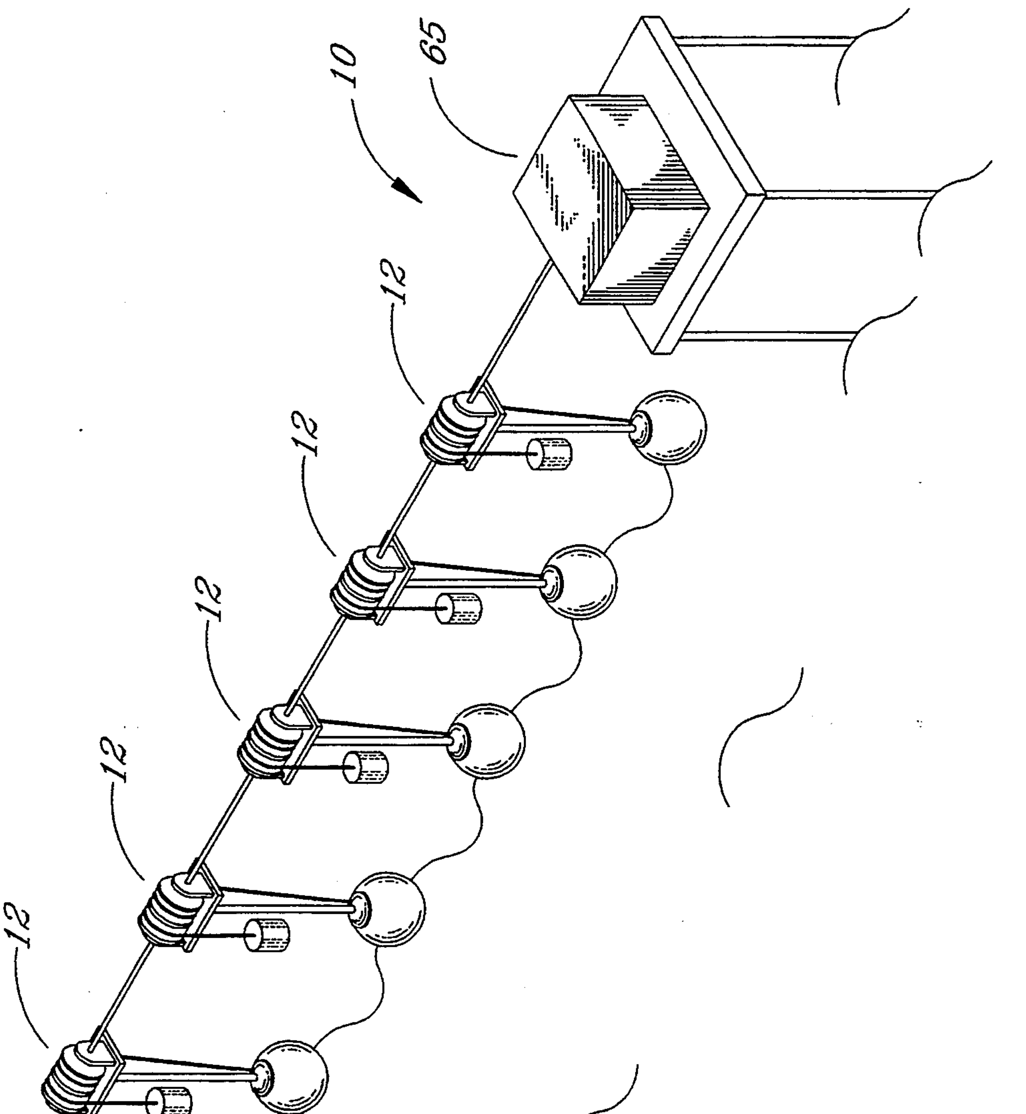


FIG. 1

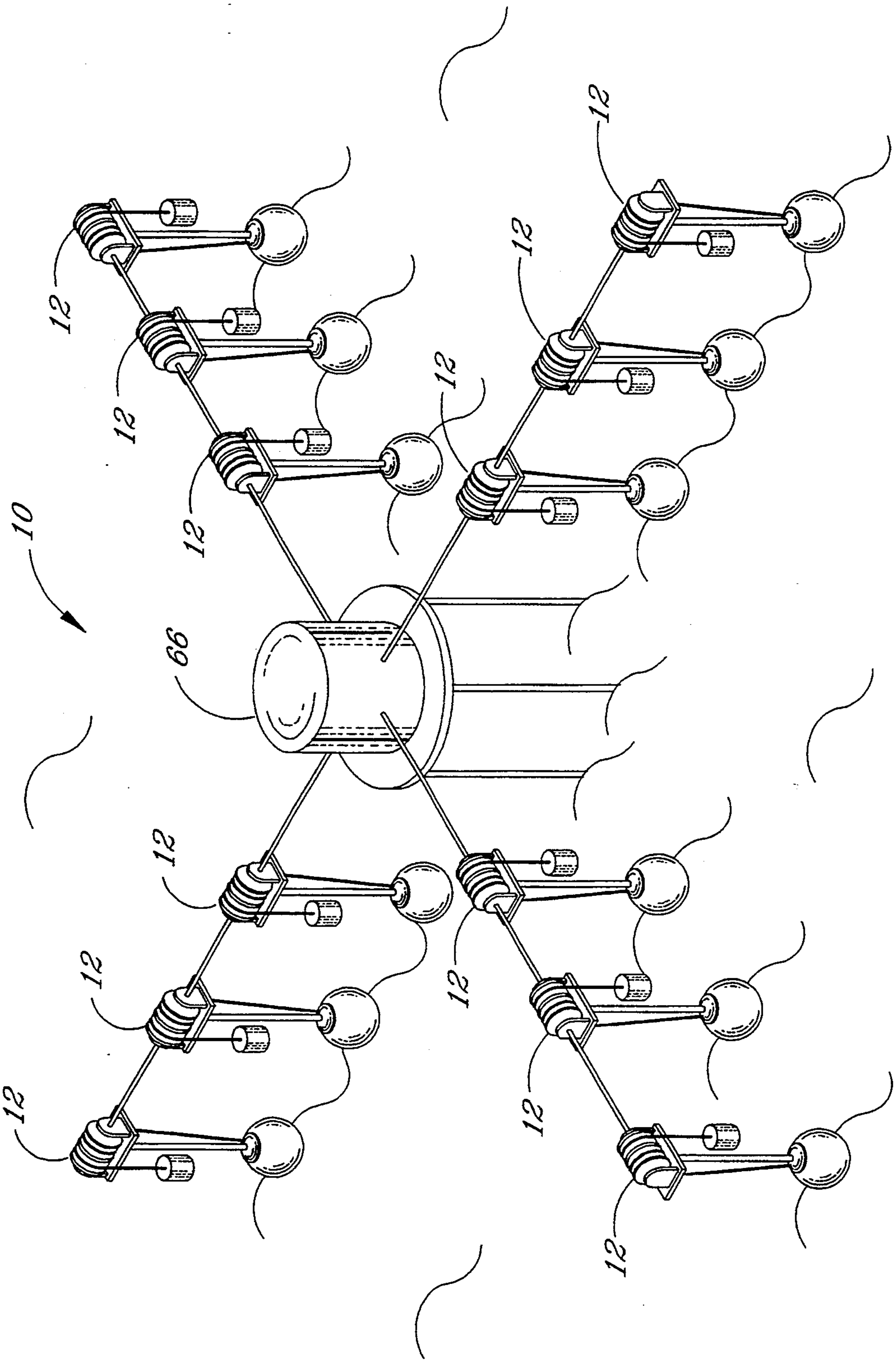


FIG. 2

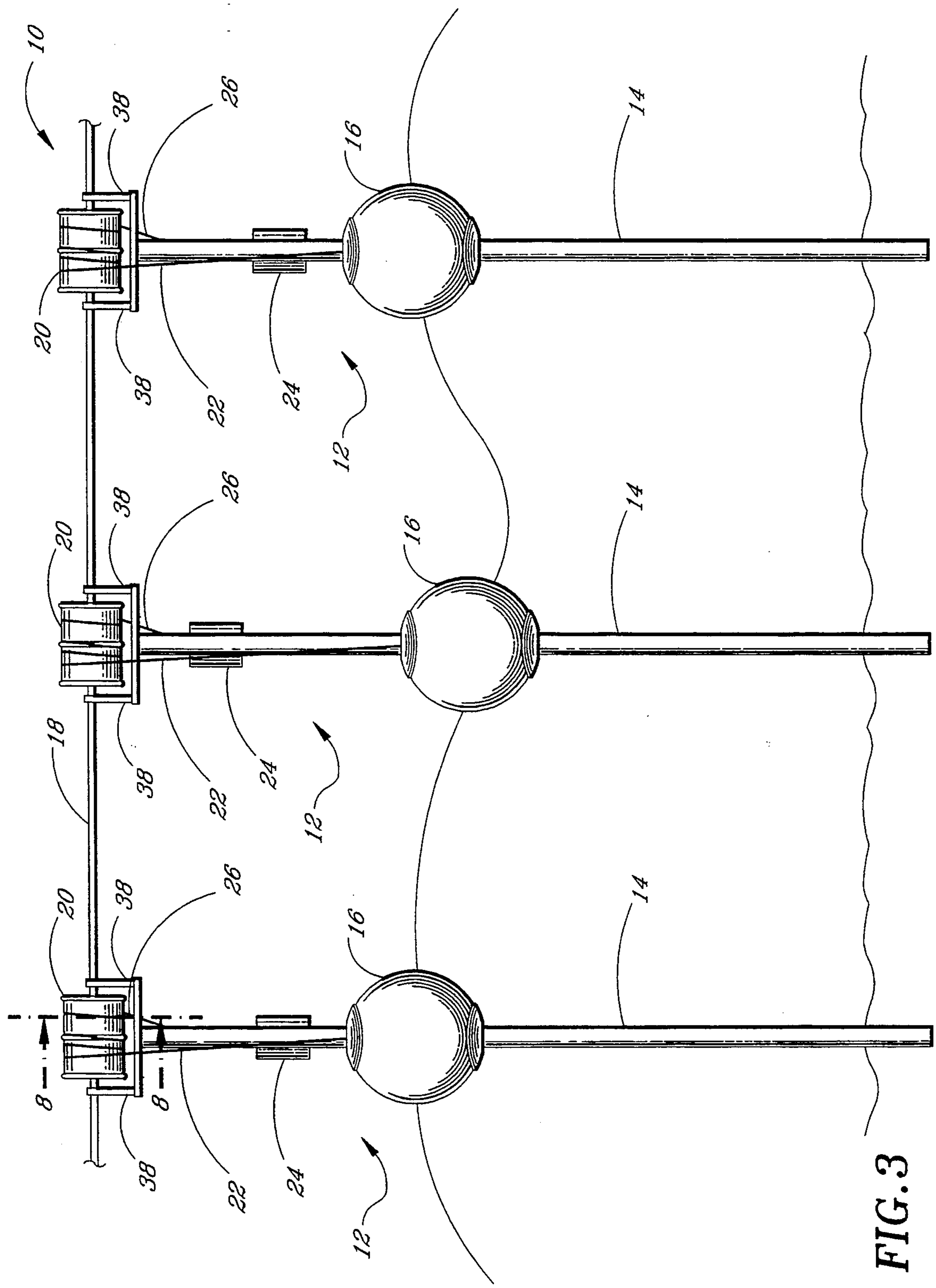


FIG. 3

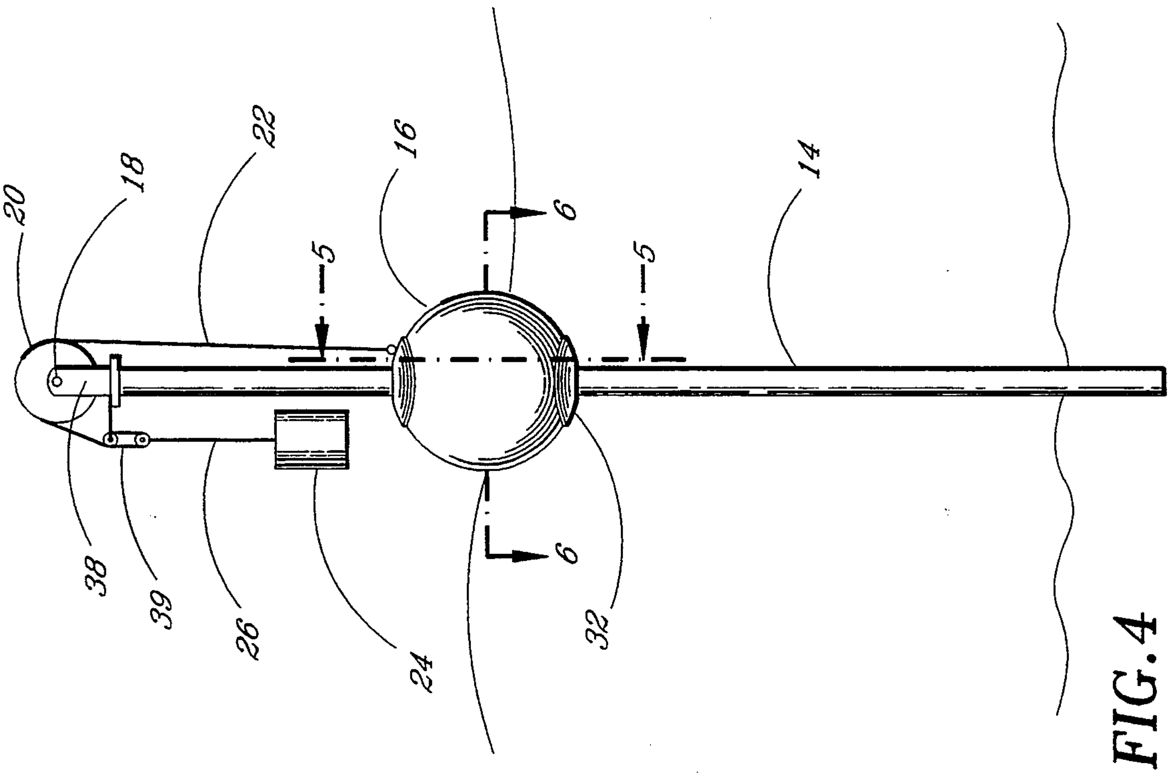


FIG. 4

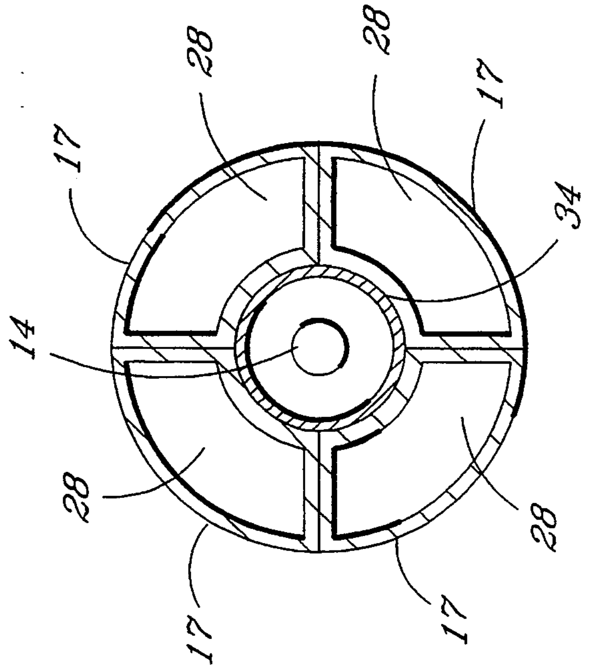


FIG. 6

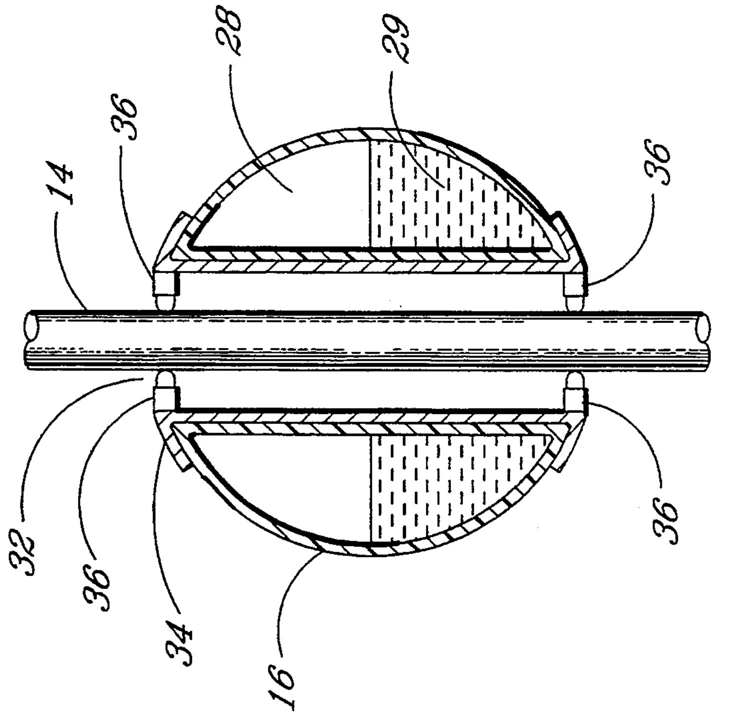


FIG. 5

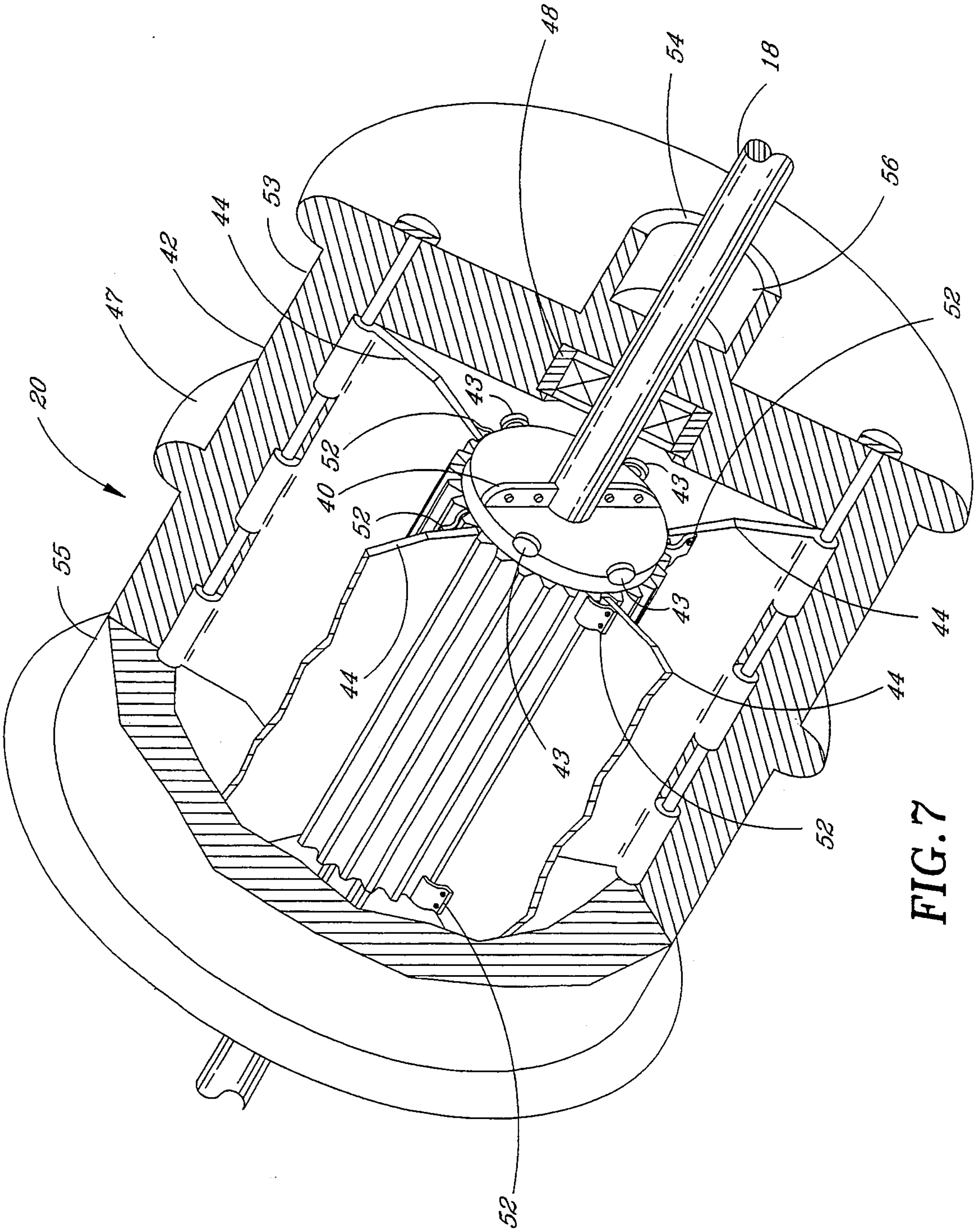


FIG. 7

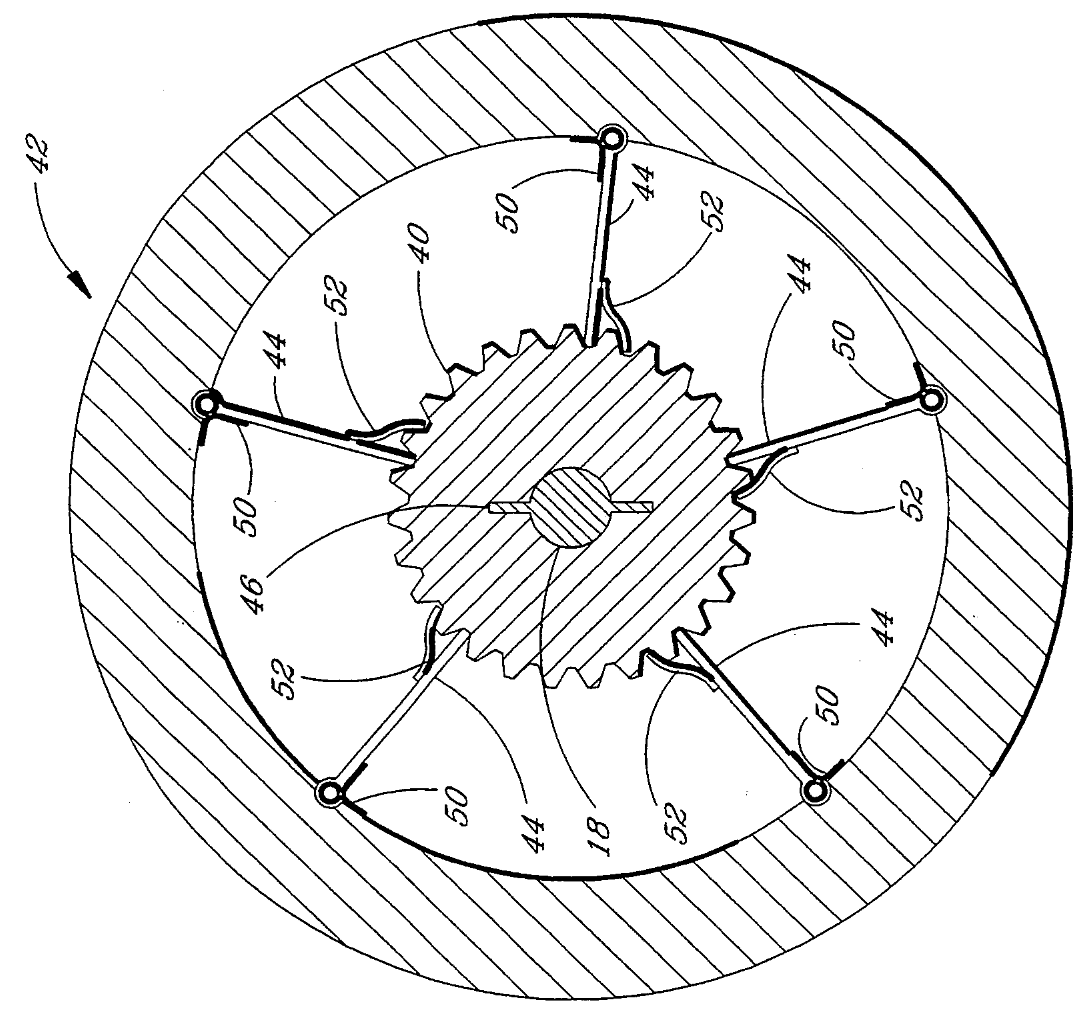


FIG. 8

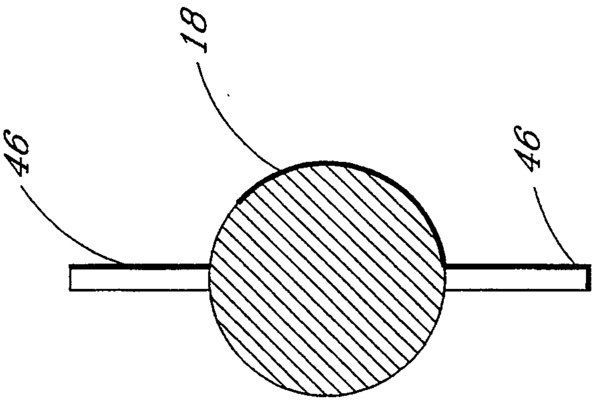


FIG. 10

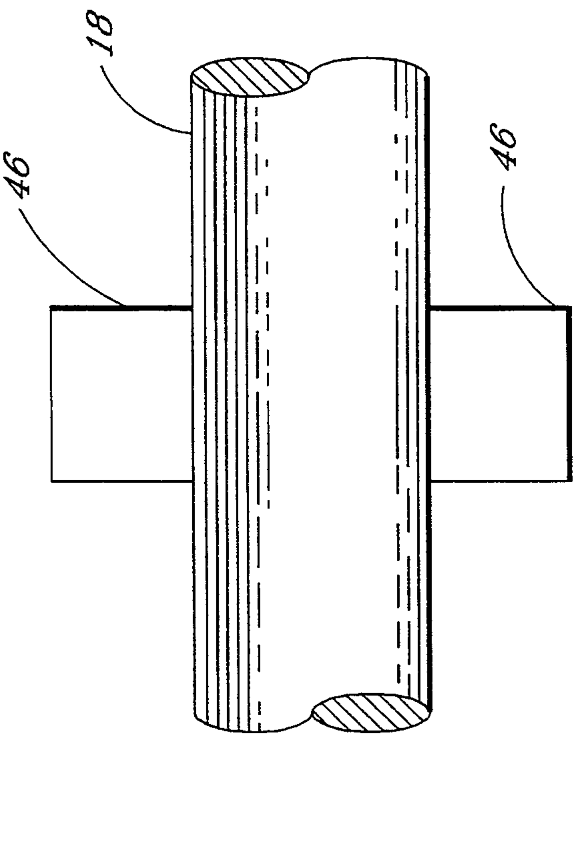


FIG. 9

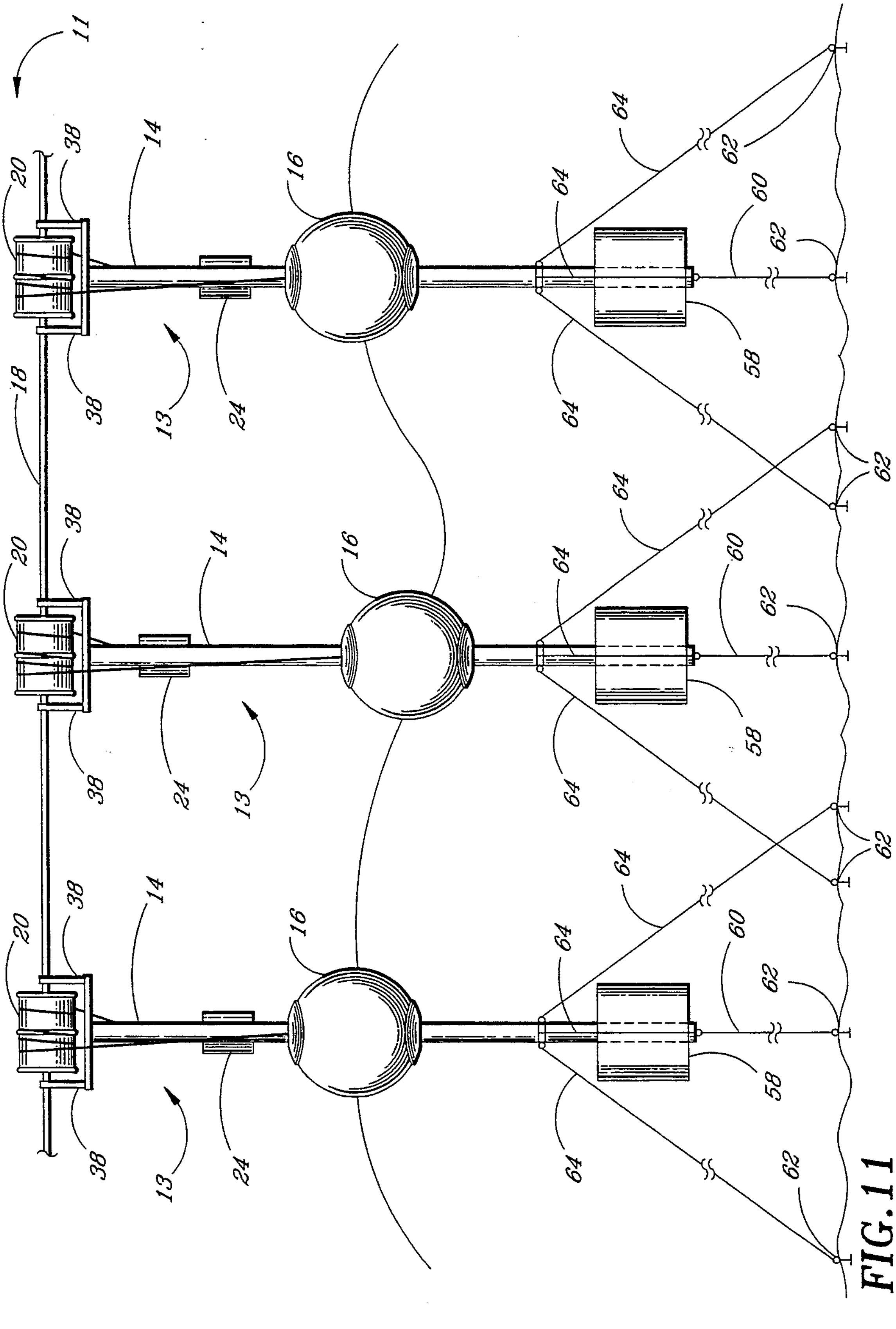


FIG. 11

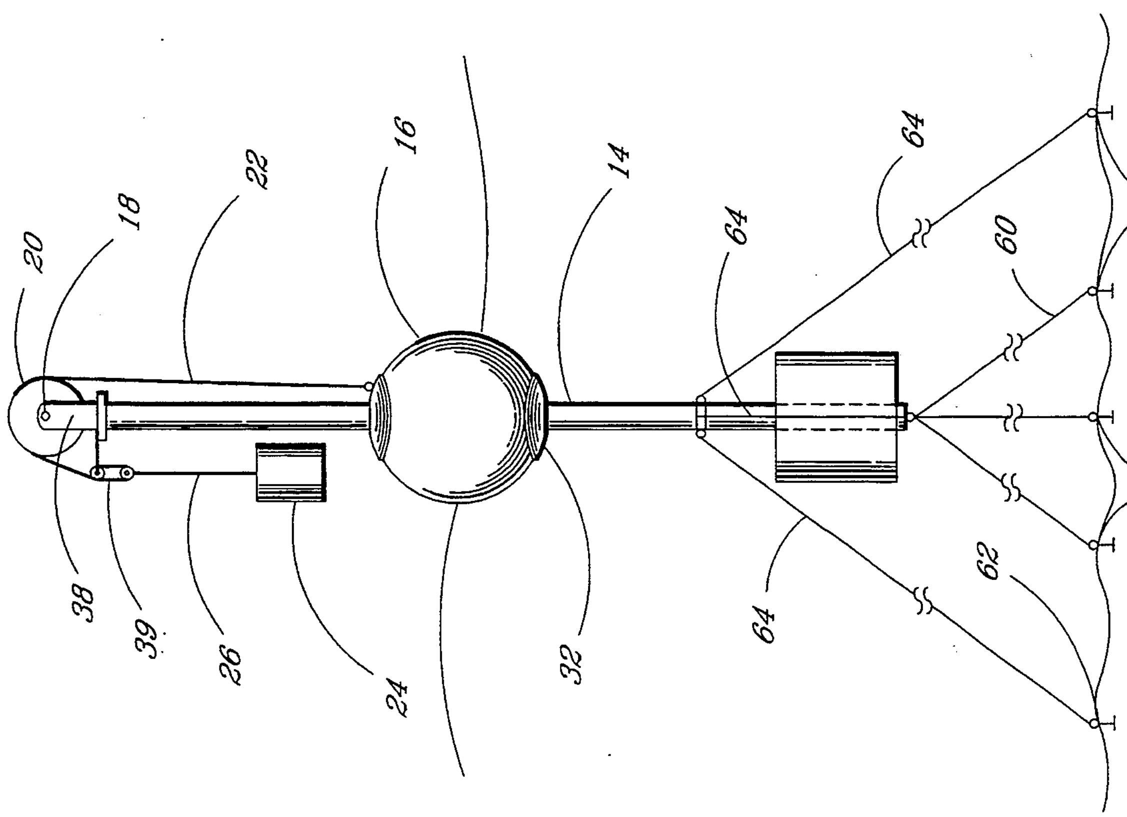


FIG. 12

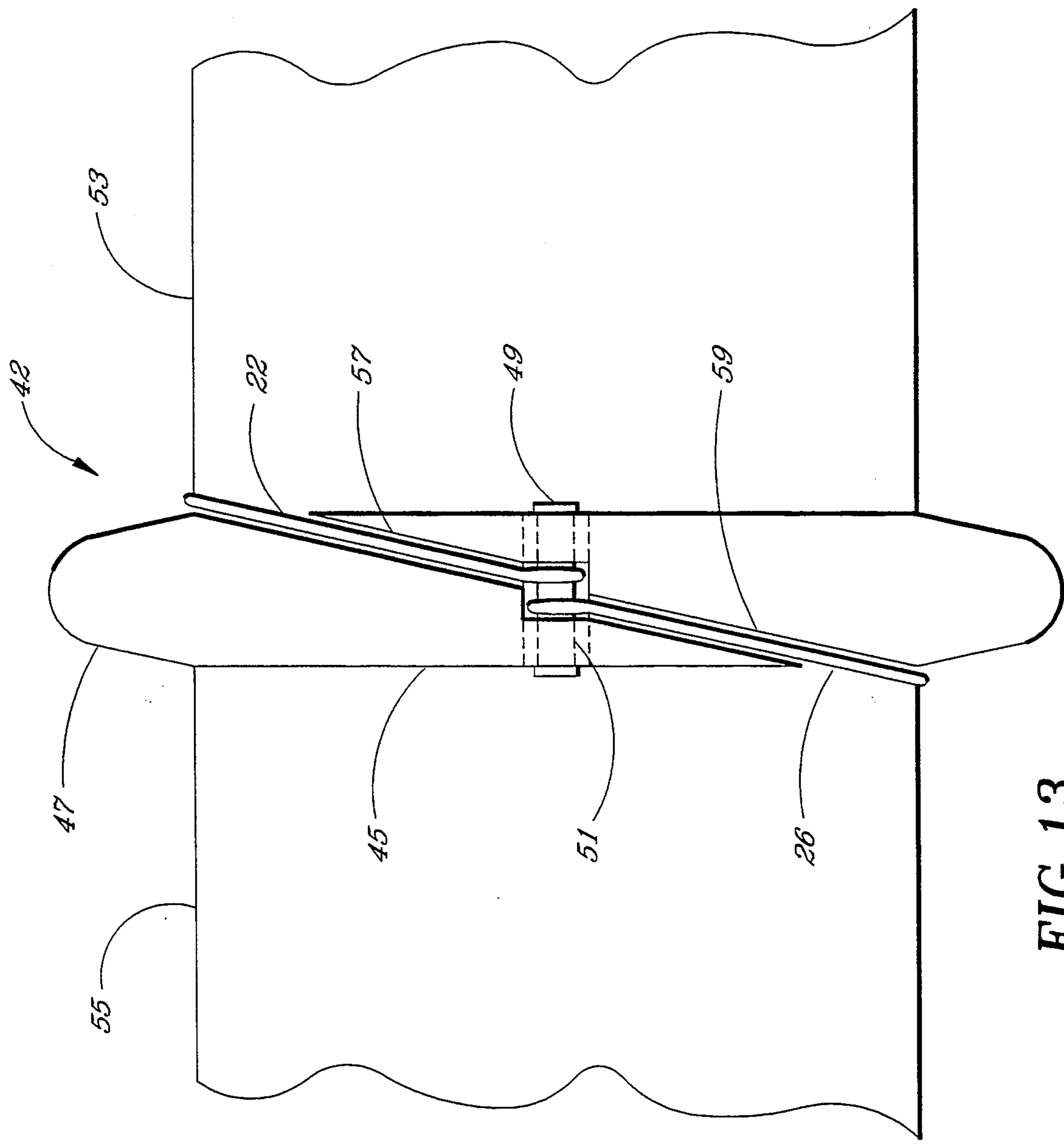


FIG. 13

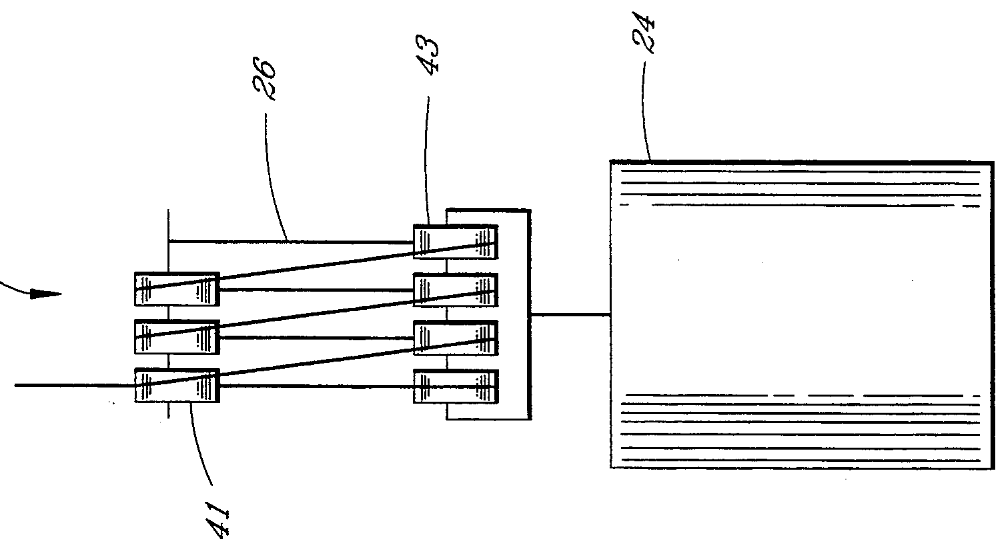


FIG. 14

APPARATUS FOR CONVERTING WAVE MOTION INTO ELECTRICAL ENERGY

This application is a continuation-in-part of application Ser. No. 08/102,891, filed Aug. 6, 1993, now abandoned.

BACKGROUND

It is well known that the periodic rising and falling of waves on the surface of a body of water provides a potential source of energy for conversion to useful power by man. Various structures have been proposed to harness this energy. The apparatus that will be most beneficial to man will be one that can be economically constructed and operated for use in locales that are suitable environments for wave energy conversion. These locales will generally be removed from more conventional sources of power generation. Additionally, a successful wave energy conversion apparatus must operate reliably in a harsh environment that could consist of salt-water, high winds, and constant wave action. Furthermore, the apparatus must be easily maintained.

SUMMARY

The present invention is directed to an apparatus that economically and reliably converts wave motion to electrical energy, and which is easy to maintain. An apparatus having features of the present invention comprises a series of conversion units interconnected so as to provide continuous rotation of a drive shaft that is connected to an electrical generator. Each conversion unit is comprised of a pylon having a lower portion submerged beneath the surface of a body of water and a top portion extending above the surface of the water. The pylon is held in a fixed position relative to the surface of the water by anchoring the pylon to the floor of the body of water. Attached to the pylon is a float which rises and falls with the rise and fall of waves on the surface of the body of water. The float has a generally spherical exterior and an internal chamber. Ballast such as water is contained within the internal chamber to provide weight to the float. The float further has a central opening through its vertical axis. Mounted within the central opening is a central guide means having a guide sleeve and a plurality of bearings secured to the guide sleeve. The central guide means allows the float to be telescopically fitted around the pylon. The float is thus guided so that it will slide up and down the pylon in a direction parallel to the vertical axis of the pylon.

A drive shaft is rotatably mounted to the pylon above the float. A downstroke drive transfer mechanism is mounted to the drive shaft. The float is connected to the downstroke drive transfer mechanism through a first cable means. A counter-weight is connected to the downstroke drive transfer mechanism through a second cable means.

The downstroke drive transfer mechanism is configured so that the drive shaft is rotated in a predetermined direction as the float moves downwards as a wave trough passes. As the float moves upwards in response to a passing wave crest, the counter-weight falls, causing the first cable means to wind around the downstroke drive transfer mechanism. The drive shaft is not rotated in response to the upward motion of the float.

An alternative embodiment of present invention has a pylon having a buoyancy means attached to the bottom portion which has a buoyant force that urges the pylon upwards. The pylon is held rigidly in place by a plurality of cables attached to the bottom of the pylon and anchored to the floor of the body of water.

The interconnected conversion units can be aligned sequentially by connecting the drive shaft of each conversion unit to that of another, with the drive shaft of a terminal conversion unit being connected to an electrical generator.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features, aspects, and advantages of the present invention will become better understood with regard to the following description, appended claims and accompanying drawings where:

FIG. 1 is a pictorial view showing an arrangement of several interconnected conversion units embodying the invention.

FIG. 2 is a pictorial view showing an alternative arrangement of several interconnected conversion units embodying the invention.

FIG. 3 is an enlarged side view showing the interconnection of one embodiment of the conversion unit embodying the invention.

FIG. 4 is an end view of the conversion unit as shown in FIG. 3.

FIG. 5 is a cross section taken substantially on line 5—5 of FIG. 4.

FIG. 6 is a cross section taken substantially on line 6—6 of FIG. 4.

FIG. 7 is an enlarged, partially broken, side view of the down stroke drive mechanism.

FIG. 8 is an enlarged cross section of the down stroke drive mechanism taken substantially along line 8—8 of FIG. 3.

FIG. 9 is a plan view of the drive shaft showing the key.

FIG. 10 is an end view of the drive shaft as shown in FIG. 9.

FIG. 11 is an enlarged side view showing the interconnection of an alternative embodiment of the conversion unit embodying the invention.

FIG. 12 is an end view of the conversion unit as shown in FIG. 11.

FIG. 13 is a frontal view of the cable guide means.

FIG. 14 is a frontal view showing the pulley system means.

DESCRIPTION

As shown in FIG. 3, an apparatus for converting wave motion into electrical energy is generally designated by numeral 10. The apparatus 10 according to the present invention comprises a plurality of operatively interconnected conversion units 12, each conversion unit having a vertical pylon 14 rigidly attached to the floor of the body of water, a float 16 slideably connected to the pylon 14, a drive shaft 18 rotatably mounted to the pylon 14, a downstroke drive mechanism 20 attached to the drive shaft 18, float cable means 22 having a first end connected to the float 16 and a second end connected to the downstroke drive mechanism 20, a counter-weight 24, and counter-weight cable means 26 (shown in FIG. 4) having a first end connected to the counter-weight 24 and a second end connected to the downstroke drive mechanism 20.

The pylon **14** is a vertical column and has a bottom portion submerged beneath the surface of the water that is securely anchored to the floor of the body of water using conventional marine construction techniques and a top portion extending well above the surface of the water.

As shown in FIG. **5**, the float **16** has a generally spherical shape. The float **16** contains one or more internal chambers **28** which are partially filled with a ballast material **29** such as water. The float will have sufficient buoyancy to be elevated by passing waves and sufficient mass to fall after the waves pass so that the downward movement of the float **16** can be efficiently converted into useful electrical energy in the manner set forth below. It will be understood by those skilled in the art that a plurality of shapes, materials and ballast configurations may be utilized in the float **16** of the present invention.

In the preferred embodiment, the float **16** is comprised of a plurality of float segments **17**, as best seen in FIG. **6**. Each float segment **17** contains a single internal chamber **28** which is partially filled with the ballast material. The individual float segments **17** are bolted together in place around the pylon **14** to form the float **16**. The float segments **17** are made of a durable material, such as plastic, fiberglass, aluminium or stainless steel.

As best seen in FIG. **5**, the float **16** further has a generally central guide means **32** which telescopes over the vertical pylon **14**. The guide means **32** thereby guides the float **16** in a vertical direction parallel to the vertical axis of the pylon **14**. In the preferred embodiment of the invention the guide means **32** consists of a guide sleeve **34** and a plurality of roller bearings **36** which allow the float **16** to easily slide up and down the vertical pylon **14** in response to the rise and fall of waves on the surface of the body of water.

The guide sleeve **34** is made in two halves which are joined together using bolts or dowels when the float **16** and guide means **32** are assembled around the pylon **14**.

As shown in FIG. **3**, the drive shaft **18** is rotatably mounted above the top of the pylon **14** and float **16** and is supported by at least one bearing support **38**. In the preferred embodiment, the drive shaft **18** is supported by two bearing supports **38**. The drive shaft **18** is driven by the downward vertical motion of the float **16** as shown in more detail below. The drive shaft **18** can be connected in series with other conversion units **12** in the apparatus **10** or may be connected to an electrical generator for producing electricity.

The downstroke drive mechanism **20** is provided for converting the downward motion of the float **16** into rotation of the drive shaft **18** in a predetermined direction. As shown in FIG. **7**, the downstroke drive mechanism **20** comprises a ratchet drum **40** attached to the drive shaft **18**, the surface of the ratchet drum **40** having a plurality of teeth parallel to the drive shaft **18**, a drive mechanism housing **42** which encloses the ratchet drum **40** and which is rotatably attached to the drive shaft **18**, a plurality of pawls **44** having a first end pivotally connected to the inside surface of the drive mechanism housing **42** and a second end matingly engageable with the teeth of the ratchet drum **40** when the float **16** is moving downwards.

In the preferred embodiment of the present invention the drive shaft **18** has two male keys **46** each located approximately 180 degrees from the other as shown in FIG. **10**. The ratchet drum **40** is comprised of two halves, each of which is solid, having a semicircular outer surface, and each having a notch for receipt of one of the male keys **46** on the drive shaft **18**. The two halves of the ratchet drum **40** are fastened together around the drive shaft **18** so that one of the notches in the ratchet drum **40** receives one of the keys **46** on the drive shaft **18**. The ratchet drum halves can be made of suitable material such as stainless steel and bolted or keyed together over the drive shaft **18**.

In the preferred embodiment of the present invention, the drive mechanism housing **42** has roller bearing means **48** on each end for rotatably mounting the drive mechanism housing **42** to the drive shaft **18**.

In the preferred embodiment of the present invention, the ratchet drum **40** will also have bearing means **43** for maintaining the ratchet drum **40** aligned within the drive mechanism housing **42**, and for preventing the ratchet drum **40** from contacting the inner end walls of the drive mechanism housing **42** due to lateral movement of the drive mechanism housing **42**. This bearing means **43** is typically called a runout bearing.

As best seen in FIG. **8**, the drive mechanism housing **42** also includes pawl biasing means **50** for limiting the pivotal movement of each of the pawls **44** as the drive mechanism housing **42** rotates in response to the downward motion of the float **16**. The pawl biasing means **50** further will maintain the pawls **44** against the teeth of the ratchet drum **40** when the drive mechanism housing **42** is rotating in response to the downward motion of the float **16**.

Each pawl **44** also has means for preventing contact between the pawl **44** and the teeth of the ratchet drum **40**, when the drive mechanism housing **42** rotates in response to the downward motion of the counterweight **24** as the float **16** moves upwards in response to the crest of a wave. The means for preventing contact between the pawls **44** and the teeth of the ratchet drum **40** comprises at least one leaf spring **52** attached to the end of the pawl **44** which engages the ratchet drum teeth. The preferred embodiment of the present invention has three leaf springs **52** on each pawl. The leaf springs **52** also align the pawl with the ratchet drum teeth for engagement therewith when the drive mechanism housing **42** rotates in response to the downward motion of the float **16**.

The drive mechanism housing **42** also includes waterproof sealing means for preventing water from entering the enclosure surrounding the ratchet drum **40**. In the preferred embodiment a lip **54** extends annularly around each end of the drive mechanism housing **42** to form a cylindrical cavity **56** on each end. Each cylindrical cavity **56** receives a waterproof packing material made of synthetic rubber such as nitrile, neoprene, silicon or butyl which forms a watertight seal between the drive shaft **18** and the drive mechanism housing **42**.

As best seen in FIG. **13** the drive mechanism housing **42** also includes cable guide means **45** for guiding the float cable means **22** and the counter-weight cable means **26** to prevent entanglement during operation. In the preferred embodiment of the present invention, the cable guide means **45** is comprised of a center partition **47** extending around the center circumference of the drive mechanism housing **42**, a removable pin **49** for attaching the float cable means **22** and the counterweight cable means **26** to the drive mechanism housing **42** and a keyway **51** for receipt of the removable pin **49**. The center partition **47** divides the outer surface of the drive mechanism housing into a float cable means section 53 and a counter-weight cable means section 55.

The float cable means 22 is connected at one end to the float 16 and at the other end to the outer surface of the drive mechanism housing 42 through the cable guide means 45. The center partition 47 has a groove 57 which receives the float cable means 22 and guides the float cable means 22 to the float cable means section 53. The float cable means 22 is wound around the outer surface of the drive mechanism housing 42 onto the float cable means section 53 a number of times sufficient to allow the float 16 a full range of unimpeded up and down motion in response to the rise and fall of waves on the surface of the water.

The counter-weight cable means 26 is connected at one end to the counter-weight 24 and at the other end to the outer surface of the drive mechanism housing 42, through the cable guide means 45. The center partition 47 has a groove 59 which receives the counter-weight cable means 26 and guides the counter-weight cable means to the counter-weight cable means section 55. The counter-weight cable means 26 is wound around the outer surface of the drive mechanism housing 42, in a direction opposite to that of the float cable means 22, onto the counter-weight cable means section 55, a number of times sufficient to allow the counter-weight 24 a full range of upward motion when the counter-weight rises as the drive mechanism housing 42 rotates in response to the downward motion of the float 16. A pulley system 39, shown in FIG. 4, may be utilized to guide the counter-weight cable means 26 and to reduce the range of vertical motion traveled by the counter-weight 24 as the float 16 rises and falls, thus preventing the counter-weight 24 from hitting the float 16 during operation.

The pulley system 39 is of the type well known in the art. As shown in FIG. 14 the pulley system 39 in the present invention includes a top fixed pulley 41 which is secured to the pylon 14 and a bottom movable pulley 43 to which the counter-weight 24 is attached. The pulley system 39 is arranged so that the lowest position of the counter-weight 24 is above the highest position of float 16 as the float moves upwards in response to the rise of a wave crest. The pulley system 39 is attached to the pylon 14.

An alternate embodiment of the invention is illustrated in FIG. 11, is generally designated by the numeral 11 and has a plurality of conversion units 13 which are operatively interconnected. In this embodiment, the pylon 14 is cylindrical with a bottom portion submerged beneath the surface of the body of water and a top portion extending well above the surface of the water. Connected to the bottom portion of the pylon 14 is a buoyancy means 58 which has a buoyant force that urges the pylon 14 upwards. The pylon 14 is held rigidly in place by a first set of cables 60 attached to the seabed by anchors 62 and connected to the pylon 14 below the buoyancy means 58 and by a second set of cables 64 attached to the seabed by anchors 62 and connected to the pylon above the first set of cables 60. The second set of cables 64 can be attached to the pylon 14 either above or below the buoyancy means 58. In this alternate embodiment of the present invention, the preferred embodiment has the second set of cables 64 attached to the pylon above the buoyancy means 58.

In operation, the float 16 rises in response to a wave crest. As the float 16 rises, the counter-weight 24 falls under the influence of gravity. The downward motion of the counter-weight 24 is transferred to the drive mechanism housing 42 through the counter-weight cable means 26 in a direction which does not allow the pawls 44 to engage the teeth of the ratchet drum, since the pawls 44 can pivot in this direction. The leaf springs 52 touch the teeth to guide the pawls 44 as the drive mechanism housing 42 rotates. Thus, as the float moves upwards no rotation is transmitted to the drive shaft 18.

As the wave passes, the float 16 falls under the influence of gravity. This downward motion of the float 16 is transmitted through the float cable means 22 to the drive mechanism housing 42 causing the drive mechanism housing 42 to rotate in a predetermined direction. As the drive mechanism housing 42 rotates in response to the downward motion of the float 16, the pawls 44 engage the teeth of the ratchet drum 40 causing the ratchet drum 40 and the drive shaft 18 to rotate in the same predetermined direction as the drive mechanism housing 42.

In actual operation of the preferred embodiment in a body of water, and in order to obtain continuous rotation of the drive shaft 18, a plurality of the conversion units 12 are connected by coupling the drive shaft 18 of each conversion unit 12 to that of another conversion unit 12, with a terminal conversion unit 12 being connected to a central electrical energy conversion platform 65 for transforming the rotation of the drive shaft into useful electrical energy. In one configuration, best seen in FIG. 1, the conversion units 12 will be aligned end to end so that a particular wave will pass the conversion units 12 sequentially rather than simultaneously, thus providing a smoother conversion of the wave action into rotation of the drive shaft 18.

In an alternative configuration, best seen in FIG. 2 the conversion units 12 will extend radially from a central electrical energy conversion platform 66, with each line of interconnected conversion units 12 connecting to an electrical generator located on the energy conversion platform 66.

These two configurations shown in FIGS. 1 and 2 can also be configured using the alternative embodiment of the conversion unit 13 shown in FIG. 11.

It will be evident to those skilled in the art that many modifications of the present invention are possible without materially departing from the scope of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined by the following claims.

What is claimed is:

1. An apparatus for converting water wave motion into electrical energy, comprising:
- a) a plurality of interconnected conversion units, each conversion unit including:
  - A) support means mounted in a substantially fixed position relative to the surface of a body of water;
  - B) float means slideably mounted to the support means;
  - C) a drive shaft rotatably mounted to the support means;
  - D) pulley system means attached to the support means;
  - E) float cable means having a first end attached to the float and a second end;
  - F) a counter-weight connected to the pulley system means;
  - G) counter-weight cable means having a first end attached to the pulley system means and a sec-

ond end, the counter-weight cable means being looped through the pulley system means to reduce the vertical motion of the counter weight in response to the rise and fall of waves;

H) a downstroke drive transfer mechanism for rotating the shaft in a predetermined direction in response to the downward movement of the float means, the downstroke drive transfer mechanism comprising,

i) a hollow drive mechanism housing rotatably mounted to the drive shaft, the drive mechanism housing having a float cable means section and a counter-weight cable means section,

ii) a cylindrical ratchet drum housed within the drive mechanism housing and secured to the drive shaft,

iii) cable guide means on the outside surface of the drive mechanism housing, the cable guide means being attached to the second end of the float cable means and to the second end of the counter-weight cable means, the float cable means being wound around the float cable means section of the drive mechanism housing in a first direction and the counter-weight cable means being wound around the counter-weight cable means section of the drive mechanism housing in a second direction opposite to that of the first direction,

iv) means for transferring the rotation of the drive mechanism housing caused by the downward motion of the float means to the ratchet drum;

b) means connected to the drive shaft for converting the rotation of the drive shaft into electrical energy.

2. The apparatus of claim 1 wherein the support means comprises:

a) a vertical pylon having a lower portion submerged beneath the surface of the water and an upper portion above the surface of the water;

b) means for anchoring the pylon to the floor of the body of water.

3. The apparatus of claim 2 wherein the float means comprises:

a) a shell having a generally spherical exterior and an internal chamber for receipt of a ballast means, the shell further having a central opening through which the shell is slideably mounted to the pylon; and

b) ballast means.

4. The apparatus of claim 3 wherein the shell further comprises:

a) a central guide means slideably mounted to the pylon for constraining the shell to generally vertical motion parallel to the axis of the pylon.

5. The apparatus of claim 4 wherein the central guide means comprises:

a) a guide sleeve mounted to the central opening of the shell and a plurality of roller bearings secured to the guide sleeve for easily sliding up and down the vertical pylon.

6. The apparatus of claim 1 wherein the means for transferring the rotation of the drive mechanism housing to the ratchet drum comprises:

a) a plurality of teeth secured to the outer surface of the ratchet drum that run parallel to the drive shaft;

b) a plurality of pawls each pivotally connected at one end to the inside surface of the drive mechanism housing for drivably engaging the teeth on the ratchet drum; and

c) pawl biasing means for limiting the pivotal movement of each pawl.

7. The apparatus of claim 6 wherein the support means comprises:

a) a vertical pylon having a lower portion submerged beneath the surface of the water and an upper portion above the surface of the water;

b) means for anchoring the pylon to the floor of the body of water.

8. The apparatus of claim 7 wherein the float means comprises:

a) a shell having a generally spherical exterior and an internal chamber for receipt of a ballast means, the shell further having a central opening through which the shell is slideably mounted to the pylon; and

b) ballast means.

9. The apparatus of claim 8 wherein the shell further comprises:

a) a central guide means slideably mounted to the pylon for constraining the shell to generally vertical motion parallel to the axis of the pylon.

10. The apparatus of claim 9 wherein the central guide means comprises:

a) a guide sleeve mounted to the central opening of the shell and a plurality of roller bearings secured to the guide sleeve for easily sliding up and down the vertical pylon.

11. The apparatus of claim 10 wherein the pylon further comprises:

a) buoyancy means attached to the lower portion of the pylon whereby the pylon is urged upwards due to buoyant forces.

12. The apparatus of claim 11 wherein the means for anchoring the pylon to the floor of a body of water comprises:

a) a first set of cables, the first set having a plurality of cables, each cable having a first end attached to the lower portion of the pylon and a second end attached to the floor of the body of water; and

b) a second set of cables, the second set having a plurality of cables, each cable having a first end attached to the pylon above the first set of cables and below the buoyancy means and a second end attached to the floor of the body of water.

13. The apparatus of claim 6 wherein the cable guide means further comprises:

a) a center partition extending around the center circumference of drive mechanism housing, the center partition having a keyway for receipt of a removable pin;

b) a removable pin;

c) a first groove for receipt of the float cable means; and

d) a second groove for receipt of the counter-weight cable means.

14. The apparatus of claim 13 wherein the support means comprises:

a) a vertical pylon having a lower portion submerged beneath the surface of the water and an upper portion above the surface of the water;

b) means for anchoring the pylon to the floor of the body of water.

15. The apparatus of claim 13 wherein each pawl further comprises:

a) at least one leaf spring, the leaf spring being connected to the pawl so that one end of the leaf spring matingly engages the teeth on the ratchet drum, thus positioning the pawl for engaging the ratchet drum teeth when the float is moving downwards.

16. The apparatus of claim **15** wherein the drive mechanism housing further comprises:

a) roller bearing means on each end for rotatably mounting the drive mechanism housing to the drive shaft; and

b) waterproof sealing means to create a watertight seal between the drive mechanism housing and the drive shaft.

17. The apparatus of claim **16** wherein the float means comprises:

a) a shell having a generally spherical exterior and an internal chamber for receipt of a ballast means, the shell further having a central opening through which the shell is slideably mounted to the pylon; and

b) ballast means.

18. The apparatus of claim **17** wherein the shell further comprises:

a) a central guide means slideably mounted to the pylon for constraining the shell to generally vertical motion parallel to the axis of the pylon.

19. The apparatus of claim **18** wherein the central guide means comprises:

a) a guide sleeve mounted to the central opening of the shell and a plurality of roller bearings secured to the guide sleeve for easily sliding up and down the vertical pylon.

20. An apparatus for converting water wave motion into electrical energy, comprising:

a) a plurality of interconnected conversion units, each conversion unit including:

A) support means mounted in a substantially fixed position relative to the surface of a body of water, the support means comprising a vertical pylon having a lower portion submerged beneath the surface of the water and an upper portion above the surface of the water and means for anchoring the pylon to the floor of the body of water;

B) float means, the float means comprising a shell and ballast means, the shell having a generally spherical exterior and an internal chamber for receipt of the ballast means, the shell further having a central opening through which the shell is slideably mounted to the pylon;

C) a drive shaft rotatably mounted to the support means in a position above the float means;

D) pulley system means attached to the support means;

E) float cable means having a first end attached to the float;

F) a counter-weight connected to the pulley system means;

G) counter-weight cable means having a first end attached to the pulley system means and a second end, the counter-weight cable means being looped through the pulley system means to reduce the vertical motion of the counter-weight in response to the rise and fall of waves;

H) a downstroke drive transfer mechanism for rotating the shaft in a predetermined direction in response to the downward movement of the float means, the downstroke drive transfer mechanism comprising a cylindrical ratchet drum secured to the drive shaft having a plurality of teeth on the outer surface that run parallel to the drive shaft, and further comprising a drive mechanism housing, the inside of the drive mechanism housing being hollow, having a plurality of pawls each pivotally connected at one end to the inside surface of the drive mechanism housing for drivably engaging the teeth on the ratchet drum assembly, the drive mechanism housing further comprising pawl biasing means for limiting the pivotal movement of each pawl, each pawl having at least one leaf spring, each leaf spring connected to the pawl so that one end of the leaf spring matingly engages the teeth on the ratchet drum assembly when the float means is moving upwards for preventing the pawl from striking the ratchet drum teeth, thus positioning the pawl for engaging the ratchet drum assembly teeth when the float means is moving downwards, the drive mechanism housing further comprising cable guide means on the outside surface of the drive mechanism housing for connecting the float cable means and the counter-weight cable means to the drive mechanism housing and for preventing the entanglement of the float cable means and the counter-weight cable means, the drive mechanism housing further having roller bearing means for rotatably mounting the drive mechanism housing to the drive shaft so that the drive mechanism housing pawls matingly engage the ratchet drum assembly teeth when the float means is moving downwards, the drive mechanism housing having waterproof sealing means to create a watertight seal between the drive mechanism housing and the drive shaft, the float cable means having a first end attached to the float means and a second end attached to the cable guide means, the counter-weight cable means having a first end attached to the pulley system means and a second end attached to the drive mechanism housing for causing the drive mechanism housing to rotate when the float means is moving downwards, the counter-weight being connected to the pulley system means for preventing the counter-weight from striking the float when it moves downward;

b) means connected to the drive shaft for converting the rotation of the shaft into electrical energy.

21. The apparatus of claim **20** wherein the shell further comprises:

a) a central guide means slideably mounted to the pylon for constraining the shell to generally vertical motion parallel to the axis of the pylon.

22. The apparatus of claim **21** wherein the central guide means comprises:

a) a guide sleeve mounted to the central opening of the shell and a plurality of roller bearings secured to the guide sleeve for easily sliding up and down the vertical pylon.

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(54) WAVE-POWER GENERATION SYSTEM

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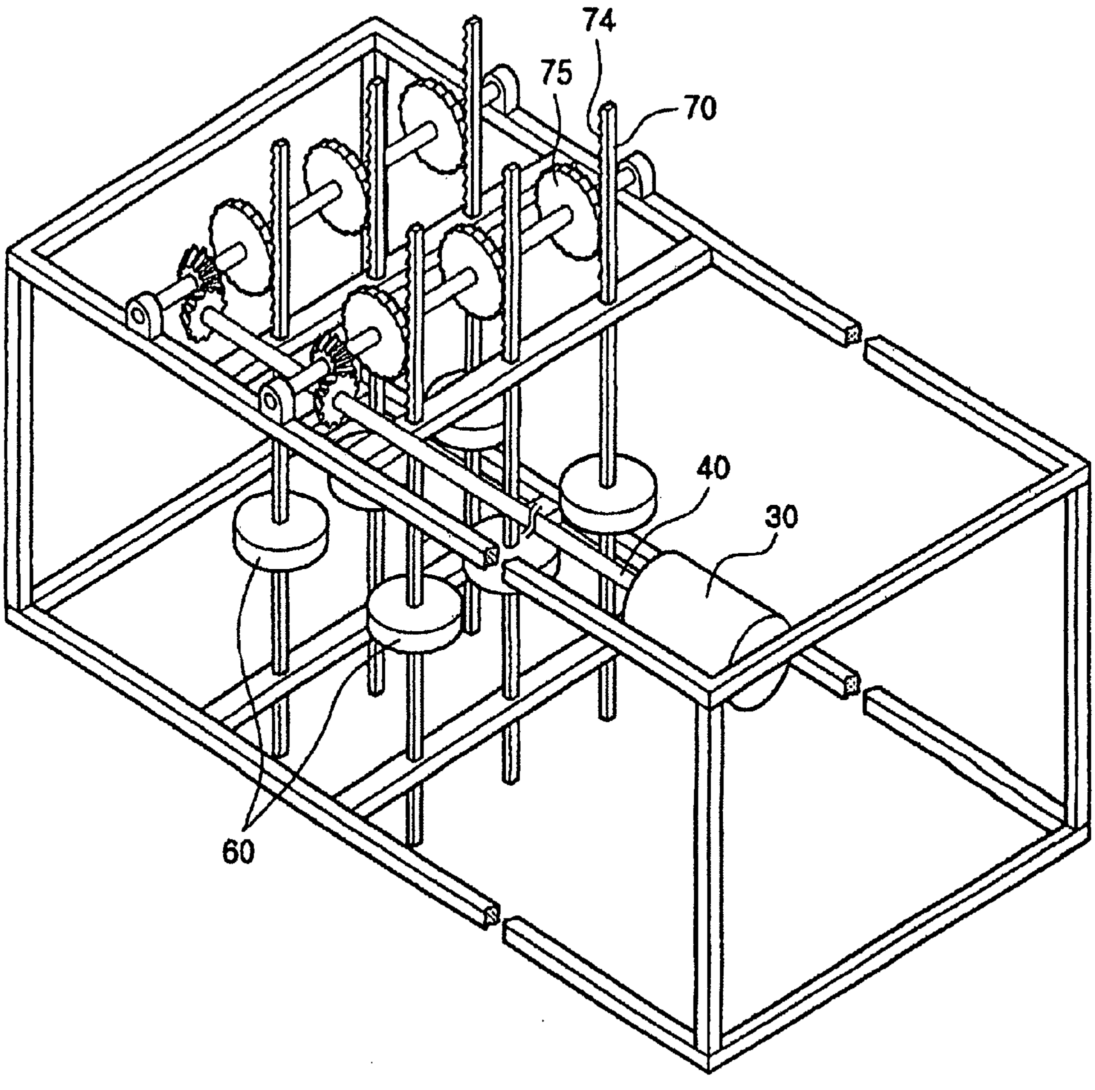
H02P 9/04 (2006.01)

(52) **U.S. Cl.** **290/53**

(57) **ABSTRACT**

Disclosed is a wave-power generation system. The system includes a stationary frame, a float structure installed to the stationary frame, a rotary shaft coupled to a generator and rotatably installed to the stationary frame, a rotary drive coupled to the rotary shaft of the generator via a one-way clutch, a three-node link rotatably installed at a point P of the stationary frame, a float installed to one end of the three-node link, a rope having one end coupled to the other end of the three-node link and the other end wound around the rotary drive, a flywheel installed to the rotary shaft, and a resiliently recovering member having one end coupled to the stationary frame and the other end coupled to the rotary drive.



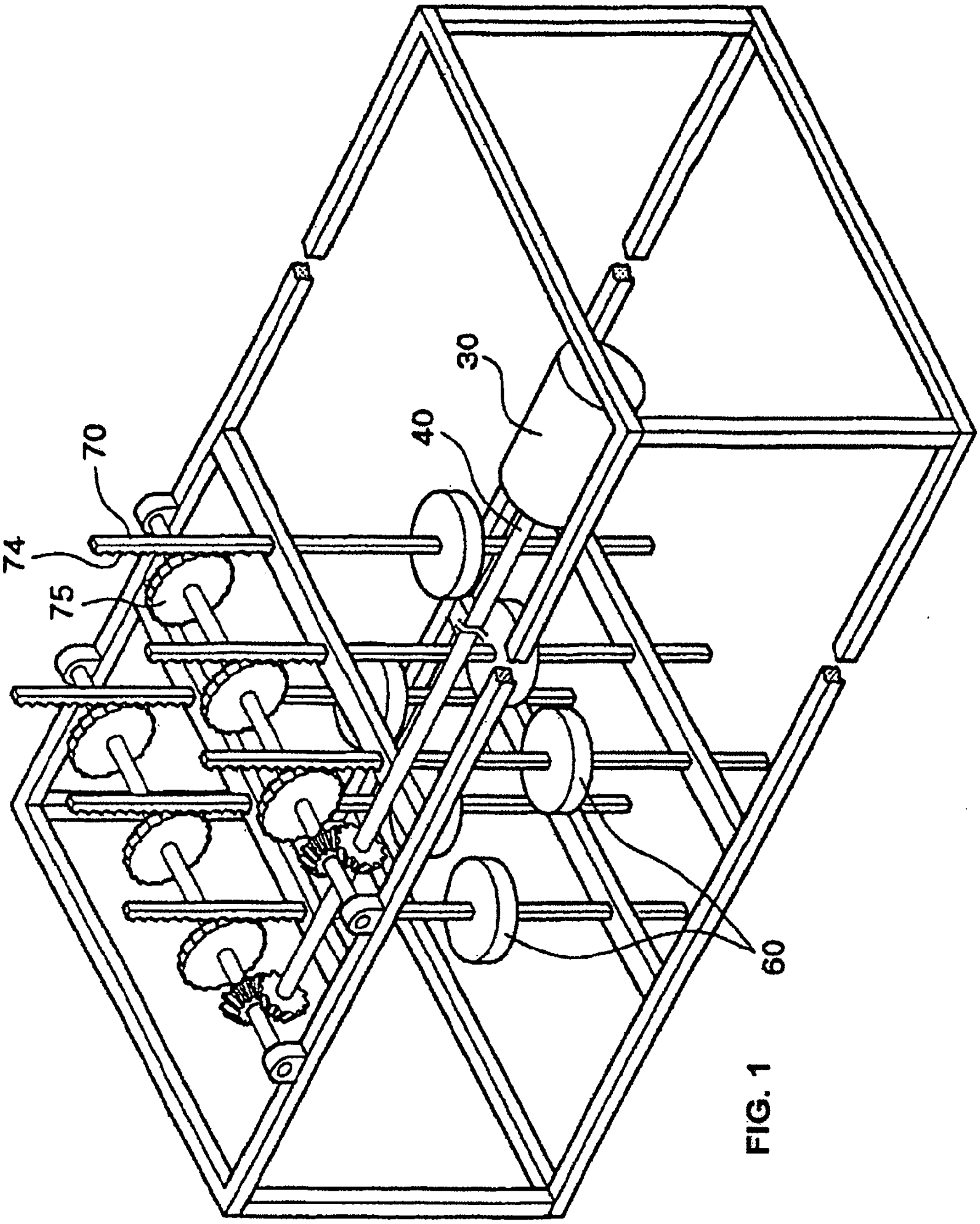


FIG. 1

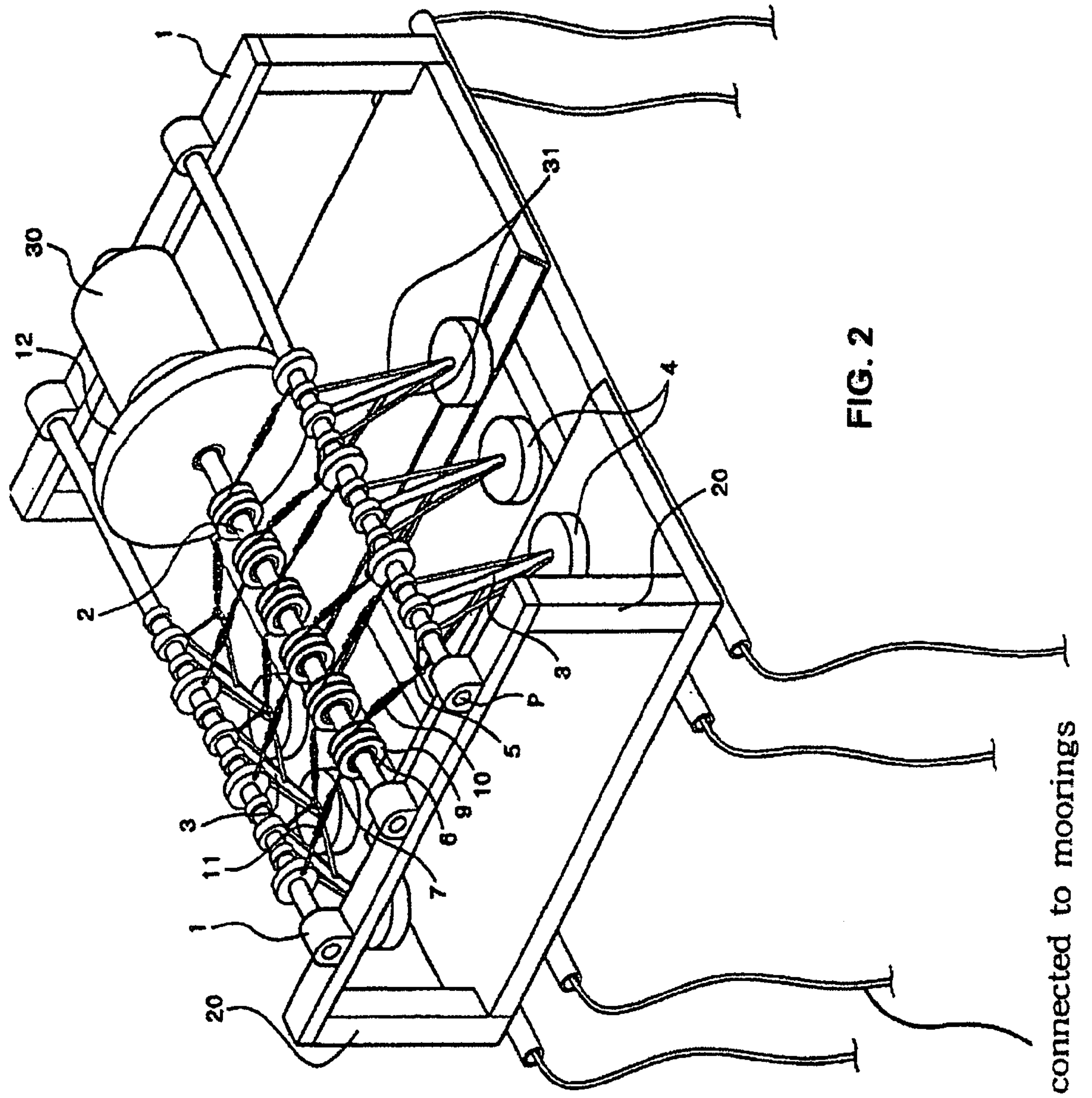


FIG. 2

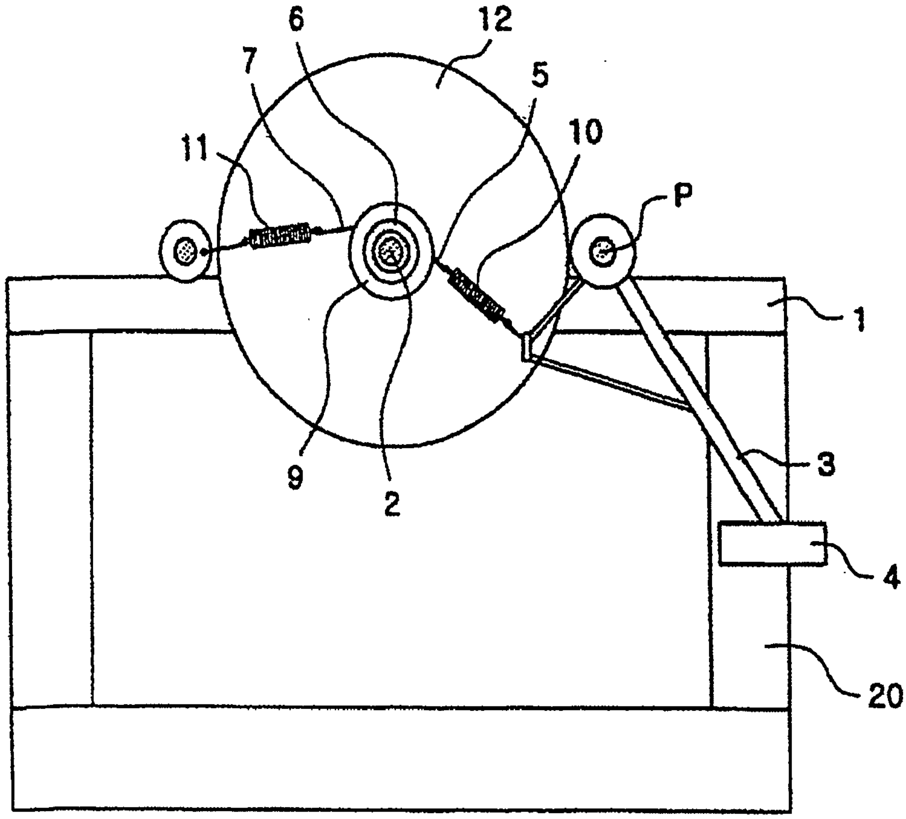


FIG. 3(a)

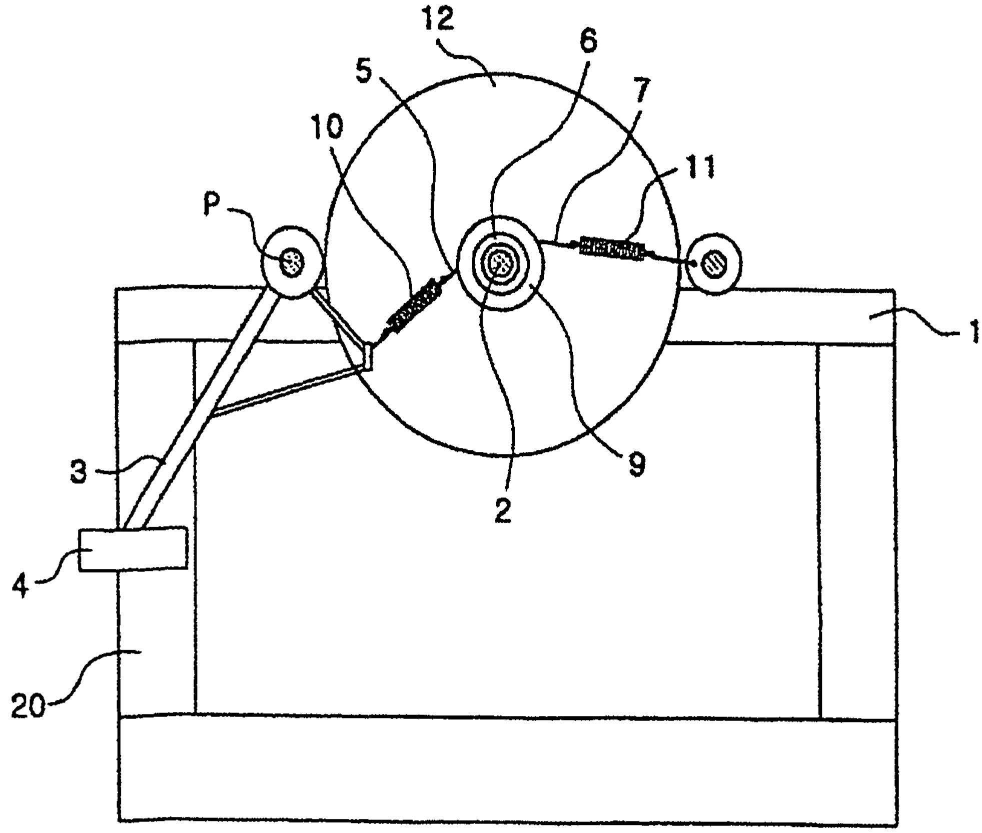


FIG. 3(b)

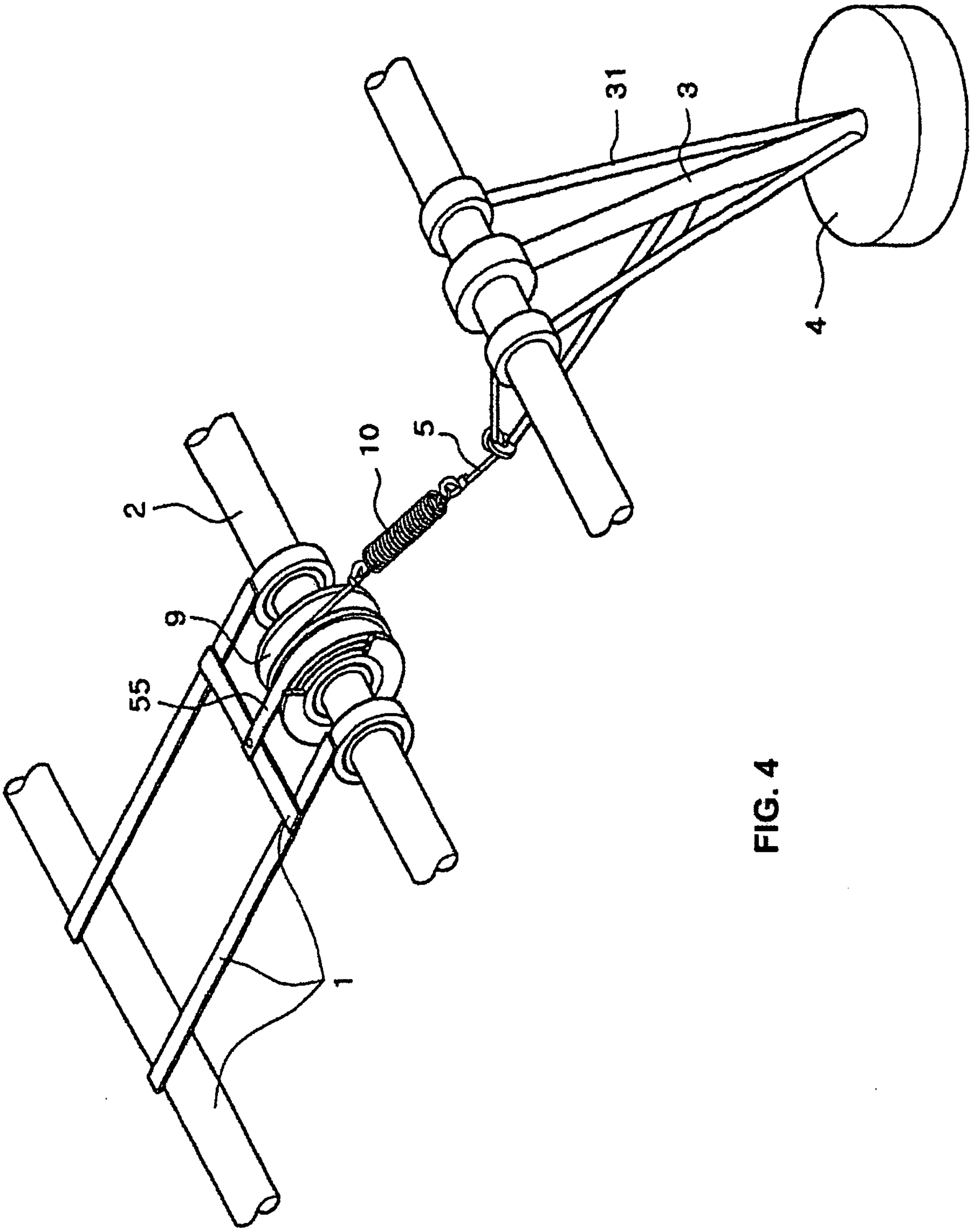


FIG. 4

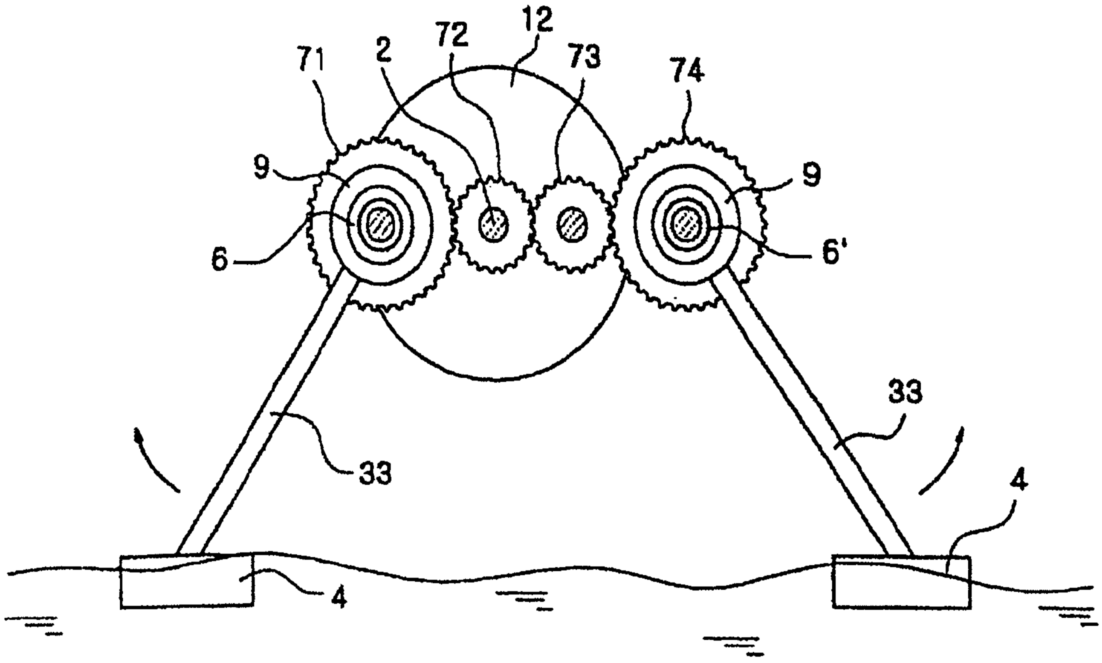


FIG. 5 (a)

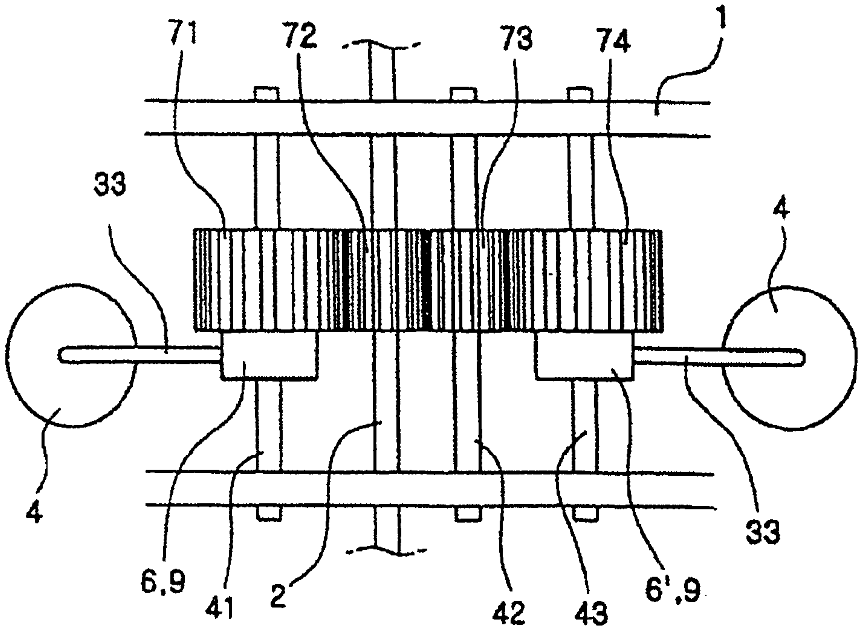


FIG. 5 (b)

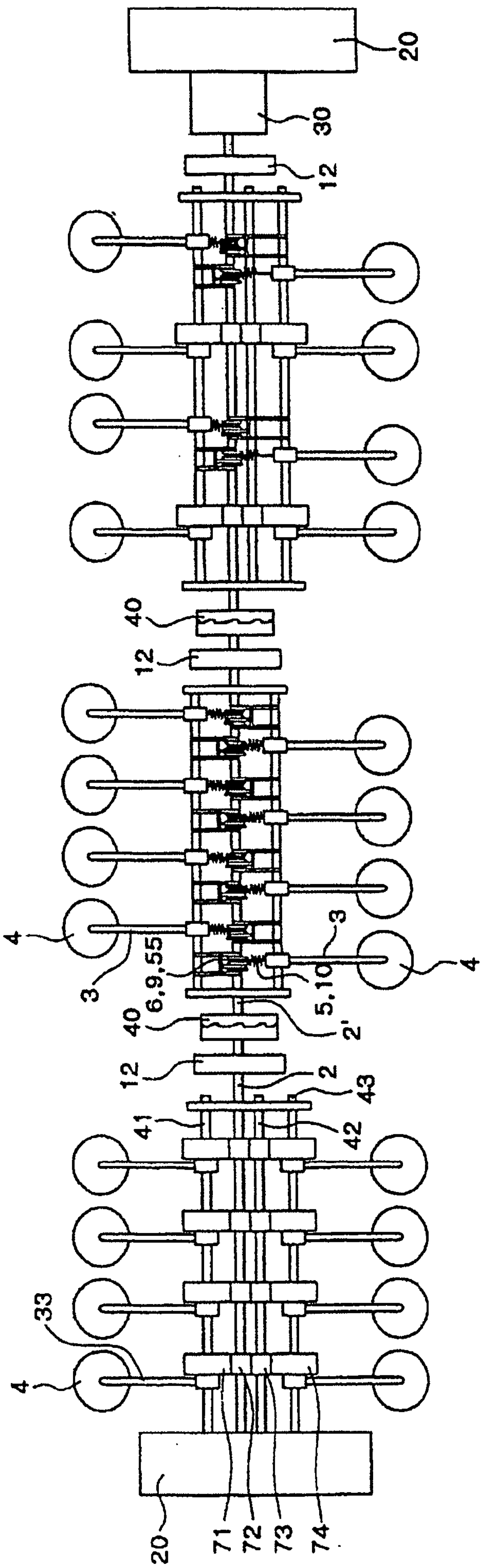


FIG. 6

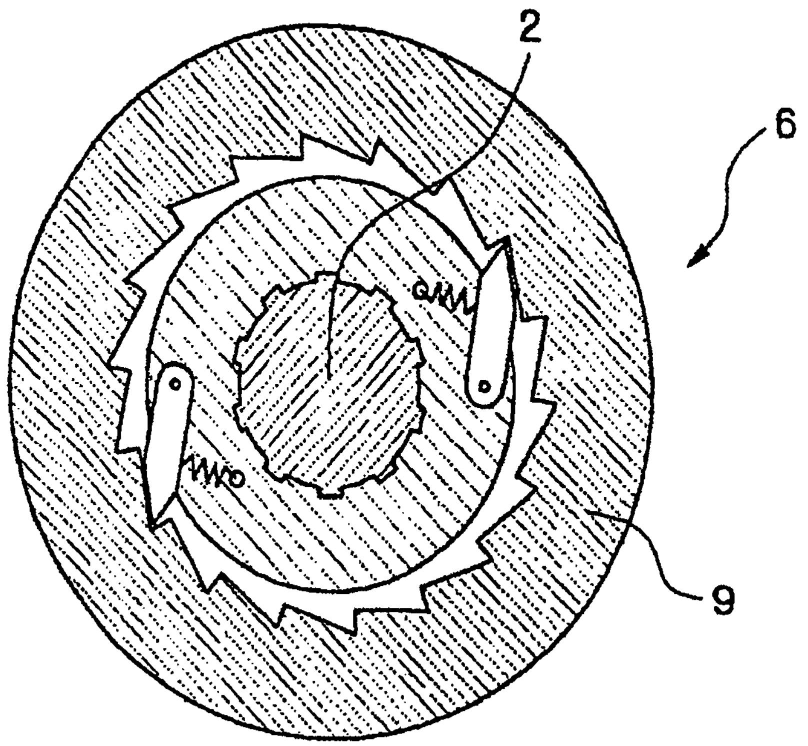


FIG. 7 (a)

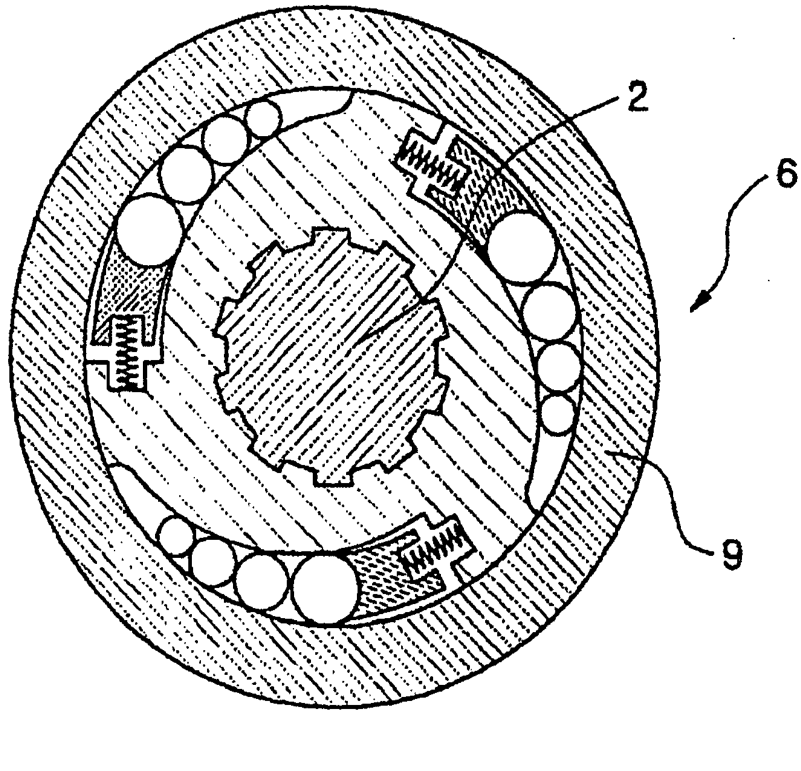


FIG. 7 (b)

WAVE-POWER GENERATION SYSTEM

[0001] This application is a continuation of pending International Patent Application No. PCT/KR2004/000874 filed on Apr. 14, 2004, which designates the United States and claims priority of Korean Application No. 10-2003-24875 filed on Apr. 19, 2003.

FIELD OF THE INVENTION

[0002] The present invention relates to a wave-power generation system, and more particularly, to a wave-power generation system converting kinetic energy into rotational energy using the forces of low and high tide to generate electric power.

BACKGROUND ART

[0003] Currently, electric power is generated by use of petroleum, fossil fuel, atomic energy, and the like. Since reserves of the petroleum and fossil fuel are limited, it should be exhausted with the passage of time. For the atomic energy, a usable period of uranium is limited because of finite exhaustion thereof and serious issue of radioactive waste.

[0004] Meanwhile, wind power or solar energy has advantages in that it can be infinitely utilized and does not cause harm to the public. However, it is difficult to search the optimum position of the wind since a wind direction is different depending upon a season and position. For the solar energy, there is a disadvantage in that since the percentage of sunshine is limited, a large-scale apparatus and an efficient energy transforming technique are required to recover the limited sunshine, which increases manufacturing costs.

[0005] Recently, power generating apparatuses have been proposed using tidal power or wave power. One typical example of those is disclosed in Korean Unexamined Patent Publication No. 2002-71492, in which the forces of low and high tide are transferred to a generator through float balls. Referring to **FIG. 1**, when a float ball **60** is lowered, a rotary shaft idles by a one-way clutch **75**. Whenever the sea rolls, the rotary shaft is continuously rotated in one direction to generate the power.

[0006] According to the prior art wave-power generation system, however, since only a simple principle is disclosed, several problems may occur in actual operation. For example, a float shaft **70** provided with the float ball **60** is formed with teeth **74**, and the one-way clutch **75** is directly engaged with the teeth **74**. When the sea rolls, the one-way clutch **75** may be detached from the teeth **64** of the float shaft **70** according to fluctuation of float shaft **70** and the one-way clutch **75** in a moment, which it is not possible to certainly transfer a drive force.

[0007] In addition, inertia force transferred to a rotary shaft **40** of the generator from the one-way clutch **75** is small. If there are no further waves, the rotation is likely distinguished at once. There is another drawback in that the prior art cannot use a large moment because of only utilizing only lifting force acting on the float balls **60**.

[0008] Furthermore, rotational speed and rotating force of the rotary shaft **40** depend upon the wave power only. There is another drawback in that in this case the fluctuation of a height of the wave is large it is difficult to stably generate an alternating current.

DISCLOSURE OF THE INVENTION

[0009] Therefore, an object of the present invention is to solve the problems involved in the prior art, and to provide a wave-power generation system, by which when wave power acts instantaneously, an operating state can be stably maintained to generate electric power.

[0010] Another object of the present invention is to provide a wave-power generation system capable of applying a rotating force to a rotary shaft using the large moment of leverage.

[0011] In order to accomplish the above and other objects, there is provided a wave-power generation system comprising: a stationary frame; a float structure installed to the stationary frame; a rotary shaft coupled to a generator and rotatably installed to the stationary frame; a rotary drive coupled to the rotary shaft of the generator via a one-way clutch; a three-node link rotatably installed at a point of the stationary frame; a float installed to one end of the three-node link; a rope having one end coupled to the other end of the three-node link and the other end wound around the rotary drive; a flywheel installed to the rotary shaft; and a resiliently recovering member having one end coupled to the stationary frame and the other end coupled to the rotary drive.

[0012] According another aspect of the present invention, there is provided a wave-power generation system comprising: a stationary frame; a float structure installed to the stationary frame; a rotary shaft coupled to a generator and rotatably installed to the stationary frame; a rotary drive coupled to the rotary shaft of the generator via a one-way clutch; a two-node link having one end fixed to the rotary drive; a float installed to one end of the two-node link; and a flywheel installed to the rotary shaft.

[0013] According further another aspect of the present invention, there is provided a wave-power generation system comprising: a first wave-power generation structure including a rotary shaft of a generator rotatably installed to a stationary frame; a rotary drive coupled to the rotary shaft of the generator via a one-way clutch; a three-node link rotatably installed at a point of the stationary frame; a float installed to one end of the three-node link; and a resiliently recovering member having one end coupled to the other end of the three-node link and the other end coupled to the rotary drive; and a second wave-power generation structure including a rotary drive coupled to the rotary shaft of the generator via a one-way clutch; a two-node link having one end fixed to the rotary drive; and a float installed to one end of the two-node link; and a flywheel installed to the rotary shaft; and wherein the wave-power generation structures are arranged along the rotary shaft of the generator, a float structure is installed to the stationary frame, and at least one flywheel is installed to the rotary shaft of the generator.

BRIEF DESCRIPTION OF DRAWINGS

[0014] The above objects, other features and advantages of the present invention will become more apparent by describing the preferred embodiment thereof with reference to the accompanying drawings, in which:

[0015] **FIG. 1** is a perspective view illustrating one example of a prior art wave-power generation system.

[0016] **FIG. 2** is a perspective view illustrating a wave-power generation system according to a first preferred embodiment of the present invention.

[0017] **FIGS. 3***a* and **3***b* are side views of the wave-power generation system in **FIG. 2**.

[0018] **FIG. 4** is a side view of a wave-power generation system including a resiliently recovering member different from that of the wave-power generation system in **FIG. 2**.

[0019] **FIG. 5***a* is a front view of the wave-power generation system and

[0020] **FIG. 5***b* is a top view of the system.

[0021] **FIG. 6** is a top view illustrating a wave-power generation system according to third embodiment of the present invention.

[0022] **FIGS.** 7*a* and 7*b* are views illustrating one example of a one-way clutch employed in the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0023] Reference will now be made in detail to preferred embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

First Embodiment

[0024] **FIGS. 2 through 4** show a wave-power generation system according to a first preferred embodiment of the present invention.

[0025] As shown in figures, the wave-power generation system of the present invention includes a stationary frame **1** for supporting various components, and a float structure **20** for floating the stationary frame **1** on the sea. The stationary frame **1** consists of relatively high-strength members engaged to each other. If the stationary frame **1** is floated on the sea together with the float structure **20**, a portion of the stationary frame is exposed from the surface of the sea, while a portion of the stationary frame sinks to the sea.

[0026] The stationary frame **1** is provided with a rotary shaft **2** of a generator which is freely rotated on the stationary frame **1**. A generator **30** coupled to the rotary shaft generates the power according to the rotation of the rotary shaft **2**. The stationary frame **10** includes a bearing (not shown) to rotatably support the rotary shaft **2**. The generator **30** has a conventional structure to generate the power by use of relative rotation between magnet and coil.

[0027] A rotary drive **9** is directly coupled to the rotary shaft **2** of the generator via the one-way clutch **6**. When the rotary drive **9** is rotated in one direction, the one-way clutch idles to interrupt the transmission. Consequently, since the rotary shaft can be rotated in one direction only, the rotary shaft may be further supplied with the rotary force whenever the sea rolls. **FIG. 7** shows examples of applicable one-way clutch **6**.

[0028] A three-node link **3** is operately installed at a point P of the stationary frame **1**. The three-node link refers to a member of which little relative displacement is between the point P, a coupling point of a rope **5** and an installing point of a float **4**. The three-node link may consist of crossed rods, as shown in the embodiment, or may be made of a flat plate. Preferably, support members **31** are installed to the three-node link in front and rear direction relative to the rotary shaft **2**.

[0029] One free end of the three-node link **3** is coupled to the float **4**, while the other free end is coupled to an end portion of the rope **5**. The float **4** floats on the sea, and is moved by the waves in a moment.

[0030] The other end of the rope **5** is wound around the rotary drive **9**. Preferably, the rotary drive **9** is provided on a circumference thereof with a common winding drum. The rotary drive is coupled to the rotary shaft **2** of the generator via the one-way clutch **6**.

[0031] The rope **5** is coupled to a tension spring **10** at a position facing the three-node link **3**, so that the float **4** raised by the waves is quickly returned to its original position by the tension spring.

[0032] As shown in **FIG. 3**, the rotary drive **9** is connected to the stationary frame **1** by the rope **7** and the tension spring **11**. After the float **4** is raised and then is lowered, the rotary drive **9** can be quickly recovered.

[0033] Referring to **FIG. 4**, if a spiral spring **55** is provided between the stationary **1** and the rotary drive **9**, the recovery may be conveniently and smoothly achieved.

[0034] As shown in **FIG. 2**, it is preferable that the three-node links **3** and the floats **4** are installed to the left and right sides of the rotary shaft **2** of the generator, respectively. In this case, the entire structure is stabilized because the weight thereof is balanced, as well as the increased rotating force.

[0035] In addition, in order to further increase the rotating force, two or more three-node links **3**, the floats **4**, the one-way clutches **6** and the ropes **5** may be provided along the rotary shaft **9**.

[0036] The rotary shaft **2** of the generator is provided with a flywheel **12**, so that a deviation of the rotating speed can be reduced by use of large inertial energy and the rotating energy can be retained in the case of no waves.

Second Embodiment

[0037] **FIG. 5** shows a wave-power generation system according to a second preferred embodiment of the present invention.

[0038] Referring to **FIG. 5**, the wave-power generation system of the present invention includes a stationary frame **1**, a float structure **20** installed to the stationary frame **1**, a generator's rotary shaft **2** rotatably installed to the stationary frame **1**, and a flywheel **12** installed to the rotary shaft **2**, which is similar to the first embodiment.

[0039] In this embodiment, the rotary drive **9** is coupled to the rotary shaft **2** of the generator via a one-way clutch **6**. One end of a two-node link **33** is coupled to the rotary drive **9**, and a float **4** is installed to a free end of the two-node link **33**.

[0040] A follower of the one-way clutch **6** and a first intermediate gear **71** are installed to a first rotating drive shaft **41** installed to the stationary frame **1** in a direction parallel with the rotary shaft **2** of the generator. The first intermediate gear **71** meshes with a second gear **72** installed to the rotary shaft **2** of the generator. As such, when a left float **4** is raised, the first intermediate gear **71** is rotated through the one-way clutch **6**, and then the rotary shaft **2** of the generator **2** is rotated by the second intermediate gear **72** meshed with the first intermediate gear **71**.

[0041] The first intermediate gear **71** has a diameter larger than that of the second intermediate gear **72** to increase a rotating speed.

[0042] A third intermediate gear **73** is installed to an intermediate rotary shaft **42** installed parallel with the rotary shaft **2** of the generator. The follower of the one-way clutch **6** and a fourth intermediate gear **74** are installed to a second rotating drive shaft **43** installed to the stationary frame **1** in a direction parallel with the rotary shaft **2** of the generator. The third intermediate gear **73** may be meshed with the second intermediate gear **72** and the fourth intermediate gear **74**.

[0043] As such, when a right float **4** is raised, the fourth intermediate gear **74** meshed with the third intermediate gear **73** is rotated, and then the second intermediate gear **72** is rotated by the third intermediate gear **73**, thereby rotating the rotary shaft **2** of the generator. When the float **4** is lowered, the transmission is interrupted by the one-way clutch **6**, while the rotary shaft **2** of the generator is continuously rotated by the flywheel **12**.

[0044] The fourth intermediate gear **74** has a diameter larger than that of the third intermediate gear **73** to increase a rotating speed.

[0045] Two or more pairs of two-node links **33**, floats **4**, one-way clutches **6** may be installed to the rotary shaft **2** of the generator to achieve a high rotating speed of the rotary shaft.

Third Embodiment

[0046] **FIG. 6** shows a wave-power generation system according to a third preferred embodiment of the present invention.

[0047] Referring to **FIG. 6**, the wave-power generation system of the present invention includes a rotary shaft **2** of a generator rotatably installed to a stationary frame **1**, a rotary drive **9** coupled to the rotary shaft **2** of the generator via a one-way clutch **6**, a three-node link **3** rotatably installed at a point P of the stationary frame **1**, a float **4** installed to one end of the three-node link **3**, and a resiliently recovering member having one end coupled to the other end of the three-node link **3** and the other end coupled to a rope **5**. One end of the rope **5** is coupled to the other end of the three-node link **3**, and the other end is coupled to the rotary drive **9**. One end of the resilient covering member is coupled to the stationary frame **1**, and the other end is coupled to the rotary drive **9**. The wave-power generating system also includes the rotary drive **9** coupled to the rotary shaft **2** of the generator via the one-way clutch **6**, a two-node link **33** having one end fixed to the rotary drive **9**, and the float **4** installed to the free end of the two-node link **33**. A float structure **20** is installed to the stationary frame **1**, and a flywheel **12** is installed to the rotary shaft **2** of the generator.

[0048] When the driving force is transmitted to the generator **30**, the rotating speed of the rotary shaft **2** of the generator is further increased. An overdriving apparatus **40** may serve as a so-called gear box.

[0049] The operation of the wave-power generation system according to the first embodiment of the present invention will now be described.

[0050] As shown in **FIG. 3**, when the float **4** is raised by the waves, the three-node link **3** installed to the float **4** is rotated. As such, the tension is acted on the rope **5** coupled to one end of the three-node link **3** to rotate the rotary drive **9** around which the rope is wound. Finally, the rotary shaft **2** of the generator coupled to the rotary drive **9** via the one-way clutch **6** starts rotating.

[0051] When the rotary shaft **2** of the generator rotates, the rotating energy is stored in the flywheel **12**. Therefore, a variation of the rotating speed is remarkably reduced to stably rotate the rotary shaft, thereby generating the power by the generator **30**.

[0052] When the raised float **4** is lowered, the three-node link is rapidly returned to its original position by the tension spring **10**. At the same time, the rotary drive **9** is reversely rotated by the tension spring **11** of the rope **7** or the spiral spring **55**.

[0053] The rotating force of the rotary shaft is more increased by installing the floats **4** to the left and right sides of the rotary shaft. In addition, a plurality of floats **4** is installed along the rotary shaft **2** of the generator to improve the efficiency of the generator.

[0054] While the present invention has been described and illustrated herein with reference to the preferred embodiments thereof, it will be apparent to those skilled in the art that various modifications and variations can be made therein without departing from the spirit and scope of the invention. Thus, it is intended that the present invention covers the modifications and variations of this invention that come within the scope of the appended claims and their equivalents.

INDUSTRIAL APPLICABILITY

[0055] As apparent from the above description, since the floats are installed to the links coupled to the stationary frame, structure strength of the system is increased.

[0056] In addition, a large moment is applied to the rotary shaft by the three-node link to remarkably increase the rotating force of the rotary shaft.

[0057] Since the flywheel is installed to the rotary shaft of the generator, the rotary shaft may be stably maintained in the rotating speed and the rotating force in the case the wave power is applied in a moment. Therefore, the system can generate the power stably.

What is claimed is:

1. A wave-power generation system comprising:

a stationary frame;

a float structure installed to the stationary frame;

a rotary shaft coupled to a generator and rotatably installed to the stationary frame;

a rotary drive **9** coupled to the rotary shaft of the generator via a one-way clutch;

a three-node link rotatably installed at a point P of the stationary frame;

a float installed to one end of the three-node link;

a rope having one end coupled to the other end of the three-node link and the other end wound around the rotary drive;

a flywheel installed to the rotary shaft; and

a resiliently recovering member having one end coupled to the stationary frame and the other end coupled to the rotary drive.

2. The wave-power generation system as claimed in claim 1, wherein a tension spring is provided between the rope and the three-node link.

3. The wave-power generation system as claimed in claim 1, wherein the resiliently recovering member includes a tension spring and a spiral spring.

4. The wave-power generation system as claimed in claim 2, wherein the resiliently recovering member includes a tension spring and a spiral spring.

5. The wave-power generation system as claimed in claim 1, wherein the wave-power generation system is installed to left and right sides of the rotary shaft, respectively.

6. The wave-power generation system as claimed in claim 5, wherein at least two sets of the wave-power generation system are installed along the rotary shaft.

7. The wave-power generation system as claimed in claim 6, wherein at least two wave-power generation systems are coupled along the rotary shaft via an overdriving apparatus and the one-way clutch.

8. A wave-power generation system comprising:

a stationary frame;

a float structure installed to the stationary frame;

a rotary shaft coupled to a generator and rotatably installed to the stationary frame;

a rotary drive coupled to the rotary shaft of the generator via a one-way clutch;

a two-node link having one end fixed to the rotary drive;

a float installed to one end of the two-node link; and

a flywheel installed to the rotary shaft.

9. The wave-power generation system as claimed in claim 8, wherein a follower of the one-way clutch and a first intermediate gear are installed to a first rotating drive shaft installed to the stationary frame in a direction parallel with the rotary shaft of the generator, and the first intermediate gear meshes with a second gear installed to the rotary shaft of the generator, in which the first intermediate gear has a diameter larger than that of the second intermediate gear.

10. The wave-power generation system as claimed in claim 9, wherein

a third intermediate gear is installed to an intermediate rotary shaft installed parallel with the rotary shaft of the generator, and the follower of the one-way clutch and a fourth intermediate gear are installed to a second rotating drive shaft installed to the stationary frame in a direction parallel with the rotary shaft of the generator, and the third intermediate gear meshes with the second intermediate gear and the fourth intermediate gear, in which the fourth intermediate gear has a diameter larger than that of the third intermediate gear.

11. The wave-power generation system as claimed in claim 8, wherein at least two sets of the wave-power generation system are installed along the rotary shaft.

12. The wave-power generation system as claimed in claim 11, wherein at least two wave-power generation systems are coupled along the rotary shaft via an overdriving apparatus and the one-way clutch.

13. A wave-power generation system comprising:

a first wave-power generation structure including

a rotary shaft of a generator rotatably installed to a stationary frame;

a rotary drive coupled to the rotary shaft of the generator via a one-way clutch;

a three-node link rotatably installed at a point P of the stationary frame;

a float installed to one end of the three-node link; and

a resiliently recovering member having one end coupled to the other end of the three-node link and the other end coupled to the rotary drive; and

a second wave-power generation structure including

a rotary drive coupled to the rotary shaft of the generator via a one-way clutch;

a two-node link having one end fixed to the rotary drive; and

a float installed to one end of the two-node link; and

a flywheel installed to the rotary shaft; and

wherein the wave-power generation structures are arranged along the rotary shaft of the generator,

a float structure is installed to the stationary frame, and

at least one flywheel is installed to the rotary shaft of the generator.

* * * * *

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Sidenmark et al.

(54) **WAVE ENERGY CONVERTER**

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(73) Assignee: **OCEAN HARVESTING TECHNOLOGIES AB**, Karlskrona (SE)

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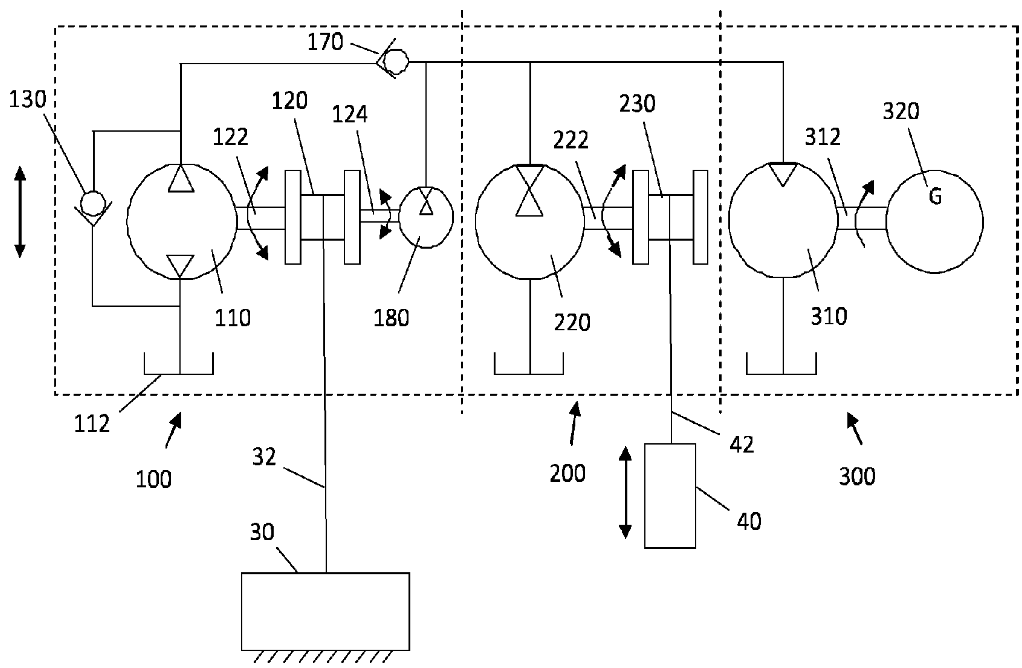
(52) **U.S. Cl.**

CPC . *F03B 13/18* (2013.01); *E02B 9/08* (2013.01); *F03G 3/00* (2013.01)

USPC **290/53**

(57) **ABSTRACT**

A wave energy converter (**10**) comprises an energy absorption unit (**100**) arranged to absorb energy generated by movements of water when the wave energy converter is arranged in a pool of water, an energy accumulation unit (**200**) connected to the energy absorption unit, and a power generation unit (**300**) connected to the energy absorption unit. The energy accumulation unit is arranged to accumulate energy from the energy absorption unit when the energy absorption unit absorbs more power than the power generation unit generates and to dissipate energy to the power generation unit when the energy absorption unit absorbs less power than the power generation unit generates. By providing hydraulic components in these units, an efficient and flexible wave energy converter is provided.



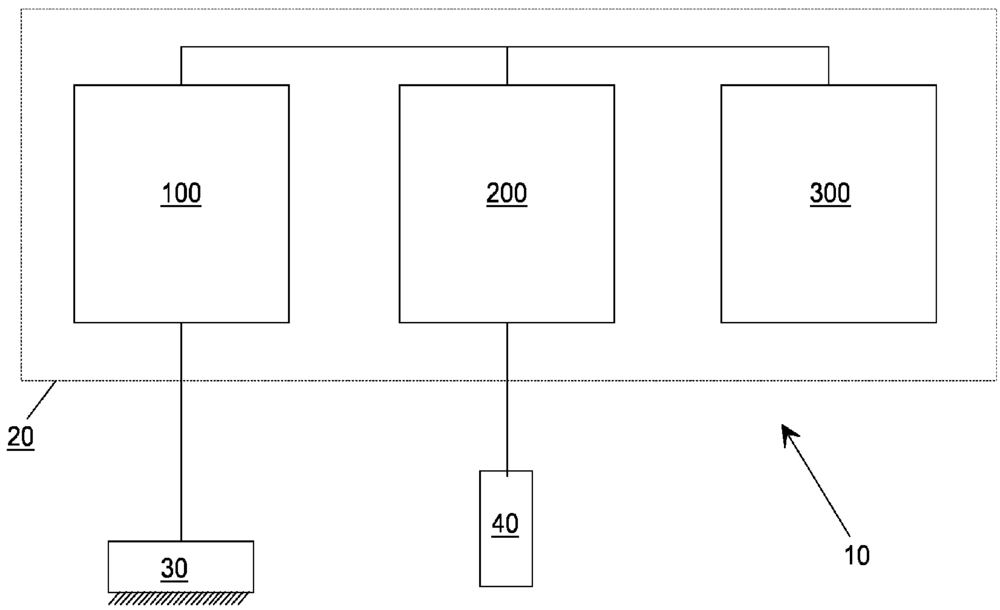

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Fig. 1

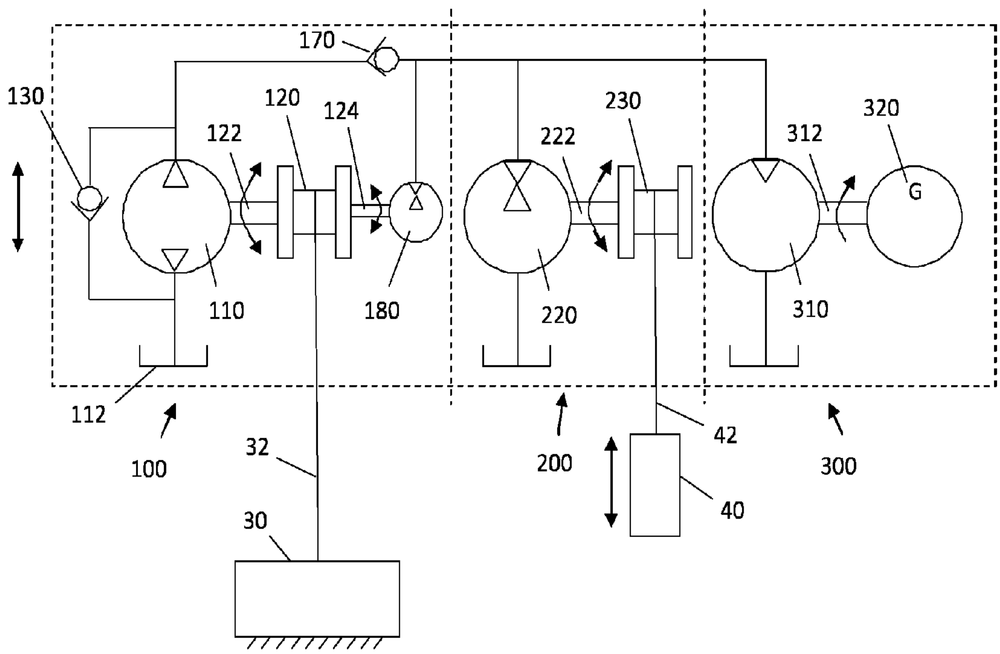
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Fig. 2

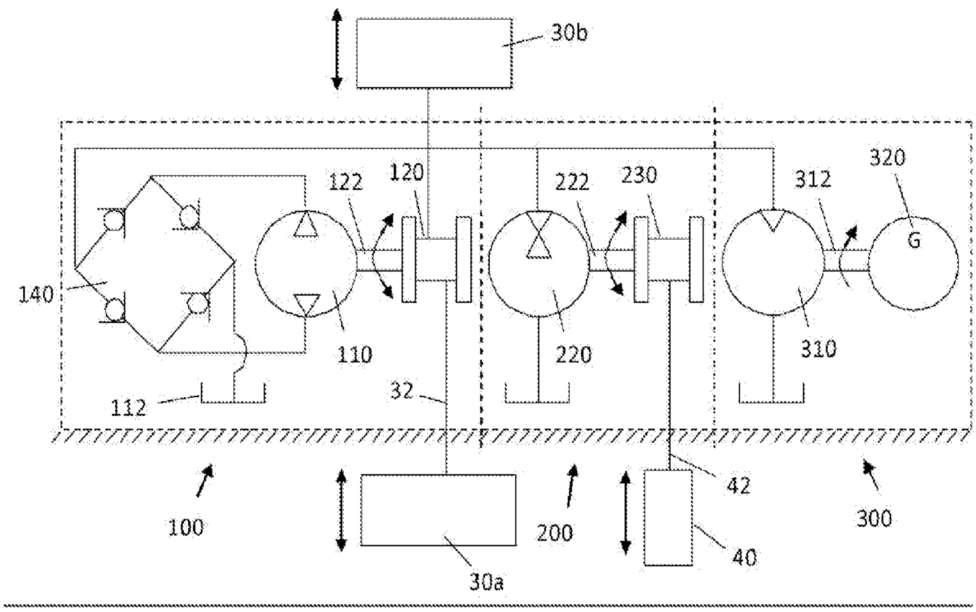
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Fig. 3

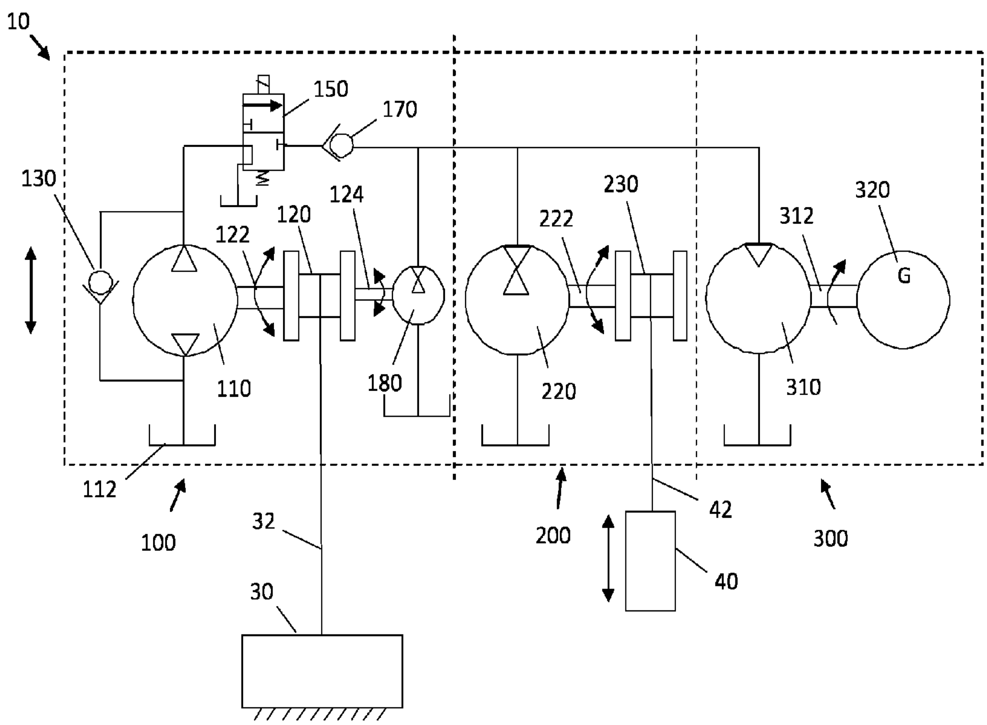
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Fig. 4

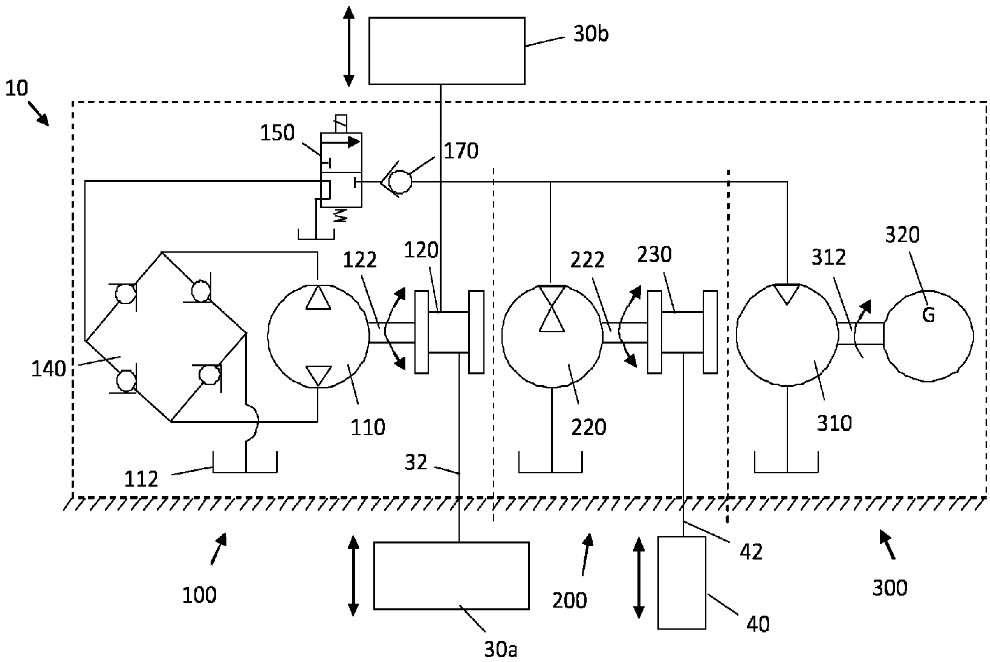
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Fig. 5

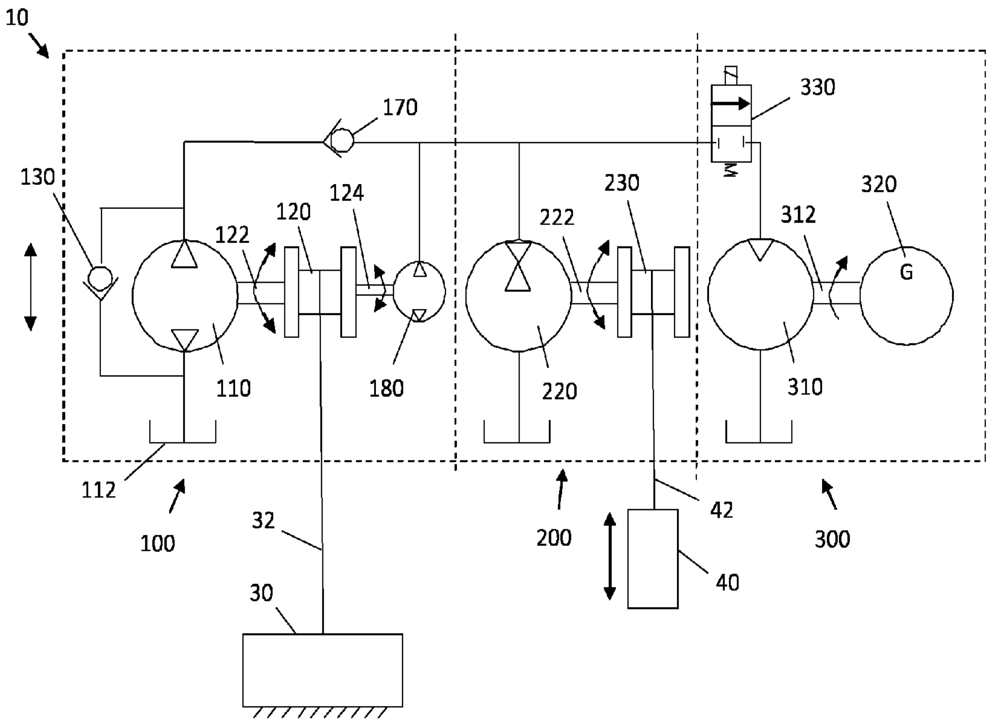
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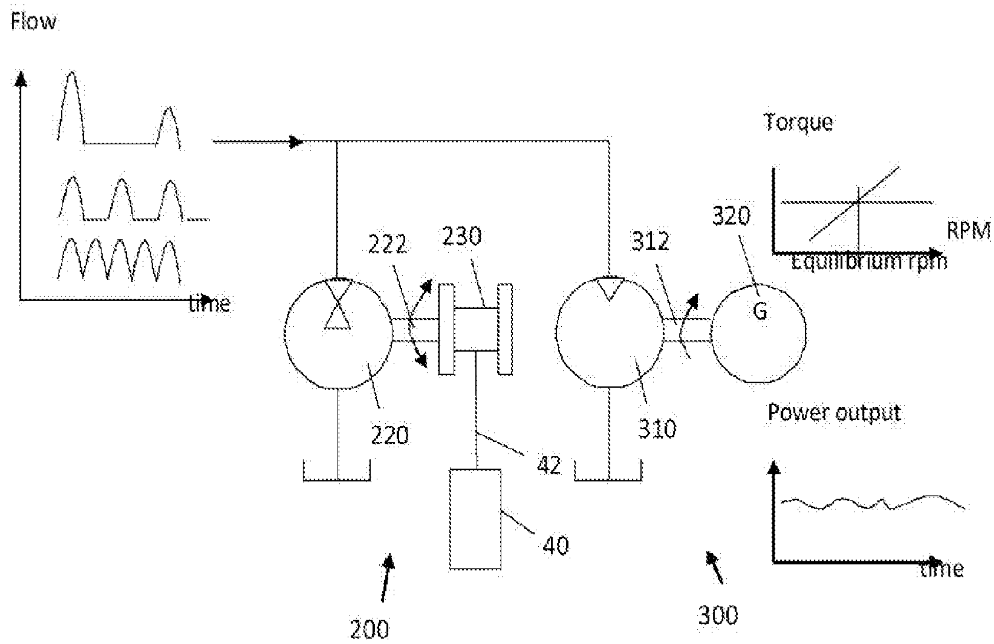
Fig. 6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Torque
RPM
Equilibrium rpm
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42
40
Power output
time
200
300

Fig. 7

WAVE ENERGY CONVERTER

TECHNICAL FIELD

[0001] The present invention relates to a wave energy converter for producing electric energy from movements of water waves, and a method of producing electric energy from more or less intermittent mechanical energy, such as more or less periodical movements of a body.

BACKGROUND ART

[0002] Wave energy is a concentrated form of renewable energy that comes from the friction between the water surface and the wind. The energy is built up by the wind on the open seas and then transported to locations closer to the shore, where it can be extracted with wave energy converters. Due to the high energy density of ocean waves, wave power is very area efficient and the average energy content changes more slowly and predictably compared to, for example, the wind. The resources are vast and can be harvested close to populated areas.

[0003] However, there are great challenges that must be solved before wave power can be commercially viable. Intermittent and highly fluctuating energy from the ocean waves must efficiently be converted into a steady output of electricity that is suitable for the power grid. Ocean waves have never ceasing variations in height, length, direction and time period (velocity) from wave to wave at a given sea state. A sea state is defined by the significant wave height (Hs) which is calculated from the average of the highest ⅓ of 100 waves in a row. The sea state will change slowly but largely over time; in storm conditions the average energy content in a sea state can be over 100 times higher than during normal conditions (annual average).

[0004] In order for a wave energy converter to capture energy efficiently, it should have sufficient length of stroke to follow the highest waves in the maximum wave condition it is designed for and intended to operate in, and it must be able to adjust to or handle changing sea levels and wave directions. Energy capture in a wave energy converter depends of the motion speed and force between an energy capturing device, such as a floating buoy, and a fixed or moving reference. If only one direction of motion can be used, e.g. the vertical motion, the motion speed will change from zero to a top level twice for every wave period. Looking at the vertical motion speed of the water particles in a wave, the motion speed is highest where the water particles pass through the average sea level and zero in crest and trough. In any given sea state the peak energy is found in the highest waves, statistically determined by Hs*1.8. The peak energy captured from the largest waves is in the order of 7-10 times higher compared to the average energy in any given sea state.

[0005] Converting the captured energy instantly is not efficient. The power will then fluctuate rapidly from zero up to the peak level which is not suitable from a conventional generator or the power grid to which it delivers the generated power. The generator must be sized to handle the peaks of energy which will lead to low utilization and low electrical efficiency with high heat generation as a consequence. The peak power can be distributed to speed and torque in the generator but neither one can be allowed to exceed a maximum value without damaging the generator. A higher speed will naturally lead to higher torque unless the damping of the generator is dynamically changed to compensate.

[0006] However, compensating the damping of the generator to reduce the peak torques will reduce the electrical efficiency even further. For this reason the peak torque/mechanical load will also reach high values as a consequence of the peak power being converted. An alternative is to limit the maximum instantaneous energy capture or spill excessive energy captured but this will reduce the utilization of all other parts of the wave energy converter by reducing the average power output.

[0007] To make possible efficient conversion of wave energy to electricity, as much energy as possible must be captured and then smoothed to a steady load on the power takeoff and generator with some kind of power smoothing device. In hydraulic power takeoffs it is common to use gas accumulators, but the gas pressure and thereby the hydraulic pressure in the hydraulic system increases exponentially with the level of energy stored in the accumulator, making it difficult to achieve sufficient power smoothing without very large size of the gas accumulator. To achieve a smooth power output matching the average energy from a given sea state, the capacity must be sufficient to smooth energy over several waves in a row. Two or three large waves may occur in a row after which number of smaller waves may occur. It is often said that every seventh wave is a large one and as said above, 100 waves in a row is measured to determine a sea state.

[0008] Wave power technologies have been developed for a long period of time but up to now it has not been shown how to design a wave energy converter that is able to efficiently convert the intermittent and highly fluctuating energy form ocean waves into a steady power output, as described above.

[0009] A frequent method of capturing the energy of water waves is to use the vertical movement of the water. Installations that use such technology are sometimes called "point absorbers". One method of using the vertical movements comprises the use of a buoy having a bottom foundation and an anchor wheel. The bottom foundation is firmly positioned on the sea-floor and is connected to the buoy which follows the ocean surface, i.e. the wave movements. When the surface rises and thereby lifts the buoy, a motive force is created which is converted into a rotational movement by a driving bar connected between the foundation and the buoy or by a wire or chain which runs over an anchor wheel journalled for rotation at the buoy or in the foundation and which is at an opposite end connected to the foundation or the buoy, respectively. The motive force increases due to the increased motion speed of the waves when the wave height becomes higher. The rotation direction and speed of an anchor wheel, if such a wheel is used, is directly dependent on the vertical direction and motion speed of the waves. However, this is not optimal for coupling a conventional generator to the anchor wheel to produce electric energy.

[0010] In order to make a wave energy converter driving a conventional rotating generator efficient, the vertical movements of the waves must be converted into a unidirectional rotational movement, and the rotation speed of an electric generator connected to the transmission must be stabilized. In a device, as described above, using a driving bar, wire or chain, which is secured to the bottom of the sea or in a frame structure and which runs along or over an anchor wheel journalled in a buoy, this problem can partly be solved in the following way. When the buoy is lifted by a wave, a motive force over the anchor wheel is produced. Thereupon, when the wave falls, an anti-reverse mechanism is disengaged and the anchor wheel is rotated backwards by a counterweight.

Then, the motive driving is only active during the rise of the wave and completely ceases when the wave sinks, this not being satisfactory.

[0011] Attempts have been made to reverse the rotation direction, so that an electric generator driven by the anchor wheel is driven by the counterweight in the same direction also when the wave sinks. It has also been attempted to reverse the rotation direction of the generator. However, changing the rotation direction of a mechanical transmission or of the generator twice in every wave period results in mechanical wear. Even though the rotation direction can be made unidirectional by the transmission, the rotation speed follows the speed of the vertical movement, this causing the speed and torque of the generator to vary according to the speed of the wave movements. This gives high fluctuations in the power output and torque load in the system and as a consequence also low efficiency and utilization of the generator since the generator has to be oversized to handle the peak loads. The power takeoff must also be oversized to handle the peak torques.

[0012] In order to make the motive force and rotation speed of a generator more even when using a mechanical transmission, multiple buoys can cooperate with each other, a phase shift then existing between the movements of the buoys. However, this only works optimally in the case where the buoys are evenly distributed over a wave period, which very seldom occurs since the length and the speed of the waves always vary.

[0013] Some of the basic disadvantages of the wave energy converters having the structure described above are eliminated or at least significantly reduced in the wave energy converters disclosed in the published International Patent Application No. WO 2009/105011. In such wave energy converters energy from water waves is in the common way, during parts of the movements of the water waves, absorbed for driving an electric generator. Part of the absorbed energy is temporarily accumulated or stored in some suitable mechanical way for driving the electric generator during other parts of the movements of the water waves. The drive-shaft coupling of the movement of the water level and the mechanical energy storage to the electric generator is in a special mechanical way arranged for a unidirectional rotation with a constant torque and a constant rotation speed.

SUMMARY OF INVENTION

[0014] An object of the present invention is to provide an efficient power takeoff for a wave energy converter wherein the drawbacks of prior art solutions are eliminated or at least minimized.

[0015] According to a first aspect of the present invention, a wave energy converter is provided comprising an energy absorption unit arranged to absorb energy generated by movements of water when the wave energy converter is arranged in a pool of water, an energy accumulation unit (**200**) connected to the energy absorption unit, and a power generation unit connected to the energy absorption unit, wherein the energy absorption unit, the energy accumulation unit, and the power generation unit are arranged in a floating body, wherein the energy accumulation unit is arranged to accumulate energy from the energy absorption unit when the energy absorption unit absorbs more energy than the power generation unit generates and to dissipate energy to the power generation unit when the energy absorption unit absorbs less energy than the power generation unit generates, characterised in that the energy absorption unit comprises a hydraulic pump connected to means for converting vertical motion into a rotational motion, the energy accumulation unit comprises a first combined hydraulic pump and motor operably connected to counterweight for converting vertical motion into a rotational motion, and the power generation unit comprises a hydraulic motor connected to an electric generator.

[0016] A hydraulic power takeoff system is believed to be more robust and allows a more flexible and controllable design, although the efficiency of a hydraulic power takeoff is much lower compared to a mechanical power takeoff due to much higher friction caused by the hydraulic flow through the system.

[0017] By arranging the energy absorption unit, the energy accumulation unit, and the power generation unit in a floating body, the wave energy converter is easy to install and retract and that the above mentioned units are easy to access for maintenance.

[0018] In a preferred embodiment, a preferably oblong means arranged for converting vertical motion into a rotational motion is connected to the input shaft of a hydraulic pump, whereby the movement of the wave energy converter is efficiently translated into a rotational force driving the hydraulic pump. It is preferred that the shaft of a return feeding device, preferably a combined hydraulic pump and motor, is mechanically connected to the means for converting vertical motion into a rotational motion, whereby the return feeding device is used to rewind the shaft attached to the means in order to keep the oblong means stretched during return feeding when the wave energy converter moves closer to the other end of the means which is attached to a more or less fixed point of reference. It is required that the means is in a stretched state in order to generate a rotational force for driving the hydraulic pump when the wave energy converter moves away from the said more or less fixed point of reference.

[0019] Further preferred embodiments are defined by the dependent claims.

BRIEF DESCRIPTION OF DRAWINGS

[0020] The invention is now described, by way of example, with reference to the accompanying drawings, in which:

[0021] FIG. **1** is a block diagram showing the overall layout of a hydraulic power takeoff in a wave energy converter according to the invention;

[0022] FIG. **2** is a detailed diagram showing the components of the hydraulic power takeoff in a wave energy converter of FIG. **1** according to a first embodiment operating with a single drive system;

[0023] FIG. **3** is a detailed diagram showing the components of the hydraulic power takeoff in a wave energy converter of FIG. **1** according to a second embodiment operating with a double drive system;

[0024] FIG. **4** is a detailed diagram showing the components of the hydraulic power takeoff in a wave energy converter of FIG. **2** with disengagement of incoming energy;

[0025] FIG. **5** is a detailed diagram showing the components of the hydraulic power takeoff in a wave energy converter of FIG. **3** with disengagement of incoming energy;

[0026] FIG. **6** is a detailed diagram showing the components of the hydraulic power takeoff in a wave energy converter of FIG. **2** but also provided with a brake system; and

[0027] FIG. **7** shows essentially constant torque operation of an accumulation unit comprised in a hydraulic power take-off in a wave energy converter according to the invention.

DESCRIPTION OF EMBODIMENTS

[0028] In the following, a detailed description of various embodiments of a wave energy converter will be given. In this description, the term "pool of water" should be taken to include any body or mass of water.

[0029] Referring to FIG. **1**, a wave energy converter according to the invention comprises an energy absorption unit **100**, an energy accumulation unit **200** connected to the energy absorption unit **100**, and a power generation unit **300** connected to the energy absorption unit **100**. These units are preferably arranged in a buoy or floating body **20**.

[0030] The energy absorption unit **100** is arranged to absorb energy generated by movements of water when the wave energy converter is arranged in a pool of water. This can be achieved for example by an arrangement connecting the energy absorption unit to the seabed, for example a foundation **30**, such as a bottom foundation, as will be explained in detail below. In the upward and downward movements of the water surface the buoy **20** is made to alternately rise or sink and/or alternately rock or tilt back and forth. Thereby a motive force can be created in relation to the bottom of the pool of water.

[0031] The energy accumulation unit **200** is arranged to accumulate energy from the energy absorption unit **100** when the energy absorption unit absorbs more power than the power generation unit **300** generates and to dissipate energy to the power generation unit **300** when the energy absorption unit absorbs less power than the power generation unit **300** generates. The accumulated energy is stored as potential energy in a counterweight **40**, which provides a nearly constant torque that only changing slightly due to inertia effects in moving and rotating parts of the system. In this way, the power output of the wave energy converter can be maintained essentially constant, despite varying wave energy levels.

[0032] Common to the energy absorption unit **100**, the energy accumulation unit **200**, and the power generation unit **300** is that they comprise hydraulic components, such as hydraulic pumps/motors, hydraulic backstop valves, conduits for hydraulic fluid etc. This is shown in FIG. **2**, which is a more detailed diagram of the hydraulic power takeoff in a wave energy converter shown in FIG. **1**. Thus, the energy absorption unit **100** comprises a hydraulic pump **110**, in this case a bidirectional pump, which is connected to a means for converting vertical motion into a rotational motion. In this embodiment, this means is an anchor drum **120** via an interconnecting first anchor drum shaft **122**. The anchor drum **120** is also provided with a second anchor drum shaft **124**.

[0033] The anchor drum **120** is, during operation, connected to a bottom foundation **30** by means of an anchor line **32**, e.g. a steel wire. As an alternative, the motive force can be created in relation to some kind of movable object such as to a weight suspended in the anchor drum **120**.

[0034] The hydraulic fluid described herein is preferably hydraulic oil.

[0035] The hydraulic pump **110** is connected in parallel by means of hydraulic conduits to a first hydraulic one-way or backstop valve **130**. This first backstop valve is arranged to enable free-wheeling of hydraulic fluid in a clockwise direction as seen in the figure through the hydraulic pump **110** and the first one-way valve **130**.

[0036] The input of a second hydraulic backstop valve **170** of the accumulation unit **200** is connected to the hydraulic pump **110** and the output of the first backstop valve **130** of the absorption unit **100** by means of a hydraulic conduit. The output of the second backstop valve **170** is connected to a first combined hydraulic pump/motor **220** and to a return feeding device in the form of a second combined hydraulic pump/motor **180**. The first pump/motor **220** comprises a shaft **222**, which is connected to a counterweight drum **230**. This in turn is connected to a counterweight **40** suspended in the counterweight drum **230** by means of a counterweight line **42**, such as a steel wire.

[0037] The second hydraulic pump/motor **180** is mechanically connected to the second anchor drum shaft **124** in order to operate as a return feeding motor. To this end, the second hydraulic pump/motor has lower displacement compared to the hydraulic pump **110**. This allows a fraction of the absorbed energy to be used for return feeding of the anchor drum **120**. The displacement of the second hydraulic pump/motor **180** is substantially lower compared to the displacement of the hydraulic pump **110**, and typically in the order of ten times lower compared to the displacement of the hydraulic pump **110**.

[0038] The output of the second backstop valve **170**, the first hydraulic motor/pump **220** and the second hydraulic motor/pump **180** are also connected to the power generation unit **300** and more specifically to the input of a hydraulic motor **310**. This hydraulic motor **310** is provided with an outgoing shaft **312** operably connected or connectable to an electric generator **320**, the outputs of which are connected to a power grid (not shown).

[0039] The operation of the wave energy converter of FIG. **2** will now be explained in detail. In the up going motion of the wave, hydraulic fluid flows through the hydraulic pump **110** in one direction. The first hydraulic backstop valve **130** blocks the flow to the hydraulic fluid reservoir. The second hydraulic backstop valve **170** allows hydraulic fluid to go into the power takeoff towards the next part of the hydraulic system comprised in the accumulation unit **200** and the power generation unit **300**. When the wave goes down the flow direction in the hydraulic pump **110** is reversed and the first hydraulic backstop valve **130** and the second hydraulic backstop valve **170** change state, allowing the hydraulic fluid to be circulated from the output to the input of the hydraulic pump **110** while the second hydraulic backstop valve **170** blocks the hydraulic fluid from flowing back into the hydraulic system of the absorption unit **100**, thereby conserving absorbed energy in the system.

[0040] There exists a state of equilibrium between the counteracting torque in the generator **320** and the motive torque of the counterweight **40**, creating a steady pressure and flow through the hydraulic motor **310** in the power generation unit **300**. When the flow from the energy absorption unit **100** is higher than the flow through the hydraulic motor **310**, the excessive flow goes through pump/motor **220** connected to the counterweight drum **230** in the accumulation unit **200**, acting as a motor and drives the counterweight drum **230** in a direction that lifts the counterweight **40**, thereby storing excess energy. When the flow from the energy absorption unit **100** is lower than the flow through the hydraulic motor **310** in the power generation unit **300**, the counterweight drum **230** instead drives the first hydraulic pump/motor **220** as a pump, and thus pressure and flow through the hydraulic motor **310** in the power generation unit **300** is maintained on a smooth level through the full wave cycle, thus driving the generator **320** to produce a smooth power output through the full wave cycle.

[0041] When the water wave sinks, the anchor drum is reversed by the second hydraulic motor/pump **180** acting as a motor in order to keep the anchor wire tensed. In the up going wave motion, the second hydraulic motor/pump **180** acts as a pump, adding flow to the high pressure side of the system.

[0042] As an alternative to providing return feeding of the anchor drum **120** with the second hydraulic pump/motor, return feeding can be implemented with any type of elastic force, such as a spring, electrical motor, weight etc.

[0043] In the embodiment of the wave energy converter described above with reference to FIG. **2**, wave energy is only absorbed in one direction of the vertical wave direction, i.e., a wire is attached to the sea bed and can only drive the power takeoff in up going wave motion. In an alternative embodiment, shown in FIG. **3**, the wave energy converter is divided into two parts: one part following the wave motion and one part counteracting the wave motion. The relative movement between these two parts can be used to drive the power takeoff in both vertical directions, creating a double drive of the system. The advantage with double drive is that the average input speed from the anchor drum is doubled which means that torque and pressure is reduced to half in relation to the power output. Torque/pressure is a major cost driver for the power takeoff, a reduction of torque can therefore lead to cost savings.

[0044] This second embodiment is in most aspects identical to the first embodiment described above with reference to FIG. **2**. Thus, the energy absorption unit **100** comprises a hydraulic pump **110**, which is connected to an anchor drum **120** via an interconnecting first anchor drum shaft **122**. However, the anchor drum **120** need not be provided with a second anchor drum shaft, as in the above explained embodiment.

[0045] The anchor drum **120** is, during operation, connected to a bottom foundation **30***a* by means of an anchor line **32**, e.g. a steel wire or rope. Through the same anchor line **32**, the anchor drum **120** is also connected to an upper foundation **30***b*, which is fixed at a predetermined distance from the bottom foundation **30***a*. Upper foundation **30***b* and bottom foundation **30***a* can be comprised in the same structure or in separate structures.

[0046] Alternatively, the absorption unit **100**, the accumulation unit **200**, and the power generation unit **300** are provided at a fixed level and the bottom foundation **30***a* and the upper foundation **30***b* are provided as buoys following the vertical movements of the water at an essentially constant mutual distance.

[0047] In this embodiment, the hydraulic motor/pump used for return feeding is no longer needed since the anchor line **32** is tensed. Instead of a hydraulic backstop valve and a return feeding device, a valve bridge **140** comprising four backstop valves is provided parallel to the hydraulic pump **110**. This means that a hydraulic absorption unit **100** delivers pressure and hydraulic flow to the accumulation unit **200** and the power generation unit **300**, irrespective of the direction of rotation of the hydraulic pump/motor **110**, i.e. both when the waves are rising and when they are sinking.

[0048] As a consequence of this, no backstop valve is needed in the connection to the accumulation unit **200**. Thus, this accumulation unit **200** comprises a first hydraulic pump/motor **220** with a shaft **222**, which is connected to a counterweight drum **230**. This in turn is connected to a counterweight **40** suspended in the counterweight drum **230** by means of a counterweight line **42**, such as a steel wire or rope.

[0049] The output end of the valve bridge **140** and the hydraulic motor/pump **220** are connected to the input of a hydraulic motor **310**. This hydraulic motor **310** is provided with an outgoing shaft **312** operably connected to an electric generator **320**, the outputs of which are connected to a power grid (not shown).

[0050] The operation of the wave energy converter shown in FIG. **3** is essentially the same as the operation of the wave energy converter of FIG. **2**. Power is absorbed by the hydraulic pump **110** and this power is stored in the counterweight **40** or converted to electrical energy through the hydraulic motor **310** and the electric generator **320**.

[0051] In order to disengage energy absorption in the wave energy converter, a 3/2-way valve **150**, also called bypass valve, can redirect the flow generated by the anchor pump directly back to the hydraulic fluid reservoar.

[0052] A wave energy converter with the possibility of disengagement of incoming energy will now be described with reference to FIG. **4**. This converter is identical to the wave energy converter described above with reference to FIG. **2** with the addition that a bypass valve **150** is located on the absorption unit side to the second hydraulic backstop valve **170** preventing hydraulic fluid from flowing back from the accumulation unit **200** and to the absorption unit **100**. When the wave energy converter is in return feeding, the pressure is very low in the absorption unit. The 3/2-way valve can therefore be operated during low pressure conditions to minimize wear and heat generation.

[0053] The 3/2-way valve can also be combined with pressure limitation or a pressure reduction function that limits the maximum pressure in the system. This can prevent damage if the system locks up or if the weather conditions causes too high mass moment of inertia in the system. This is equivalent to a mechanical clutch with limited torque transfer.

[0054] The same type of 3/2-way valve can be used in the double drive system of FIG. **3** which is then also complemented with a back stop valve **210** in order to prevent stored energy to escape through the 3/2-way valve when it is in bypass mode. Thus, a double drive wave energy converter with the possibility of disengagement of incoming energy will now be described with reference to FIG. **5**. This converter is identical to the converter described above with reference to FIG. **3** with the addition that a bypass valve **150** and a back stop valve **210** is located in the absorption unit side between the output of the valve bridge **140** and the accumulation unit **200**.

[0055] In order to hold the counterweight when the generator is not in operation, a hydraulic brake is required. In a hydraulic system, a 2/2-way valve that can block the flow to the generator is provided. 2/2-way valves can be used also to block the flow from each drum in the system, to be used as service brakes. In other words, to enable release of pressure in the main part of the hydraulic system during service and maintenance. To completely release pressure for the whole system, the counterweight must be secured to the buoy or a service vessel or lowered down to the sea floor.

[0056] A wave energy converter with the possibility of braking will now be described with reference to FIG. **6**. This converter is identical to the converter described above with reference to FIG. **2** with the addition that a 2/2 valve **330** is located connected to the input of the hydraulic motor **310**.

[0057] As an alternative to a drum for the counterweight, a wheel for a chain or toothed bar or any other means to convert the vertical motion between the two bodies into a rotational motion, can of course be used.

[0058] In the wave energy converter described herein, the counterweight is used as a constant torque accumulator and the power output from the system is controlled by the state of equilibrium between the motive torque of the counterweight and the counteracting torque of the electric generator. The counteracting torque in an electric generator depends on the speed or phase difference and the magnetic coupling between rotor and stator. With a fixed damping coefficient in the generator, the speed will increase or decrease until the counteracting generator torque matches the motive torque from the counterweight where the speed is stabilized and thereby also the power output. Control of the damping coefficient can in this way be used to control the speed of the generator and thereby the power output, independently of the absorbed energy and with a torque load in the system only changing slightly due to mass moment of inertia in the system. Different electric generators have different techniques to control the damping coefficient but it can be controlled for all types of generators, for example by adjusting field current, different speeds of anchor and rotor or different phases of anchor and rotor.

[0059] When momentarily more energy is absorbed in the system compared to the electric generator output power, excess energy is stored in the counterweight as potential energy, i.e. the counterweight is lifted. When momentarily less energy is absorbed in the system compared to the generator output, stored energy in the counterweight is used to create a continuous drive of the generator. The power output is stable through the full wave cycle, independently of the intermittent and highly fluctuating input power from the waves. The counterweight will move up and down to compensate for the fluctuations in the wave spectrum.

[0060] When for a period of time more energy is absorbed than generated in the system, the counterweight will move in an upward trend and vice versa. However, the power output is controlled to match the average level of incoming energy over a suitable time frame by tuning the damping coefficient in the generator so that the output power from the generator matches the average level of input power from the waves. This enables the average position of the counterweight to be maintained while providing a stable power output that matches the current wave situation, often defined by the significant wave height or Hs.

[0061] The hydraulic motors/pumps used in the energy absorption unit **100**, energy accumulation unit **200** and power generation unit **300** can comprise variable displacement in order to enable additional tuning capabilities of the power takeoff.

[0062] Instead of dissengaging energy absorption completely with a bypass valve **150** shown in FIG. **4**, the energy capture can instead be reduced by lowering the displacement in the hydraulic motor/pump **110** in the energy absorption unit **100**.

[0063] The displacement in the hydraulic motor/pump **110** can also be used for changing the damping effect that the power takeoff has on the buoy. Tuning of the damping in the power takeoff can be used to optimize energy capture for different sea states, e.g. optimizing the heave response of the buoy. For a certain wave frequency, the optimal combination of displacement and damping gives the highest hydraulic flow into the power takeoff, and thereby the highest energy capture. Too high or too low damping reduces the heave response of the buoy. This is some times referenced to as tuning the power takeoff to find the resonance to the wave frequency.

[0064] A variable displacement in the hydraulic motor/pump **220** in the energy accumulation unit **200** can be used to reduce the movement speed of the counterweight in rough sea conditions, to reduce the peak loads caused by inertia in the counterweight **40**. Tuning displacement in the hydraulic motor/pump **220** also changes the hydraulic pressure given by the counterweight, which in turn also has an impact on the damping effect that the power takeoff has on the buoy.

[0065] A variable displacement in the hydraulic motor **310** in the power generation unit **300** can be used for tuning the torque/rpm of the generator, to take as high values as possibly without the risk of overloading the generator due to fluctuations caused by inertia effect in moving and rotating parts of the system. Tuning the torque in the generator can improve generator efficiency and maximum power output possible without overloading the generator.

[0066] The power takeoff described herein can be implemented in many different types of wave energy converter systems. The input flow can be generated from a hydraulic pump as shown in FIGS. **2** and **3**, a hydraulic cylinder or any other means of creating a hydraulic flow into the power takeoff.

[0067] The power takeoff can be located inside a buoy that follows the water movements at the surface. The power takeoff can also be located below, at or above the water surface in a structure, typically the structure is fixed to the seafloor, to a heave plate or to a large mass body, arranged to counteract the movements of any kind of device that uses wave motion to create movements in relation to the counteracting structure, typically a buoy, submerged body or a plate.

[0068] The main advantage with the described power takeoff with power smoothing capabilities is a stable mechanical and electrical load in the system, with very low peak torque/pressure in the power takeoff and peak power in the generator compared to other power takeoffs. The system also reduces the working range for the generator which leads to higher efficiency and utilization of the power electronics, and less heat generation. Other advantages are that the system can limit energy absorption while maintaining rated power by temporary disengaging from incoming energy and that the system can be put to a complete stop, which is not possible with other counterweight technologies without stopping the motion of the buoy.

[0069] Preferred embodiments of a wave energy converter have been described. It will be appreciated that these can be varied within the scope of the appended claims without departing from the inventive idea.

[0070] Although the electric generator has been described as provided on the floating body, it is appreciated that it can be provided at a distance from the wave energy converter itself, such as at the sea bed or at shore.

1. A wave energy converter comprising:

an energy absorption unit arranged to absorb energy generated by movements of water when the wave energy converter is arranged in a pool of water,

an energy accumulation unit connected to the energy absorption unit, and

a power generation unit connected to the energy absorption unit, wherein the energy absorption unit, the energy accumulation unit, and the power generation unit are arranged in a floating body,

wherein the energy accumulation unit is arranged to accumulate energy from the energy absorption unit when the energy absorption unit absorbs more energy than the power generation unit generates and to dissipate energy to the power generation unit when the energy absorption unit absorbs less energy than the power generation unit generates,

wherein:

the energy absorption unit comprises a hydraulic pump connected to means for converting vertical motion into a rotational motion, the energy accumulation unit comprises a first combined hydraulic pump and motor operably connected to counterweight for converting vertical motion into a rotational motion, and the power generation unit comprises a hydraulic motor connectable to an electric generator.

2. The wave energy converter according to claim **1**, wherein the hydraulic pump is a bidirectional hydraulic pump.

3. The wave energy converter according to claim **1**, wherein the means for converting vertical motion into a rotational motion is connectable to a foundation.

4. The wave energy converter according to claim **1**, wherein the means for converting vertical motion into a rotational motion is a drum.

5. The wave energy converter according to claim **4**, wherein the drum is, during operation, connected to a bottom foundation and also to an upper foundation, which is fixed at a predetermined distance from the bottom foundation.

6. The wave energy converter according to claim **1**, comprising a return feeding device mechanically connected to the means for converting vertical motion into a rotational motion.

7. The wave energy converter according to claim **6**, wherein the return feeding device is a second combined hydraulic pump and motor hydraulically connected to the first combined hydraulic pump and motor.

8. The wave energy converter according to claim **7**, wherein the displacement of the second hydraulic pump/motor is substantially lower compared to the displacement of the hydraulic pump.

9. The wave energy converter according to claim **1**, comprising a first backstop valve connected in parallel with the hydraulic pump.

10. The wave energy converter according to claim **1**, comprising a second backstop valve, the input of which is connected to the hydraulic pump and the output of which is connected to the first combined hydraulic pump and motor.

11. The wave energy converter according to claim **10**, comprising a 3/2 valve located on the absorption unit side to the second hydraulic backstop valve preventing hydraulic fluid from flowing back from the accumulation unit and to the absorption unit.

12. The wave energy converter according to claim **1**, comprising a valve bridge provided parallel to the hydraulic pump.

13. The wave energy converter according to claim **1**, comprising a 2/2 valve connected to the input of the hydraulic motor.

14. The wave energy converter according to claim **1**, wherein at least one of the hydraulic pump, the first combined hydraulic pump and motor, and the hydraulic motor has variable displacement.

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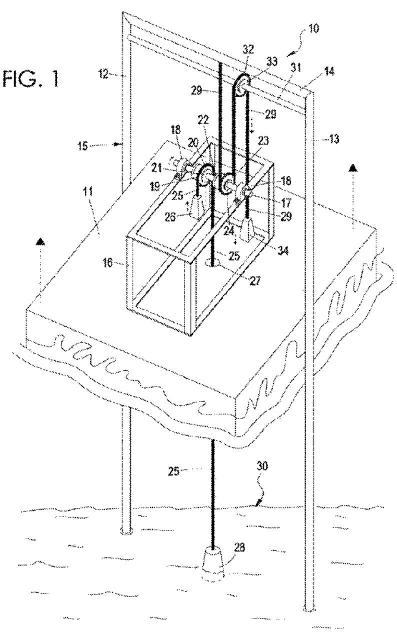
FIG. 1



(57) Abstract: A vertical motion wave power generator (10) having a flotation device (11), a vertical support structure (15) fixed to the ocean bottom (30), and a single power shaft (17) attached rotatably to the flotation device (11). By the use of a pair of one-way clutches (19, 22) the single power shaft (17) converts the up and down motion of ocean waves into continuous unidirectional rotational force to drive an electric generator (65). The power shaft (17), transmission (52), and generator (65) are all attached to the flotation device (11) and move up and down in unison with the flotation device (11). In an alternant embodiment a paddle wheel-driven horizontal wave generator system (70) is situated on the ocean shore for converting shore waves to unidirectional rotational force for generating power.

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OCEAN WAVE POWER GENERATOR

TECHNICAL FIELD

This invention relates generally to devices for generating power from vertical and horizontal motion and, more particularly, to an apparatus for generating power from the vertical or horizontal motion of ocean waves using a single power shaft with a pair of one way clutches.

BACKGROUND ART

Vertical motion wave power generators for producing electricity from ocean waves are known. It has been effective to use one-way clutches to convert the up and down vertical motion of waves into unidirectional rotary motion to turn an electric generator. However, existing devices have been too complex, or insufficiently durable, or too small to be practical or of commercial value.

U.S. Patent Application No. 2006/0232074 discloses a stationary wave generator that uses a float and lever with a linkage system to drive a drive shaft clockwise and counterclockwise. The drive shaft engages a power shaft so as to rotate it in one direction. The float and lever system, with the linkage to a stationary generator, is susceptible to damage due to the force of waves. The flotation capacity of the float in this system is small and many units would be required to produce sufficient power.

U.S. Patent No. 6,476,512 describes a stationary wave generator that moves a float up and down in a tall tower. Five different rotating shafts in this system are required to convert the up and down vertical motion of the float into unidirectional rotational motion. The float is relatively small so that many units would be required to produce sufficient power.

U.S. Patent Application No. 2006/0028026 discloses a stationary wave generator that captures only the upward force of a wave using a plurality of worm gears and rack and pinion gears. The system has low total buoyancy.

U.S. Patent No. 7,315,092 discloses a floating wave generator in which the generator portion is connected by arms to two floats which move up and down in a direction opposite to that of the generator portion. One of the floats turns a drive shaft clockwise and counterclockwise. The drive shaft engages a power shaft so as to rotate it in one direction. The constant opposing motion between the floats and the generator creates problems of wear and insufficient durability. There is no capacity for a flywheel in this system which is usually required with the use of one-way clutches. The system is inherently limited in size and many units would be required to produce sufficient power.

U.S. Patent No. 4,539,484 discloses a floating wave generator system in which the generator system is attached to a float which moves up and down with the motion of waves. The float is confined within a frame which is connected to the ocean bottom. Cables are connected to the frame below and above the float. The central portions of the cables are wound several times around drums to rotate the drums clockwise and counterclockwise as the float moves up and down with the motion of the waves. One-way clutches are attached to each end of the drums. A plurality of reversing gears and worm gears are used to convert the clockwise and counterclockwise rotation of the drums into unidirectional rotation. A third over-running clutch is required to transfer the unidirectional rotation to an electric generator. The cable that is wound around the drum is subject to considerable friction which causes undue wear on the cable and the drum. The plurality of reversing gears and worm gears also causes undue friction, wear, and maintenance. The float is relatively difficult to disengage from the frame when it is necessary to remove the float to a harbor, such as during a storm or for repair.

What is needed, but which has never been available, is a system in which the generator is attached to a float and moves up and down with the float to prevent wear, tear, and damage; up and down motion is converted to unidirectional rotary motion with a single power shaft without the need for a plurality of intervening power shafts and gears so that the system is durable and requires little maintenance and repair; the power generating capacity of the system can be equal to that of a nuclear power plant; and the flotation system is easy to disengage from a support frame structure for transport.

Horizontal motion wave power generators for producing electricity from ocean shore waves are known. U.S. Patent 5,105,094 discloses a stationary wave generator that operates by an incoming shore wave moving a piston up and down in a cylinder. The piston engages a drive through a rack and pinion gear system which then engages a unidirectional rotary power shaft. The rack and pinion arrangement is subject to excessive wear. The piston and cylinder need constant maintenance and there needs to be a draining regulation mechanism. The device is useful only for incoming shore waves. Paddle wheel structures are well-known and are particularly useful for capturing the energy of water moving in one direction. As such, they are not suited to capture both the inflow and outflow energy of ocean shore waves. U.S. Patent No. 6,133,644 discloses a surf driven electrical apparatus which has a shaft on a buoyant body with blades or paddles attached to the shaft. The paddles intercept an incoming ocean wave at a point where the surf breaks and receive the energy produced from the breaking wave, thereby rotating the shaft to operate an electric generator. This device captures the energy only from the incoming motion of the ocean surf.

What is needed, but which has never been available, is a paddle wheel system wherein both the incoming flow and the outgoing flow of the ocean shore waves are converted to unidirectional motion which can drive an electric generator.

DISCLOSURE OF THE INVENTION

The present invention is a vertical motion power generator system for converting vertical up and down motion to unidirectional rotational force for generating power. The system has a platform, such as a flotation device, associated with a vertical support structure fixed to the ground, including the bottom of a body of water, such as an ocean. A single power shaft is attached rotatably to the platform. First and second one-way clutches are fixed to the power shaft, with each of the one-way clutches having an outer casing. A sprocket or pulley is fixed to each outer casing, and the sprocket or pulley is also attached rotatably to the power shaft. A first chain, belt, or cable has a first end attached to the ground or to the vertical support structure at a position below the platform and the power shaft. The first chain has a second opposite end extending upward over the sprocket or pulley on the first one-way clutch and extends downward therefrom. A second chain, belt, or cable has a first end attached to the vertical support structure at a position above the platform and power shaft, and has a second opposite end extending downward under the sprocket or pulley on the second one-way clutch. The second opposite end extends upward therefrom and over an idler pulley attached to the vertical support structure at a position above the platform and power shaft, and extends downward therefrom.

The first clutch engages the power shaft as the platform is raised upward, thereby rotating the power shaft in a fixed direction while the second clutch is disengaged from said power shaft. The second clutch engages the power shaft as the platform is lowered downward, thereby rotating the power shaft in the fixed direction while the first clutch is disengaged from said power shaft. The power shaft thus rotates continuously in the fixed direction as the platform moves up and down, thereby providing continuous unidirectional rotational force to drive a generator.

An alternate embodiment of the present invention is a horizontal motion power generator system for converting the incoming and outgoing flow of ocean shore waves to unidirectional rotational force for generating power. This generator system has a base having one or more troughs. An axle is attached rotatably to the base and has one or more paddle wheels attached thereto. The lower portion of the paddle wheel is positioned in the trough so that the paddle wheel engages incoming and outgoing shore waves at the portion of the paddle wheel positioned in the trough. A single power shaft is attached rotatably to the base. First and second one-way clutches are fixed internally to the power shaft. A gear is fixed to the first one-way clutch, the gear is attached rotatably to the power shaft, and the gear engages a reverse gear fixed to the paddle wheel axle. A sprocket is fixed to the second one-way clutch, the sprocket is attached rotatably to the power shaft, and the sprocket engages a sprocket attached to the paddle wheel axle by means of a chain or cable. The second one-way clutch engages the power shaft as the flow of a wave, such as an incoming wave, rotates the paddle wheels in a first direction, thereby rotating the power shaft in a fixed direction, while the first clutch is disengaged from the power shaft. The first one-way clutch engages the power shaft as the flow of a wave, such as an outgoing wave, rotates the paddle wheels in a second opposite direction, thereby rotating the power shaft in the same fixed direction while the second clutch is disengaged from said power shaft. The power shaft is thus rotated in unidirectional manner by the paddle wheels as the paddle wheels rotate in a first direction and in a second opposite direction, thereby providing unidirectional rotational force from incoming and outgoing waves to drive a generator. A transmission with a flywheel is positioned between the power shaft and the generator. The transmission increases the speed of rotation from the power shaft to the generator.

An advantage of the vertical wave motion power generator of the present invention is that the power shaft, transmission, and generator are all together on a flotation device, and they all move up and down in unison with the flotation device.

Another advantage is a wave motion power generator that uses a simple vertical frame structure attached to the ocean bottom and only a single drive chain needs to be attached to the ocean bottom.

Another advantage is a wave motion power generator that uses a single, simple power shaft to convert the up and down vertical motion of ocean waves into continuous unidirectional rotation.

Another advantage is a wave motion power generator that can be scaled up to produce power output similar to a nuclear reactor.

Another advantage is a wave motion power generator that is easy to disengage from the vertical support structure for transportation.

An advantage of the horizontal wave motion power generator of the present invention is that it uses a single, simple power shaft to convert the inward and outward horizontal motion of shore waves into continuous unidirectional rotation.

Another advantage is the use of a pair of simple durable one-way clutches on the power shaft to convert inward and outward horizontal motion to unidirectional rotation.

Another advantage is the use of simple durable paddle wheels to capture the energy of horizontal inward and outward motion of shore waves.

Another advantage is a wave motion power generator system that can be scaled up to produce as much power output as desired.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates the floating vertical wave power generating system of the present invention as it floats upwards to the top of an ocean wave.

Fig. 2 illustrates the floating vertical wave power generating system as it floats downwards to the trough of an ocean wave.

Fig. 3 illustrates the elements of the power shaft as shown in Fig 1 in more detail.

Fig. 4 illustrates the elements of the power shaft as shown Fig. 2 in more detail.

Fig. 5 shows a cross-sectional view of one type of one-way clutch that can be used on the power shaft.

Fig. 6 shows an example of a transmission that can be used to increase the speed of rotation from the power shaft to an electric generator.

Fig. 7 illustrates the alternate embodiment of a horizontal wave power generating system of the present invention.

Fig. 8 illustrates how the horizontal wave power generating system converts the back and forth flow of incoming and outgoing ocean shore waves into unidirectional rotation of a power shaft.

BEST MODES FOR CARRYING OUT THE INVENTION

This application claims the benefit of U.S. Provisional Application No. 61/090,295 filed August 20, 2008, the disclosure of which is incorporated herein in its entirety as if fully set forth below.

While the following description details the preferred embodiments of the present invention, it is to be understood that the invention is not limited in its application to the details of construction and arrangement of the parts illustrated in the accompanying drawings, since the invention is capable of other embodiments and of being practiced in various ways.

A preferred embodiment of the present invention is a floating vertical wave electric generator system or apparatus which is attached to a flotation device. The system has a power shaft with first and second one-way clutches arranged so that both clutches rotate the power shaft in a first direction when they are rotated in this first direction, but are disengaged when rotated in a second opposite direction. The first clutch is attached to a sprocket which is driven by a chain attached to the floor of the ocean. The second clutch is attached to an overhead horizontal support which is attached to vertical supports attached to the ocean floor. As the flotation device moves up towards the top of a wave, the first clutch turns in the first direction which turns the power shaft in the first direction. The second clutch is turned in the opposite second direction and is disengaged. As the flotation device moves downwards to the bottom of a wave, the first clutch turns in the opposite second direction and is disengaged. The second clutch is turned in the first direction which turns the power shaft in the first direction. Thus, the up and down vertical motion of the waves are converted into unidirectional rotation of the power shaft. The power shaft can be connected to an electric generator through a transmission to rotate the electric generator in one direction, thereby producing electric current.

Fig. 1 illustrates a floating vertical wave generator system **10** as it is floating upwards to the top of an ocean wave. A support frame **16** is attached to a platform, such as a flotation device **11**. A power shaft **17** is attached rotatably to the flotation device **11** by means of support frame **16** and bearings **18**. One-way clutches **19**, **22** are attached to the power shaft **17** in such a way that they engage when rotated clockwise and disengage when rotated counterclockwise. They can also be attached to engage when rotated counterclockwise and disengage when rotated clockwise if desired. A sprocket **20** is attached to clutch **19**. Sprocket **20** is also attached to a bearing **21**, and bearing **21** is attached to power shaft **17**. Bearing **21** supports sprocket **20** on power shaft **17** and allows sprocket **20** to rotate on power shaft **17**. Likewise, attached to clutch **22** is a sprocket **23** attached to bearing **24** which is attached to power shaft **17**. Bearing **24** supports sprocket **23** on power shaft **17** allowing sprocket **23** to rotate on power shaft **17**. In this manner the sprockets **20** and **23** are attached rotatably to power shaft **17** while being attached fixedly to clutches **19** and **22**.

Support frame **16** is positioned within a vertical support structure **15** having a first vertical support **12**, a second vertical support **13**, and a horizontal support **14** attached in between the top ends of vertical supports **12** and **13**. The vertical supports **12**, **13** are attached to the ocean floor **30**. A first chain **25** is attached at one end to the ocean floor **30** by anchor **28** or can be attached to the vertical support structure **15** below the flotation device **11**. The opposite end of first chain **25** extends up through flotation device **11** through opening **27**. First chain **25** is positioned over sprocket **20** and extends downward therefrom, and the opposite end has a first weight **26** having just sufficient weight to keep chain **25** taut. Just beneath horizontal support **14** is a horizontal shaft **31** attached in between vertical supports **12**, **13**. An idler sprocket **32** is attached to horizontal shaft **31** by means of a bearing **33** which allows sprocket **32** to rotate freely around horizontal shaft **31**. As shown in Figs. 1 and 2, horizontal support **14**, horizontal shaft **31**, and idler sprocket **32** are positioned above flotation device **11** and power shaft **17**. A second chain **29** is attached at one end to horizontal support **14** above the power shaft **17**. The opposite end of second chain **29** extends down and is positioned under sprocket **23**, and extends upward over idler sprocket **32** and downwards therefrom. The opposite end of second chain **29** has a second weight **34** with just sufficient weight to keep second chain **29** taut. Sprocket **20** rotates clockwise and sprocket **23** rotates counterclockwise as flotation device **11** moves upward (see Fig. 3).

Fig. 1 shows that as flotation device **11** moves upward towards the top of a wave, first chain **25** pulls on sprocket **20** causing it to rotate clockwise and weight **26** moves upward. This causes clutch **19** to rotate clockwise so that it engages power shaft **17**, causing power shaft **17** to rotate clockwise. Second chain **29** pulls on sprocket **23** causing it to rotate counterclockwise, and weight **34** moves downward. Clutch **22** is, thus, disengaged and exerts no rotational force on power shaft **17**. Fig. 2 illustrates the floating wave generator system **10** as it is floating downwards to the bottom or trough of a wave. As the float **11** moves downward sprocket **20** rotates counterclockwise and sprocket **23** rotates clockwise. The first chain **25** pulls on sprocket **20** causing it to rotate counterclockwise and weight **26** moves downward. This causes clutch **19** to rotate counterclockwise so that it is disengaged and, thus, exerts no rotational force on power shaft **17**. Second chain **29** pulls on sprocket **23** causing it to rotate clockwise and weight **34** moves upward. This causes clutch **22** to rotate clockwise so that it engages power shaft **17**, causing power shaft **17** to rotate clockwise. Figs. 3 and 4 illustrate the elements of power shaft **17** in more detail.

Figure 5 shows a cross-sectional view of one type of one-way clutch that could be used as clutch **19** or **22**. The clutch in this example has a pawl-wheel **40** which is fixed to power shaft **17**. Ratchet pawls **41** are attached rotatably to pawl-wheel **40** and are biased away from pawl-wheel **40** by springs **42**. Surrounding pawl-wheel **40** is an outer casing **43** having saw-tooth elements **44** on its inner circumference. The sprockets **20** or **23** can be fixed to outer casing **43**. As the sprocket rotates clockwise the outer casing **43** rotates clockwise. As the outer casing **43** rotates clockwise the saw-teeth **44** engage the ratchet-pawls **41**, causing the power shaft **17** to rotate clockwise. As the sprocket rotates counterclockwise the outer casing **43** rotates counterclockwise. As the outer casing **43** rotates counterclockwise the saw-teeth **44** slip freely over the ratchet-pawls **41**, causing the clutch to be disengaged and no rotational force is applied to power shaft **17**. The one-way clutch can be configured to operate in a reverse manner.

Fig. 6 shows an example of how power shaft **17** can be connected to an electric generator **65** by means of a transmission **52** to increase the speed of rotation from the power shaft **17** to the electric generator **65**. Power shaft **17** can have a large power pulley **50** which transmits the unidirectional rotational force of power shaft **17** to a smaller first pulley **55** on a first shaft **53** of transmission **52** by means of belt **51**. First shaft **53** is held in place on support frame **16** by bearings **54** (see Figs. 3 and 4). First shaft **53** has a large pulley **56** which transmits the unidirectional rotational force to a smaller second pulley **60** on a second shaft **58** of transmission **52** by means of belt **57**. Second shaft **58** is held in place on support frame **16** by bearings **59** (see Figs. 3 and 4). Second shaft **58** can have a flywheel **63** to maintain a constant rotation of shaft **58**. Shaft **58** also has a large pulley **61** which transmits the unidirectional rotational force to a smaller pulley **64** on an electric generator **65** by means of belt **62**. Thus, as power shaft **17** is made to rotate clockwise at about 5 to 10 times per minute, depending upon the frequency of waves moving flotation device **11** up and down, transmission **52** can make electric generator **65** turn at speeds as high as 2000 rpm.

An alternate embodiment of the present invention is a paddle wheel driven horizontal wave electric generator system or apparatus which is situated on the ocean shore. The system has a power shaft with first and second one-way clutches arranged so that both clutches rotate the power shaft in a first direction when they are rotated in this first direction, but not at the same time. The clutches are disengaged when rotated in a second opposite direction, but not at the same time, in which case they do not rotate the power shaft. The first clutch is attached to a gear which is driven by a reverse gear on the axle of a paddle wheel. The second clutch is attached to a sprocket which is driven by a chain attached to a sprocket on the axle of the paddle wheel. As a shore wave comes in it turns the paddle wheel in a first direction, and the second clutch turns in the first direction which turns the power shaft in the first direction. The first clutch is turned in the opposite second direction and is disengaged. As the shore wave goes out it turns the paddle wheel in the second opposite direction, and the first clutch is turned in the first direction which turns the power shaft in the first direction. The second clutch turns in the opposite second direction and is disengaged. Thus, the inward and outward horizontal flows of the shore waves are converted into unidirectional rotation of the power shaft. The power shaft can be connected to an electric generator through a transmission, thereby producing electric current.

Fig. 7 provides a diagrammatic illustration of preferred embodiment of the present invention which can convert the horizontal motion of shore waves into electric energy. The shore wave generator system **70** has a concrete base **71** with troughs **72**. Paddle wheels **73** are positioned within troughs **72** and are fixed to a drive axle **74** connected rotatably to vertical supports **75** by means of bearings **90**. Vertical supports **75** are fixed to concrete base **71**. Axle **74** has a reverse gear **76** and a sprocket **77** which are fixed to axle **74**. Adjacent axle **74** is a power shaft **78** connected rotatably to vertical supports **80** by means of bearings **79**. Vertical supports **80** are fixed to concrete base **71**. In this figure one-way clutches **81**, **84** are shown attached to the power shaft **78** in such a way that they engage when rotated clockwise and disengage when rotated counterclockwise, but not at the same time. They can also be attached to work in a reverse manner if desired. A gear **82** is attached to clutch **81**. Gear **82** is also attached to a bearing **83**, and bearing **83** is attached to power shaft **78**. Bearing **83** supports gear **82** on power shaft **78** and allows gear **82** to rotate on power shaft **78**. Likewise, attached to clutch **84** is a sprocket **85** attached to bearing **86** which is attached to power shaft **78**. Bearing **86** supports sprocket **85** on power shaft **78** allowing sprocket **85** to rotate on power shaft **78**. In this manner the gear **82** and sprocket **85** are attached rotatably to power shaft **78** while being attached fixedly to clutches **81** and **84**, respectively. Power shaft **78** also has a power pulley **88**. Gear **76** on axle **74** engages gear **82** on power shaft **78**. Sprocket **77** on axle **74** engages sprocket **85** on power shaft **78** by means of chain or cable **87**.

Fig. 8 shows a diagram of how the shore wave generator system **70** (Fig. 7) converts the back and forth horizontal motion of incoming and outgoing shore waves into unidirectional rotation of power shaft **78**. With an incoming wave, paddle wheels **73** engage the wave in troughs **72** (Fig.7), rotate clockwise, and cause axle **74** to rotate clockwise. This causes gear **76** and sprocket **77** to rotate clockwise. As gear **76** rotates clockwise, gear **82** on power shaft **78** rotates counterclockwise, which makes clutch **81** (a first clutch) rotate counterclockwise, thus, disengaging clutch **81** (Fig. 7). As sprocket **77** rotates clockwise, sprocket **85** on power shaft **78** rotates clockwise, which makes a second clutch **84** (Fig. 7) on power shaft **78** rotate clockwise, thus, making power shaft **78** rotate clockwise. With an outgoing wave, paddle wheels **73** engage the wave in troughs **72**, rotate counterclockwise, and cause axle **74** to rotate counterclockwise (Fig. 7). This causes gear **76** and sprocket **77** to rotate counterclockwise. As gear **76** rotates counterclockwise, gear **82** on power shaft **78** rotates clockwise. As gear **82** rotates clockwise it makes clutch **81** on power shaft **78** rotate clockwise, thus, making power shaft **78** rotate clockwise. As sprocket **77** rotates counterclockwise, sprocket **85** on power shaft **78** rotates counterclockwise, which makes clutch **84** rotate counterclockwise, thus, disengaging clutch **84**. Power shaft **78** can be connected to a transmission by means of power pulley **88** to drive an electric generator, as described above in Fig. 6.

The foregoing description has been limited to specific embodiments of this invention. It will be apparent; however, that variations and modifications may be made by those skilled in the art to the disclosed embodiments of the invention, with the attainment of some of all of its advantages and without departing from the spirit and scope of the present invention. For example, the floating vertical motion wave power generator **10** (Figs. 1 and 2) of the present invention can be scaled up to any desirable size, and the flotation device can be of any desired buoyancy capacity. The vertical motion floating wave generator **10** can be attached to a large ship, such as a 60 million gallon oil tanker. This is equivalent to 516 million pounds of buoyancy which converts to about the same electric energy output as a nuclear reactor, assuming 7 foot waves at a frequency of 7 waves per minute. The flotation device can be tethered to the horizontal and vertical supports to prevent it from drifting. Other types of one-way clutches can be used, such as Sprague clutches and Reynolds clutches. Cables or belts may be used in place of a chain, and pulleys may be used in place of sprockets. The vertical motion wave power generator can be adapted to interface with any type of up and down vertical motion to generate electricity. For example, as trains move across railroad tracks, the tracks are pushed down and then spring back up as the train passes. This motion of the railroad tracks can be converted to electricity by means of the present invention using a lever having one end attached under the track. As the trains move across the railroad tracks the lever would be pushed up and down. The opposite end of the lever can have a platform to attach the power shaft, transmission, and generator, and the vertical support frame and drive chain can be attached to the ground, as described above, providing the system for generating power from the up and down vertical motion of the tracks. The vertical motion wave power generator can generate pressure power in addition to electric power. The power shaft **17**, attached rotatably to support frame **16** (see Figs 1-4), can extend over an end or side of the flotation device **11**, with the second opposite end of first chain **25** extending upward over said sprocket or pulley **20** without passing through an opening **27** in the flotation device **11**.

The horizontal motion wave power generator **70** (Fig. 7) of the present invention can be scaled up to any desirable size. As many paddle wheels as desired can be attached to a power shaft. Other types of one-way clutches can be used, such as Sprague clutches and Reynolds clutches. The horizontal motion wave power generator can generate pressure power in addition to electric power. The paddle wheels **73** and the base **71** can be constructed of any suitable materials, including metals, plastics, wood, or a combination thereof.

It will be understood that various changes in the details, materials, and arrangements of the parts which have been described and illustrated above in order to explain the nature of this invention may be made by those skilled in the art without departing from the principle and scope of the invention as recited in the following claims.

CLAIMS

1. An apparatus for converting vertical up and down motion to unidirectional rotational force for generating power, comprising:
   a) a platform;
   b) a vertical support structure fixed to the ground;
   c) a single power shaft attached rotatably to said platform;
   d) first and second one-way clutches fixed to said power shaft, said one-way clutches each having an outer casing;
   e) a sprocket or pulley fixed to each outer casing, and said sprocket or pulley attached rotatably to said power shaft;
   f) a first chain, belt, or cable having a first end attached to the ground or to said vertical support structure at a position below said platform and said power shaft, and having a second opposite end extending upward over said sprocket or pulley on said first one-way clutch and extending downward therefrom;
   g) a second chain, belt, or cable having a first end attached to said vertical support structure at a position above said platform and said power shaft, and having a second opposite end extending downward under said sprocket or pulley on said second one-way clutch and extending upward therefrom and over an idler pulley attached to said vertical support structure at a position above said platform and said power shaft, and extending downward therefrom;
   h) said first clutch engaging said power shaft as said platform is raised upward, thereby rotating said power shaft in a fixed direction while said second clutch is disengaged from said power shaft;
   i) said second clutch engaging said power shaft as said platform is lowered downward, thereby rotating said power shaft in said fixed direction while said first clutch is disengaged from said power shaft; and

j) said power shaft rotating in said fixed direction as said platform moves up and down, thereby providing unidirectional rotational force to drive a generator.

2. The apparatus of claim 1 wherein said power shaft is positioned over said platform and said second opposite end of said first chain, belt, or cable passes through an opening in said platform.

3. The apparatus of claim 2 further comprising a transmission with a flywheel, wherein said transmission is positioned between said power shaft and said generator to increase the speed of rotation from said power shaft to said generator.

4. The apparatus of claim 3 wherein said platform is a flotation device for use on a body of water to convert the up and down motion of waves in the body of water into unidirectional rotational force through said power shaft.

5. The apparatus of claim 4 wherein said power shaft, transmission, and generator are all attached to said flotation device and move up and down in unison with said flotation device.

6. The apparatus of claim 1 wherein said power shaft extends over an end or side of said platform with said second opposite end of said first chain extending upward over said sprocket or pulley without passing through said platform.

7. The apparatus of claim 6 further comprising a transmission with a flywheel, wherein said transmission is positioned between said power shaft and said generator to increase the speed of rotation from said power shaft to said generator.

8. The apparatus of claim 7 wherein said platform is a flotation device for use on a body of water to convert the up and down motion of waves in the body of water into unidirectional rotational force through said power shaft.

9. The apparatus of claim 8 wherein said power shaft, transmission, and generator are all attached to said flotation device and move up and down in unison with said flotation device.

10. An apparatus for converting the horizontal incoming and outgoing motion of shore waves to unidirectional rotational force for generating power, comprising:

a) a base;

b) an axle attached rotatably to said base, said axle having one or more paddle wheels attached thereto;

c) a single power shaft attached rotatably to said base;

d) first and second one-way clutches fixed to said power shaft;

e) a gear fixed to said first one-way clutch, said gear attached rotatably to said power shaft, and said gear engaging a reverse gear fixed to said axle;

f) a sprocket fixed to said second one-way clutch, said sprocket attached rotatably to said power shaft, and said sprocket engaging a sprocket attached to said axle;

g) said second one-way clutch engaging said power shaft as the flow of a wave rotates said paddle wheels in a first direction, thereby rotating said power shaft in a fixed direction while said first clutch is disengaged from said power shaft;

h) said first clutch engaging said power shaft as the flow of a wave rotates said paddle wheels in a second opposite direction, thereby rotating said power shaft in said fixed direction while said second clutch is disengaged from said power shaft; and

i) said power shaft rotated in said fixed direction by said paddle wheels as said paddle wheels rotate in a first direction and in a second opposite direction, thereby providing unidirectional rotational force to said power shaft from incoming and outgoing waves to drive a generator.

11. The apparatus of claim 10 further comprising said base having troughs, a portion of said paddle wheels being positioned in said troughs, and said paddle wheels engaging

incoming and outgoing shore waves at said portions of said paddle wheels positioned in said troughs.

12. The apparatus of claim 11 further comprising a transmission with a flywheel positioned between said power shaft and said generator, wherein said transmission increases the speed of rotation from said power shaft to said generator.

13. An apparatus for converting the horizontal incoming and outgoing motion of shore waves to unidirectional rotational force for generating power, comprising:

a) a base having one or more troughs;

b) an axle attached rotatably to said base, said axle having one or more paddle wheels attached thereto, a portion of said paddle wheels being positioned in said troughs, and said paddle wheels engaging incoming and outgoing shore waves at said portions of said paddle wheels positioned in said troughs;

c) a single power shaft attached rotatably to said base;

d) first and second one-way clutches fixed to said power shaft;

e) a gear fixed to said first one-way clutch, said gear attached rotatably to said power shaft, and said gear engaging a reverse gear fixed to said axle;

f) a sprocket fixed to said second one-way clutch, said sprocket attached rotatably to said power shaft, and said sprocket engaging a sprocket attached to said axle;

g) said second one-way clutch engaging said power shaft as the flow of a wave rotates said paddle wheels in a first direction, thereby rotating said power shaft in a fixed direction while said first clutch is disengaged from said power shaft;

h) said first clutch engaging said power shaft as the flow of a wave rotates said paddle wheels in a second opposite direction, thereby rotating said power shaft in said fixed direction while said second clutch is disengaged from said power shaft; and

i) said power shaft rotated in said fixed direction by said paddle wheels as said paddle wheels rotate in a first direction and in a second opposite direction, thereby providing unidirectional rotational force to said power shaft from incoming and outgoing waves to drive a generator.

14. The apparatus of claim 13 further comprising a transmission with a flywheel positioned between said power shaft and said generator, wherein said transmission increases the speed of rotation from said power shaft to said generator.

FIG. 1

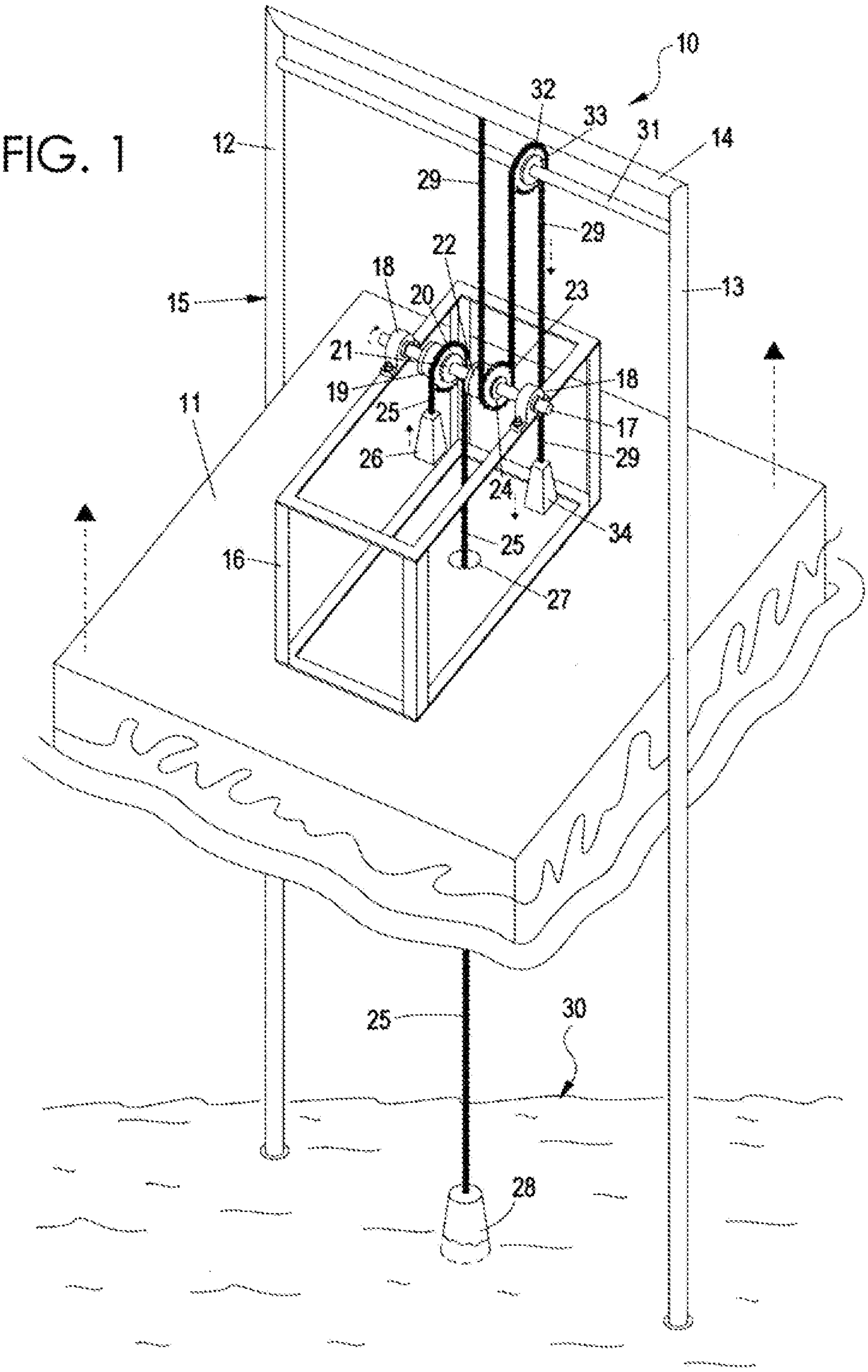
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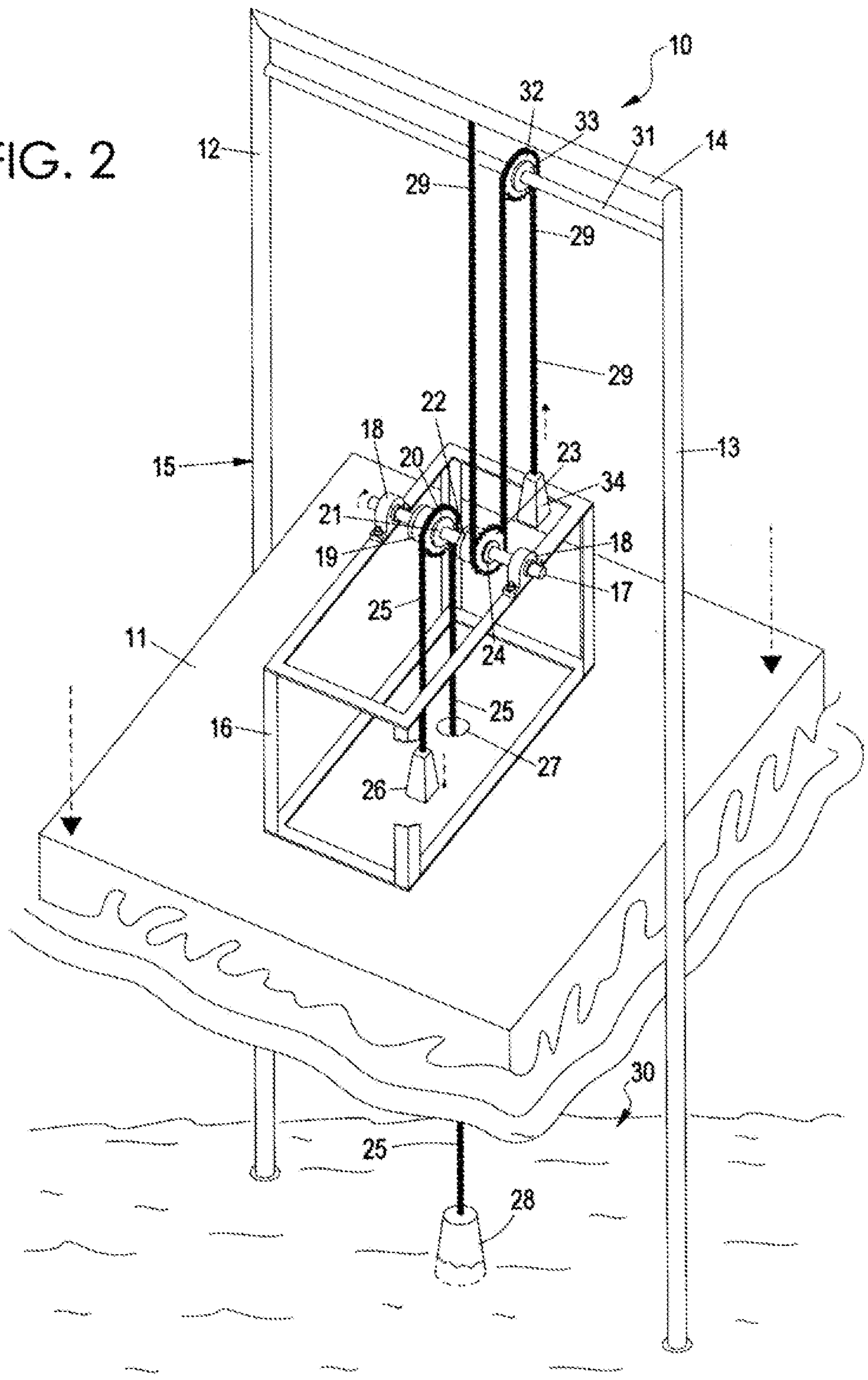
FIG. 2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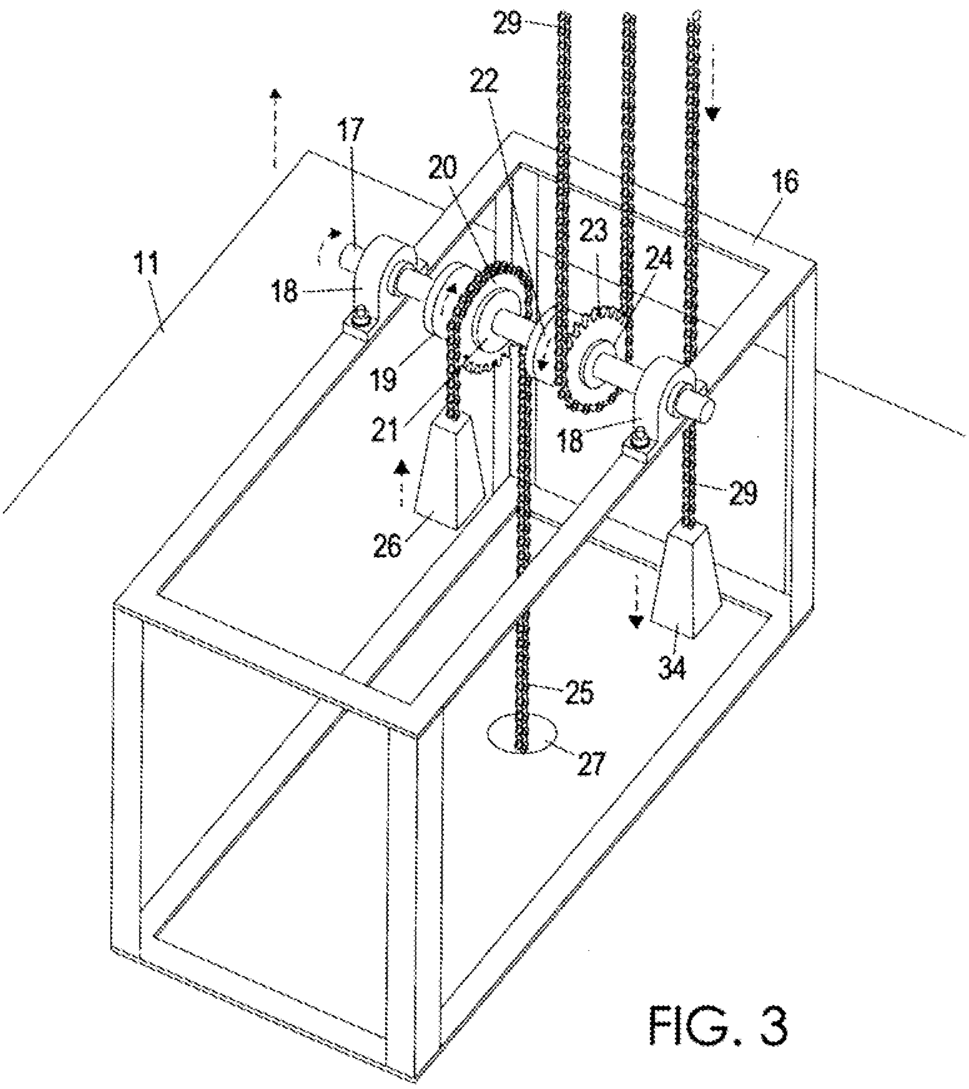

FIG. 3

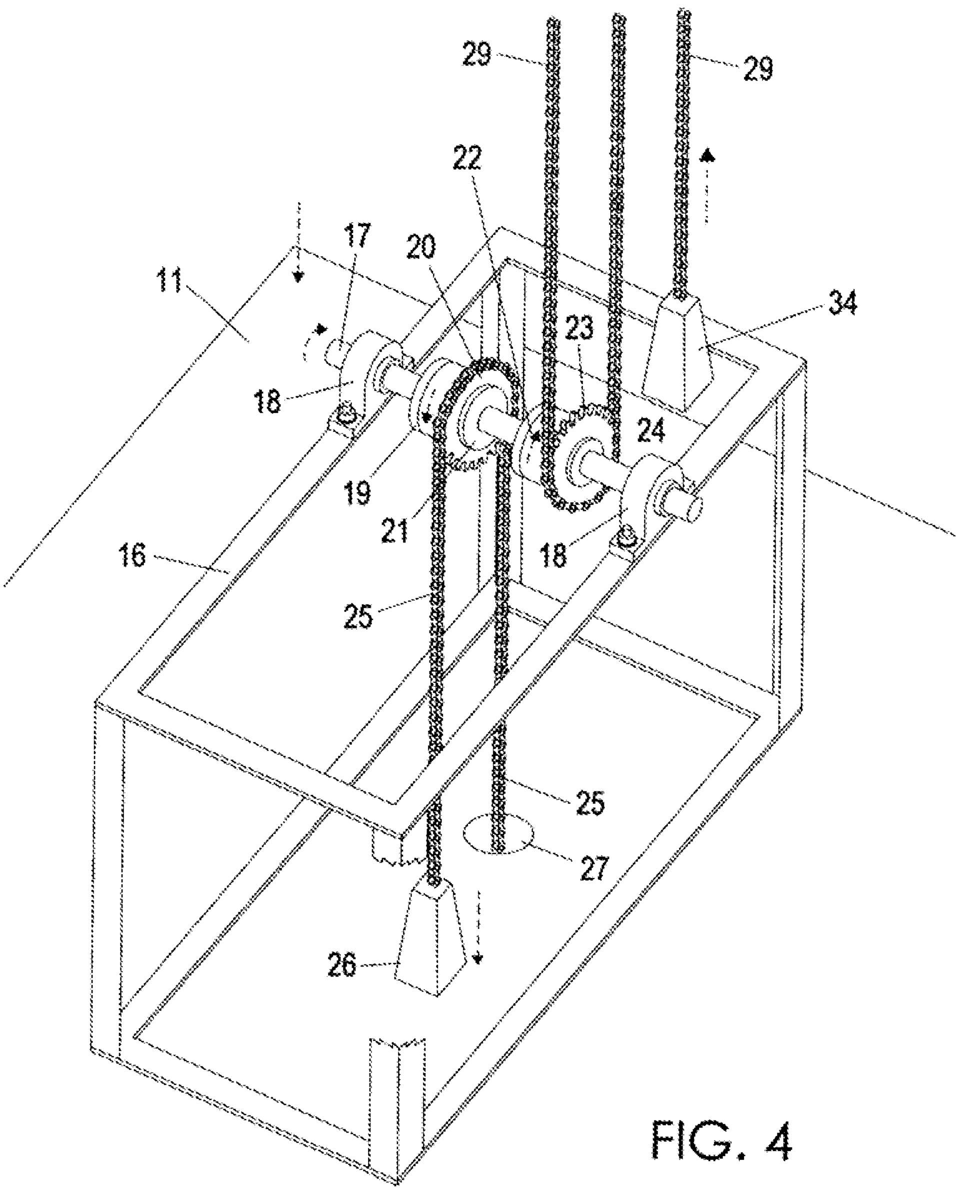

FIG. 4

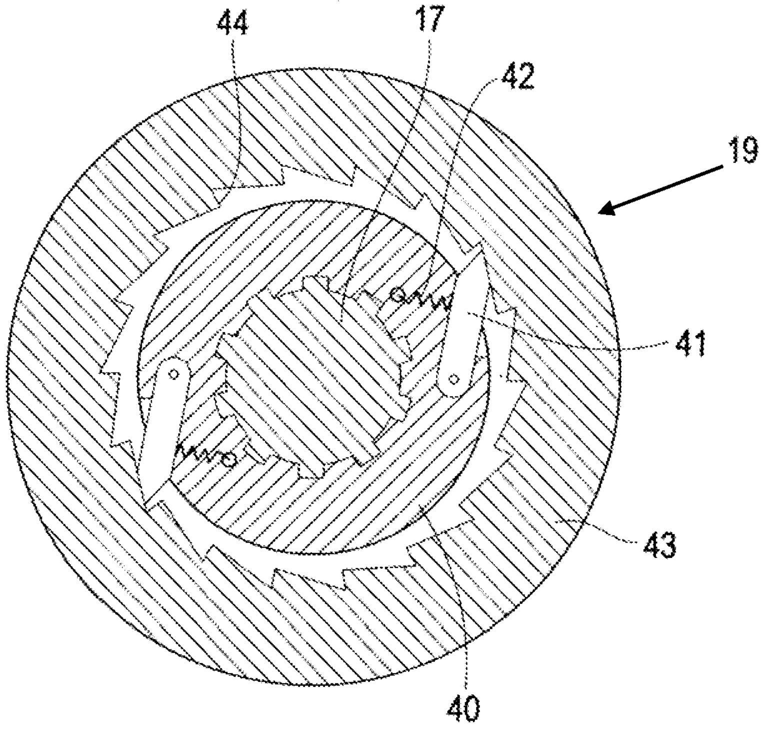

FIG. 5

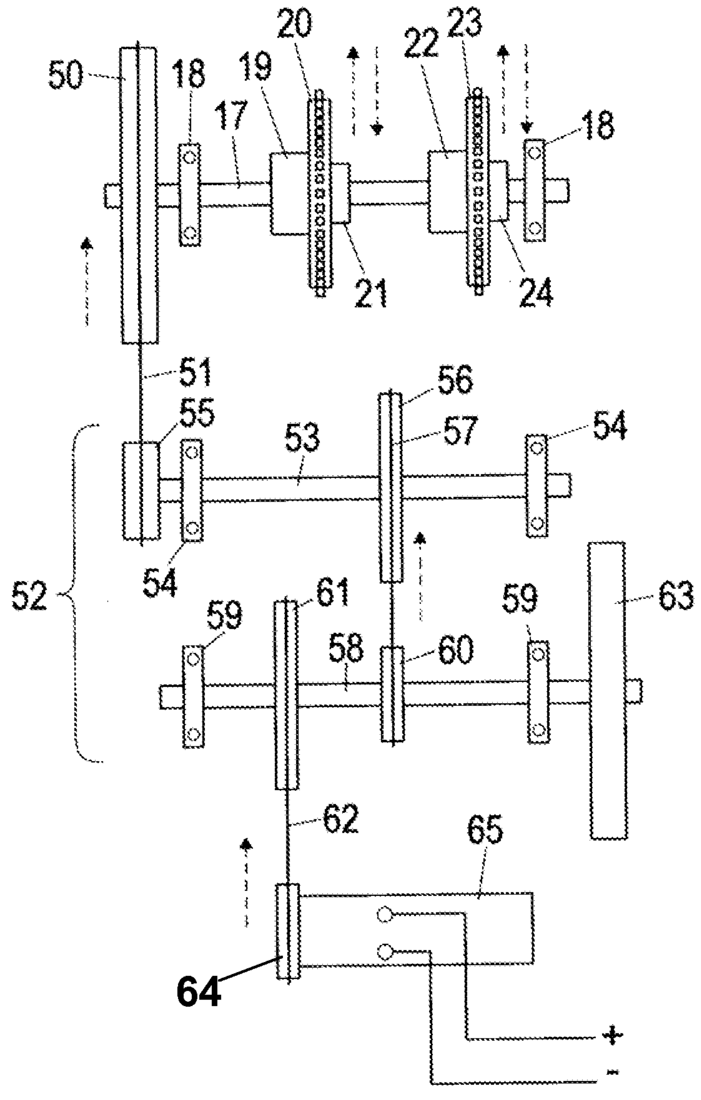
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FIG. 6

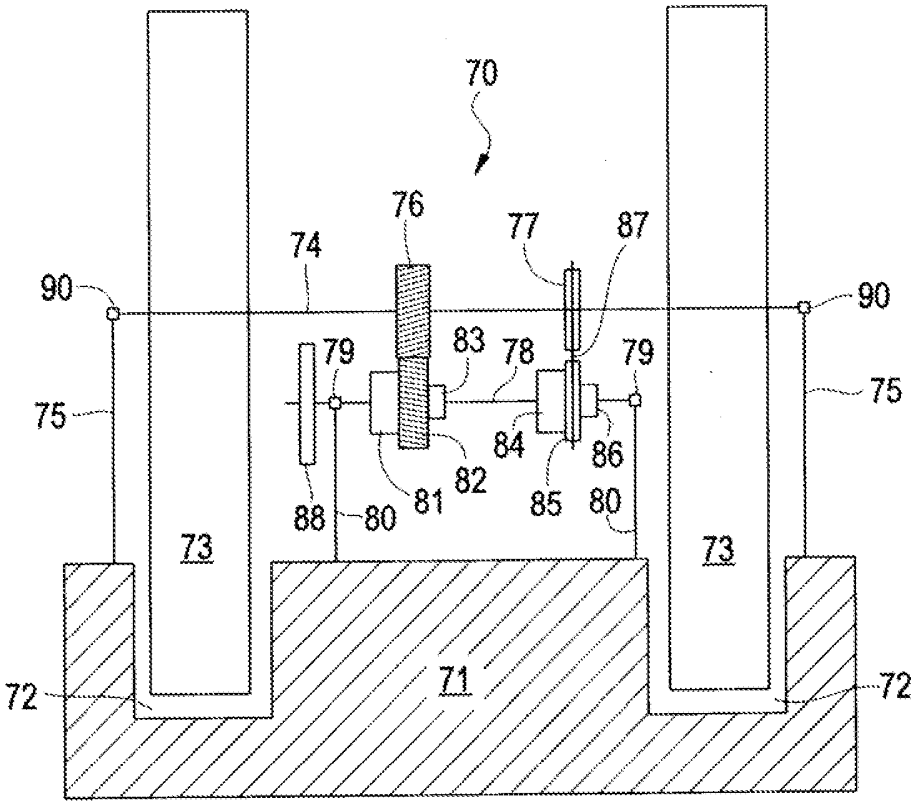
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FIG. 7

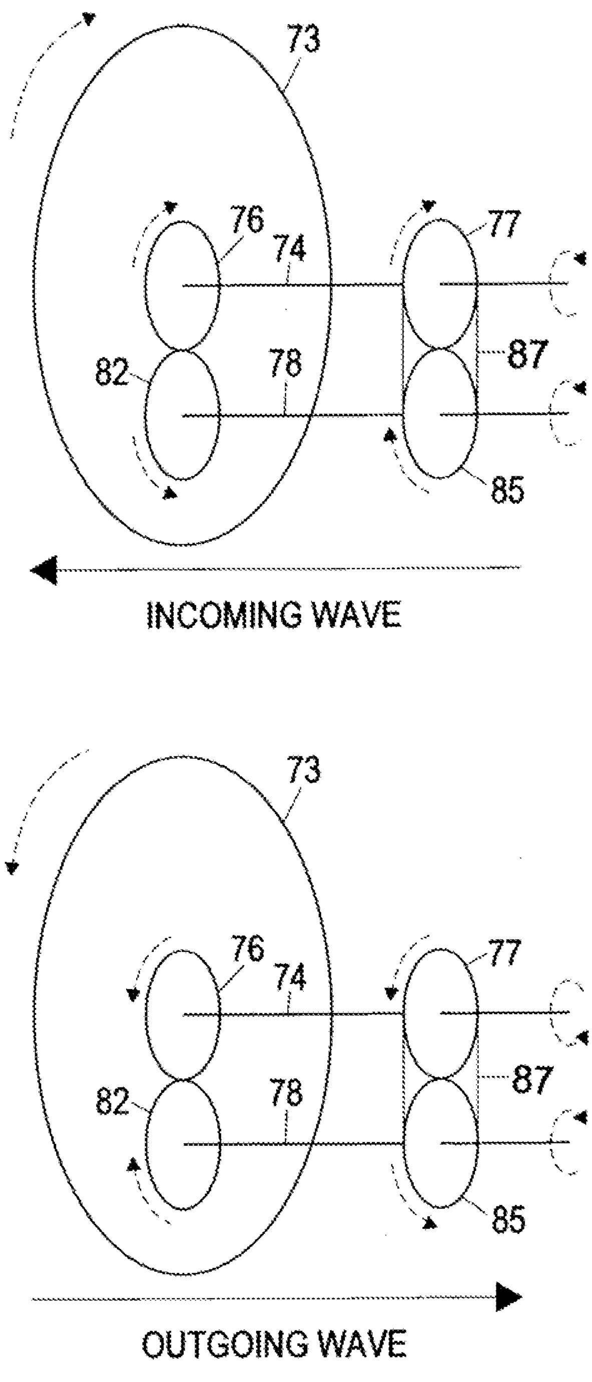
73
76
74
77
87
82
78
85
INCOMING WAVE
73
76
74
77
87
82
78
85
OUTGOING WAVE

FIG. 8

INTERNATIONAL SEARCH REPORT

PCT/US2009/054335 08.10.2009

International application No.
PCT/US2009/054335

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F03B 13/12 (2009.01)
USPC - 290/53
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - F03B 13/10, 13/12, 13/14, 13/16 (2009.01)
USPC - 60/398; 290/53

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

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 3,911,287 A (NEVILLE) 07 October 1975 (07.10.1975) entire document	1-14
Y	US 2008/0084069 A1 (LEE) 10 April 2008 (10.04.2008) entire document	1-14
Y	US 7,076,949 B2 (FERNANDEZ GOMEZ et al) 18 July 2006 (18.07.2006) entire document	3-5, 7-9, 12, 14
A	US 4,145,885 A (SOLELL) 27 March 1979 (27.03.1979) entire document	1-14

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

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
30 September 2009	08 OCT 2009

Name and mailing address of the ISA/US	Authorized officer:
Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Blaine R. Copenheaver PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

US 20090211240A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2009/0211240 A1**

Patton (43) **Pub. Date: Aug. 27, 2009**

(54) **METHOD AND APPARATUS FOR CONVERTING ENERGY IN A MOVING FLUID MASS TO ROTATIONAL ENERGY DRIVING A TRANSMISSION**

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(21) Appl. No.: **12/379,578**

(22) Filed: **Feb. 25, 2009**

Related U.S. Application Data

(60) Provisional application No. 61/064,262, filed on Feb. 25, 2008.

(30) **Foreign Application Priority Data**

Feb. 25, 2008 (CA) 2,622,284

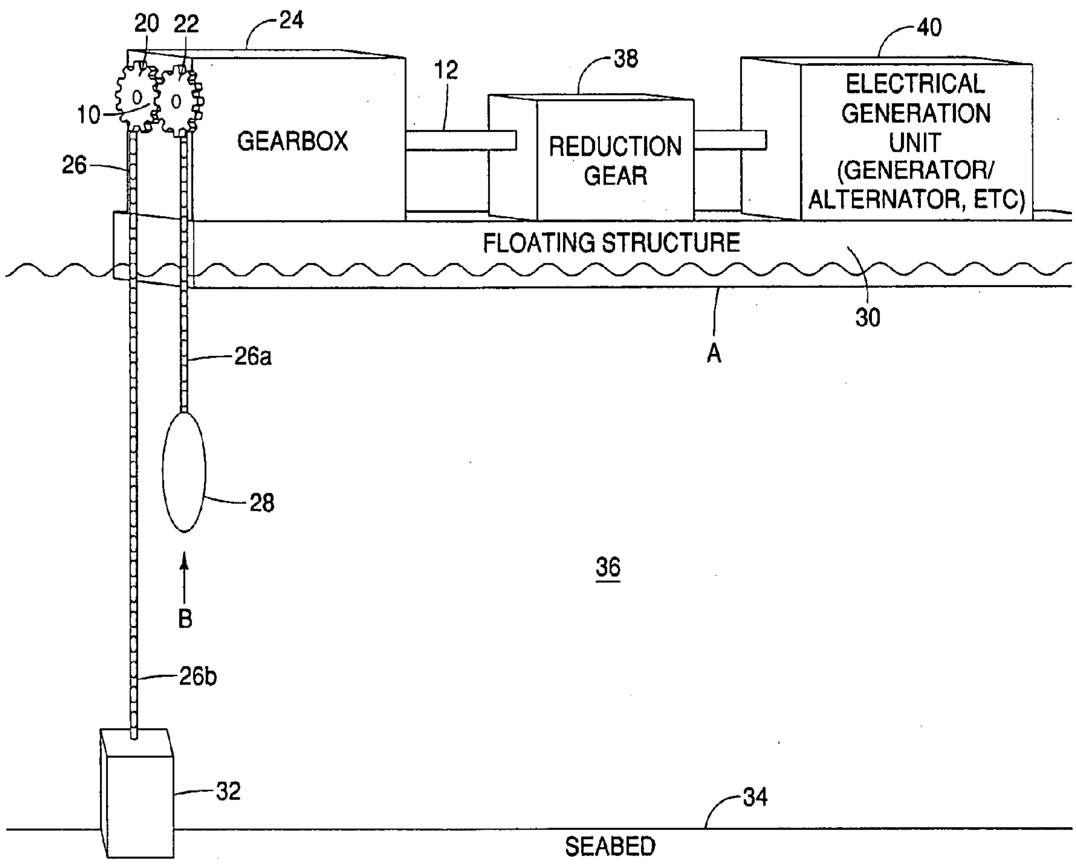
Publication Classification

(51) **Int. Cl.**
F03B 13/18 (2006.01)

(52) **U.S. Cl.** **60/498**; 60/504

(57) **ABSTRACT**

Three bodies interact to drive a transmission having a pair of one-way clutches coupling a single length of drive chain or other elongate flexible member to an intermeshed pair of counter rotatable gears so as to drive a primary shaft in a single rotational direction. The three bodies are a fixed body, a floating body, and a suspended and usually submerged weighted body. The three bodies are interconnected by the single length of the elongate flexible member and are spaced apart there along. The weighted body is mounted at one end of the elongate flexible member. The primary shaft is mounted above the surface of a moving fluid mass to either the fixed or floating body. The end of the flexible member opposite to the weight is mounted to the other of the fixed or floating body.



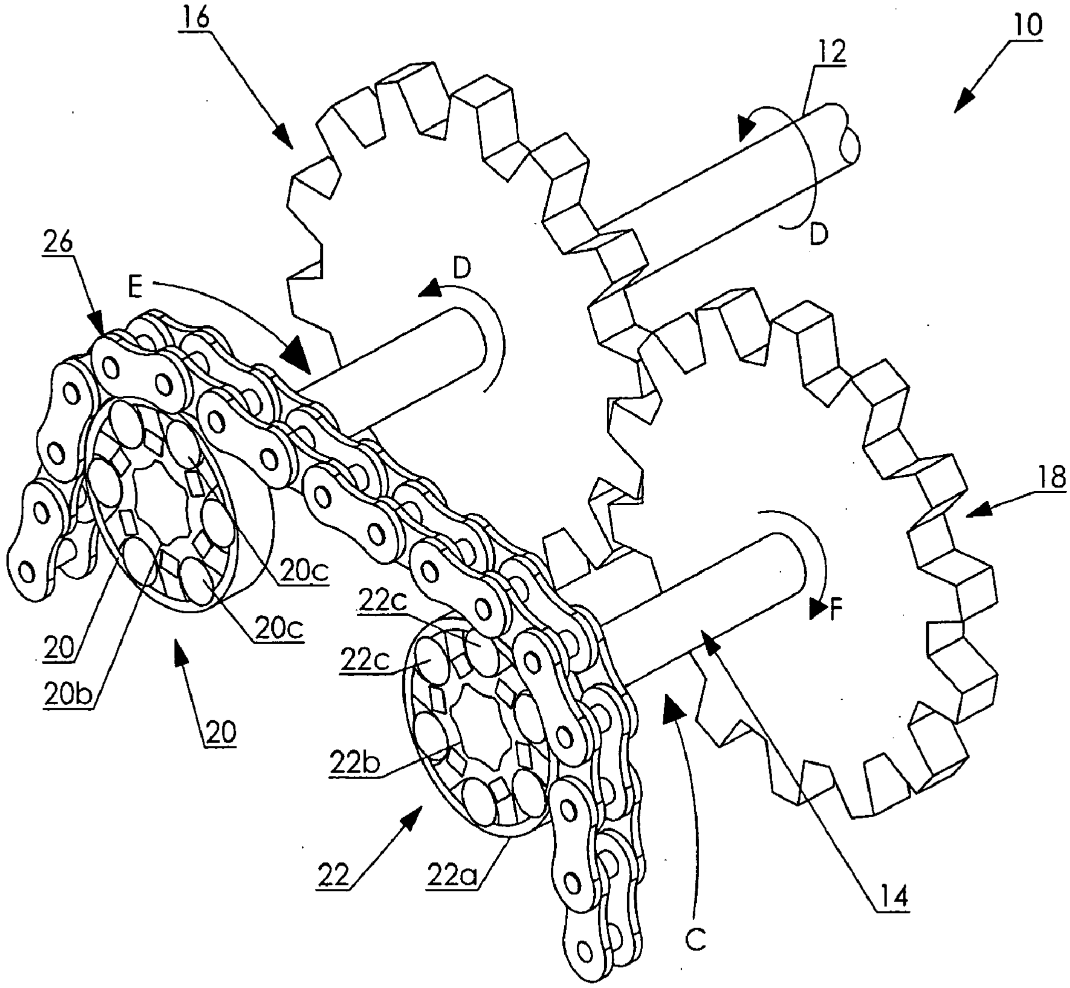


Figure 1

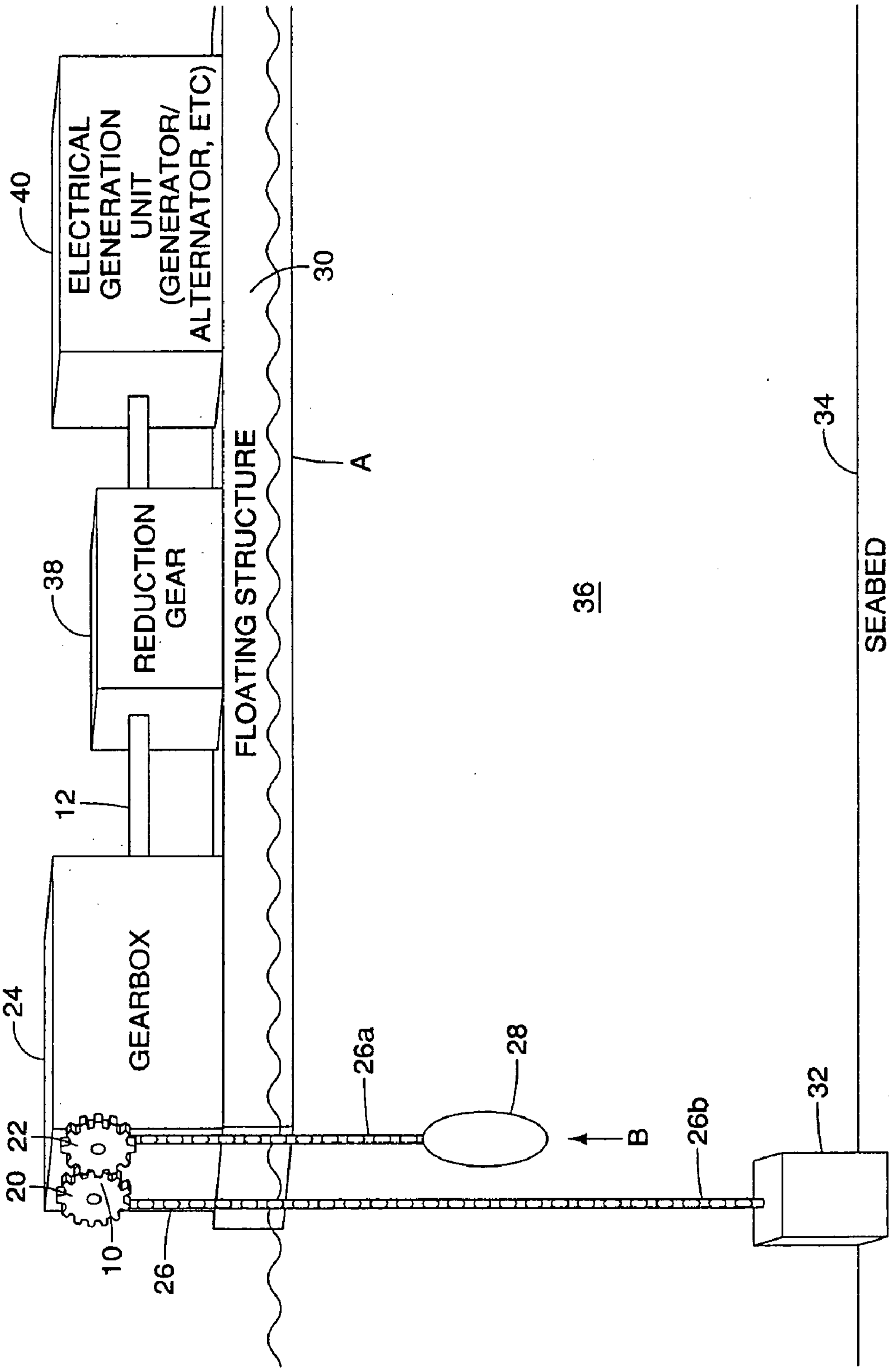
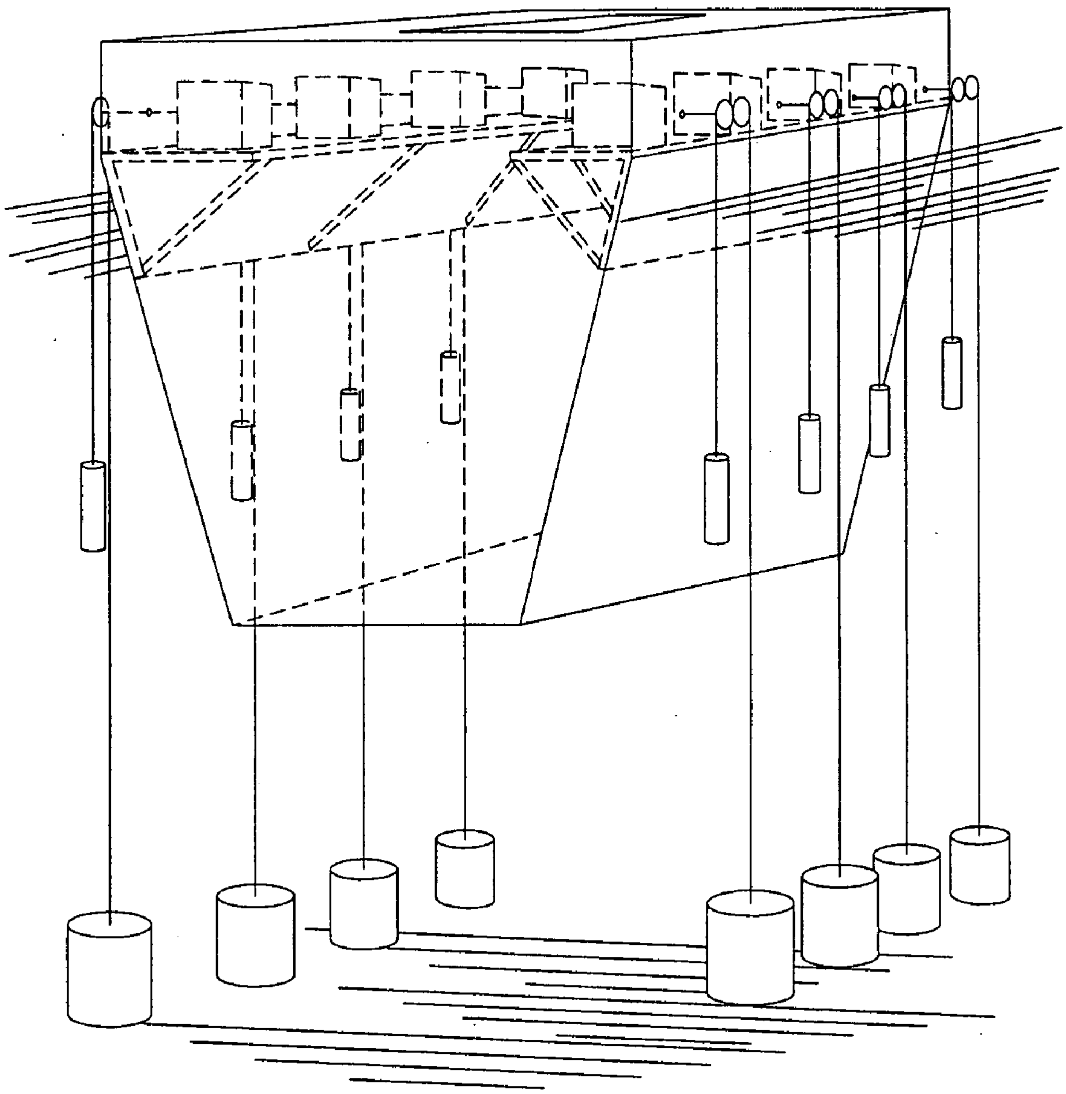

ELECTRICAL GENERATION UNIT (GENERATOR/ ALTERNATOR, ETC)
40
REDUCTION GEAR
38
GEARBOX
24
12
FLOATING STRUCTURE
30
A
36
34
SEABED
22
20
10
26
26a
28
B
26b
32

Figure 2

Figure 2a



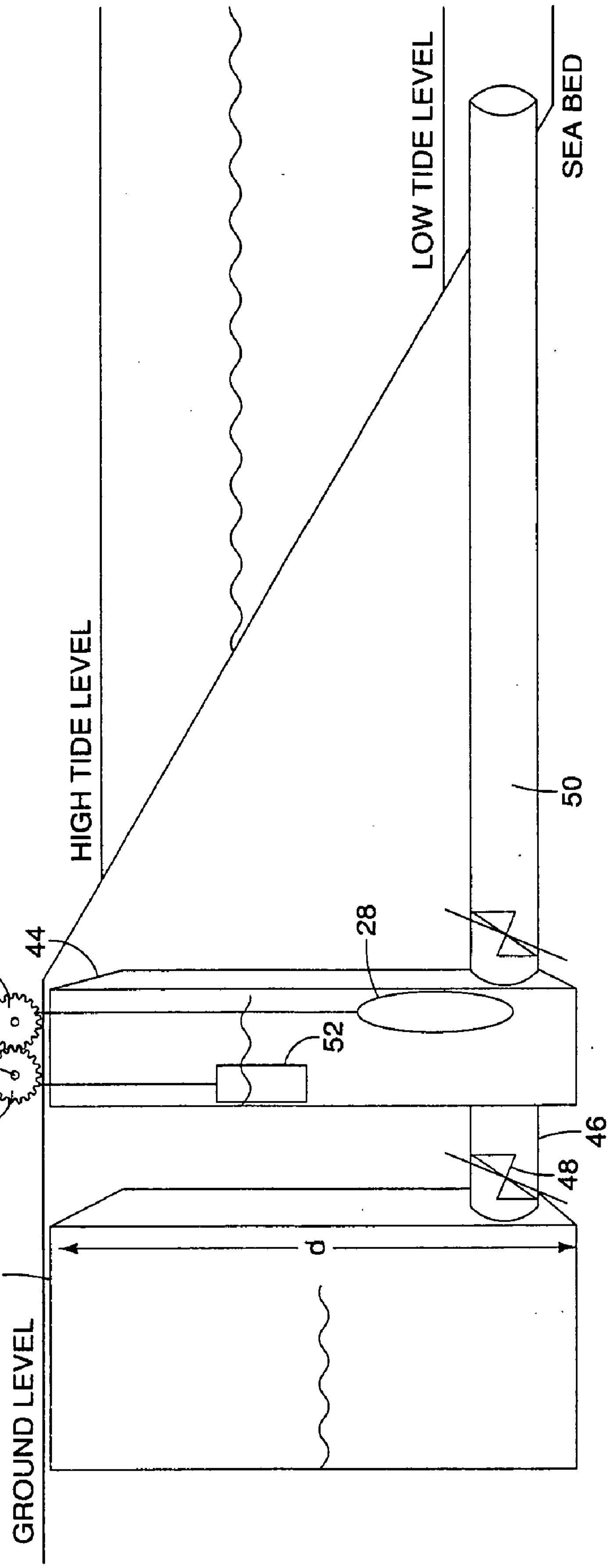

HIGH TIDE LEVEL
LOW TIDE LEVEL
SEA BED
GROUND LEVEL
22
12
20
44
28
52
42
46
48
50
d

Figure 3

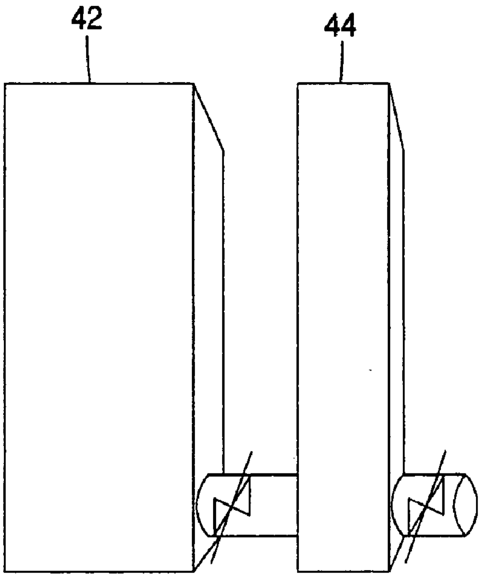


Figure 4a

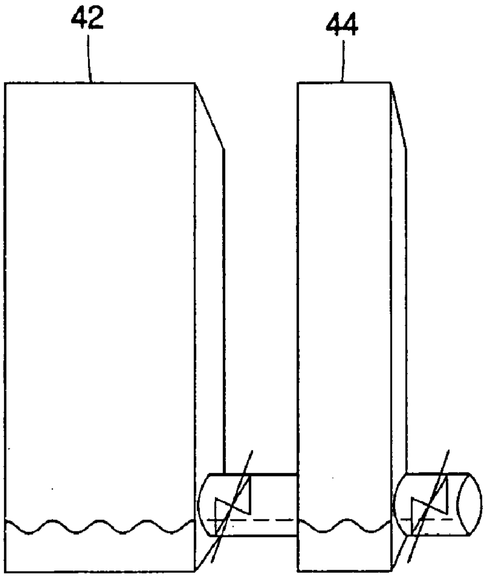


Figure 4b

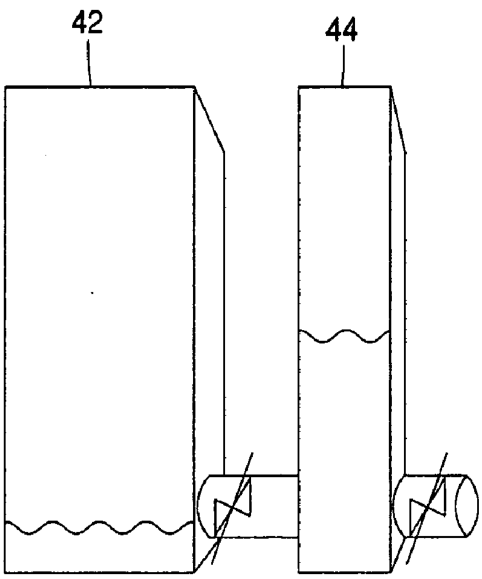


Figure 4c

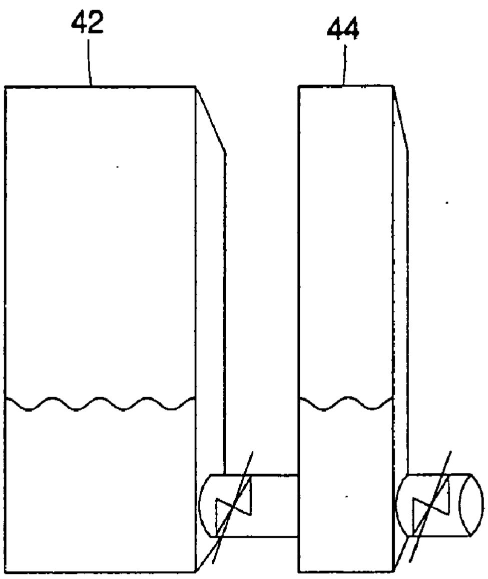


Figure 4d

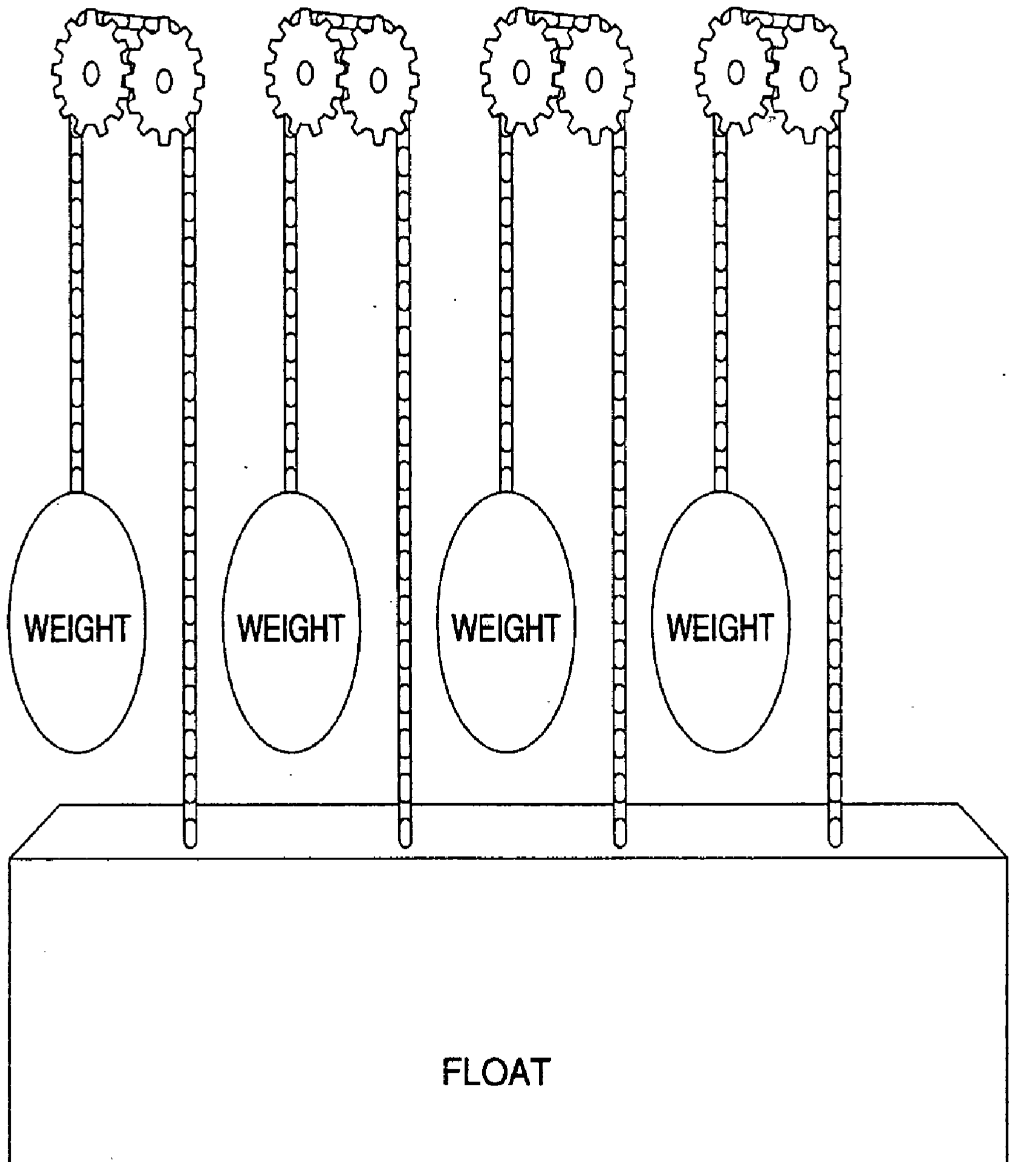


Figure 5

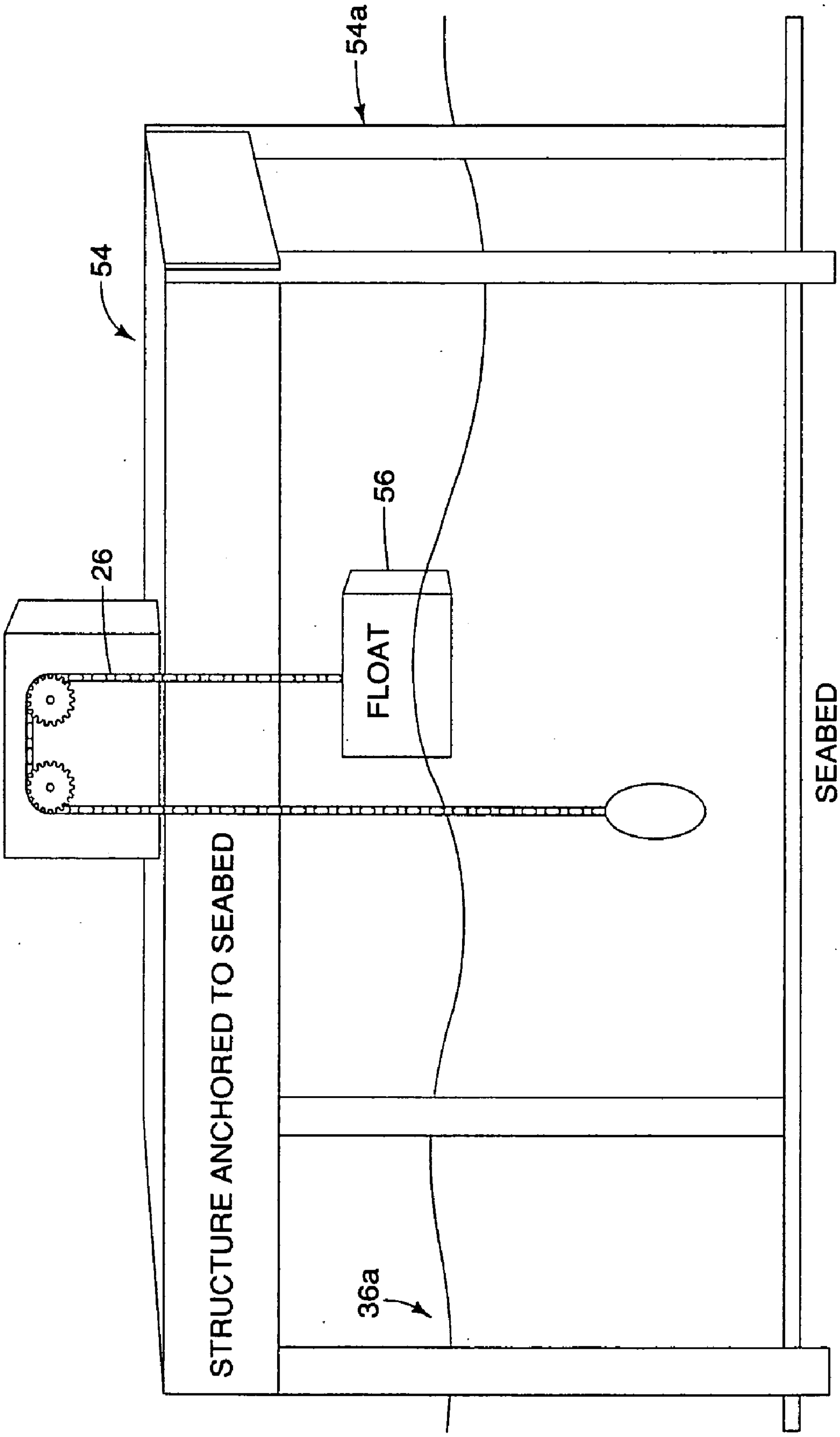


Figure 6

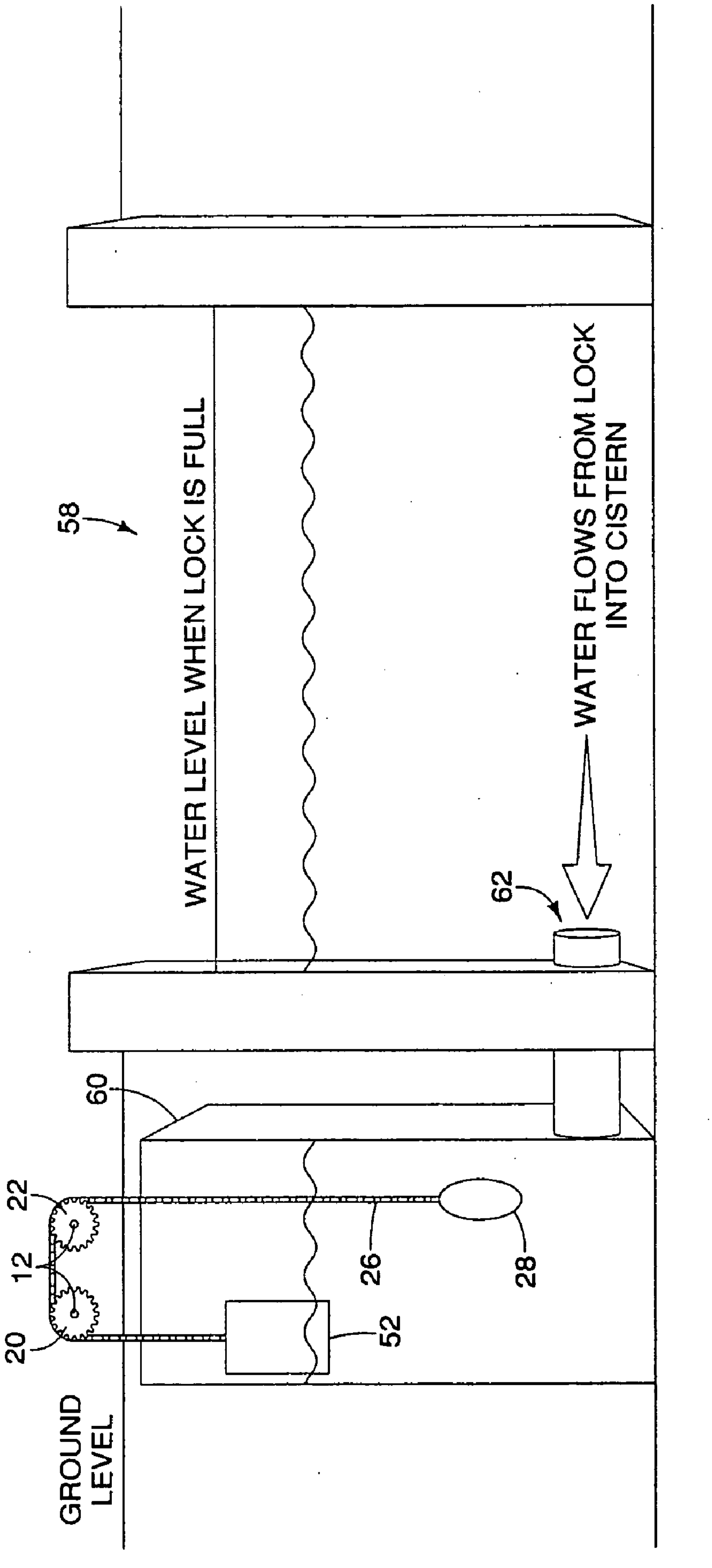

58
WATER LEVEL WHEN LOCK IS FULL
WATER FLOWS FROM LOCK INTO CISTERN
62
60
22
12
20
26
28
52
GROUND LEVEL

Figure 7

METHOD AND APPARATUS FOR CONVERTING ENERGY IN A MOVING FLUID MASS TO ROTATIONAL ENERGY DRIVING A TRANSMISSION

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims priority from U.S. Provisional Patent Application No. 61/064,262 filed Feb. 25, 2008 entitled. Method and Apparatus for Converting Energy in a Moving Fluid Mass to Rotational Energy Driving a Transmission, and from Canadian Patent Application No. 2,622,284 filed Feb. 25, 2008 entitled. Method and Apparatus for Converting Energy in a Moving Fluid Mass to Rotational Energy Driving a Transmission.

FIELD OF THE INVENTION

[0002] This invention relates to the field of motors for converting energy from ocean waves, tides or other moving bodies of water or other fluids to mechanical work, and in particular to converting the energy found in such moving fluid masses to rotational energy so as to drive a transmission which in turn may drive a generator or the like.

BACKGROUND OF THE INVENTION

[0003] As stated by Solell in U.S. Pat. No. 4,145,885 which issued Mar. 27, 1979 for a Wave Motor, it is known that the energy in the sea constitutes a vast reservoir of energy which has reinained largely untapped to the present time. In that patent Solell proposes a wave motor which includes a float, a displaceable member coupled to the float so as to be displaceable by the ascent and descent of the float, a pair of shafts, and a transmission including a pair of one-way clutches coupling the displaceable member to the shafts to rotate one in one direction during the ascent of the float and to rotate the other in the opposite direction during the descent of the float. In particular, Solell discloses that the displaceable member is a wheel that is rotated in opposite directions by the ascent and descent of the float, or that may be a rack which is moved upwardly by the ascent of the float and downwardly by its descent.

[0004] The Solell patent, the floats float on the exposed surface of the ocean waves and in applicant's view are therefore exposed to the waves' action. In the embodiment depicted in FIGS. 1-3 of the Solell patent, the operation of the wave motor is reliant on a consistent or predominant wave direction, it being applicant's opinion that if the wave direction changes for example, to a direction which is at right angles to the consistent or predominant wave direction, the counter rotation by the then out of phase rise and fall of the pair of floats may jam or greatly reduce the consistent operation of the wave motor. In the embodiment of FIGS. 5 and 6 in the Solell patent, a single float drives a corresponding vertically translating rack so as to rotate the pair of shafts via the one-way clutches. Again, the float floats on the exposed surface of the waves and, in applicant's opinion, may be subject to considerable battering which may impair its function over time.

SUMMARY OF THE INVENTION

[0005] In the present invention, three bodies interact to drive a transmission having a pair of one-way clutches coupling a single length of drive chain or other elongate flexible member to an intermeshed pair of counter rotatable gears so as to drive a primary shaft in a single rotational direction. A first gear of the pair of gears is mounted on the primary shaft, and a second gear of the pair of the intermeshed gears is mounted on a secondary shaft adjacent and parallel to the primary shaft. The pair of one-way clutches are mounted on each of the ends of the two shafts.

[0006] The three bodies required for the operation of the present invention are a fixed body, a floating body, and a suspended and usually submerged weighted body. The three bodies are interconnected by the single length of the elongate flexible member and are spaced apart there along. The weighted body, which may simply be a weight, however could be a spring or other device, is mounted at one end of the elongate flexible member. The elongate flexible member extends upwardly from the weight and follows the shape of an inverted "u" as it extends over, so as to be coupled with, the pair of one-way clutches which are mounted on the ends of the primary and secondary shafts. The pair of clutches are spaced apart in a planar arrangement in the vertex of the inverted u-shaped flexible member. The primary and secondary shafts are mounted to a second body above the surface of the moving fluid mass, and the end of the flexible member opposite to the weight is mounted to a third body disposed underneath the second body.

[0007] In one embodiment, the second body is a floating structure and the third body is an anchor resting in a fixed position underneath the floating structure such that movement of the moving fluid mass, which may for example be the ocean, causes the floating structure to translate in a direction having a predominately vertical direction. As the floating structure oscillates predominately vertically, during its ascent the length of the flexible member extending between the floating structure and the anchor lengthens, thereby shortening the length of the flexible member between the floating structure and the weight, it being understood that the elongate flexible member is substantially inelastic and therefore of a substantially fixed length. In this embodiment then the transmission, and in particular its exposed pair of one-way clutches, are mounted high enough up on the floating structure to minimize battering by the waves, and the weight and the anchor remain submerged, again, to minimize the battering effect of waves travelling on the surface of the moving fluid mass. On the ascent of the floating structure, the flexible member drives one of the one-way clutches to rotate its corresponding shaft in one direction and rotates the other one-way clutch and corresponding shaft in the opposite direction during the descent.

[0008] In a second embodiment, the second body is a fixed structure mounted above the surface of the moving fluid mass, and the third body is a float riding on the surface of the moving fluid mass. The transmission is mounted onto the fixed structure, that is, the second body, so as to once again be mounted high enough to be up out of the way of interference by the waves. The transmission operates in the same fashion as described for the first embodiment, and differs from the teaching of Solell in his U.S. Pat. No. 4,145,885 described above, in at least that the use of the suspended weight allows the operation of the transmission no matter which direction the waves are moving relative to the fixed structure and float.

[0009] Thus as may be seen by an understanding of the first and second embodiments of the present invention, it is the use of the weight, or other suspended weighted body, that enables the relative movement between the first, second and third bodies as the fluid mass moves or swells (or is otherwise elevated, rises and falls or such other hydraulic actuation) to drive the drive chain or other flexible member riding over the pair of one-way clutches, the weight tensions the chain while suspended either above-surface or subsurface, and enables the drive chain to continuously drive the primary and secondary shafts via the clutches resulting in a continuous rotation of the primary shaft in a useful rotational direction so as to for example drive an electrical generator or otherwise to provide work.

[0010] The relative movement between the first, second and third bodies provides for an upward stroke of the weight as the distance between the second and third bodies lengthens and provides for a downward stroke of the weight as the distance between the second and third bodies shortens as the moving body of fluid swells and subsides respectively. The hydraulic energy in the swelling or otherwise elevation of the surface of the fluid mass provides the energy to raise the weight, and then as the surface of the fluid mass falls, the weight falls correspondingly thereby tensioning the flexible member over the one-way clutches as the change in relative position between the three bodies causes the rotation of the one-way clutches and the corresponding rotation of either the primary shaft directly with the secondary shaft being free running or of the primary shaft indirectly as driven by the driven rotation of the secondary shaft driving the pair of intermeshed gears which thereby drive the primary shaft in its useful rotational direction.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. **1** is, in perspective partially cut-away view, the one-way clutch and one-way gear drive mechanism according to one aspect of the present invention.

[0012] FIG. **2** is a diagrammatic view of one embodiment of a power generation system according to the present invention employing an anchor weight and a suspended weight at opposite ends of the transmission drive chain.

[0013] FIG. **2***a* is a perspective diagrammatic view of a large scale pontoon having a multiplicity of the power generation units of FIG. **2** mounted thereto, and wherein the corresponding generators are mounted within the water-tight pontoon.

[0014] FIG. **3** is, in perspective view, a further embodiment of a power generation system according to the present invention employing a tidal tank, an equalization tank, and a low tide level supply pipe.

[0015] FIG. **4***a* is the system of FIG. **3** showing initial filling of the tidal tank.

[0016] FIG. **4***b* is the system of FIG. **3** showing filling of the equalization tank from the tidal tank.

[0017] FIG. **4***c* is the system of FIG. **3** showing further filling of the tidal tank to the level of the rising tide.

[0018] FIG. **4***d* is the system of FIG. **3** showing the further filling of the equalization tank from the tidal tank.

[0019] FIG. **5** is a partially cut-away perspective view of a multiple chain driven transmission according to one aspect of the present invention wherein the weight may in one embodiment be suspended on the exterior of a tank containing the float.

[0020] FIG. **6** is a perspective view of a suspended weight and float mounted on opposite ends of a drive chain driving a transmission mounted on a fixed structure fixed over the ocean.

[0021] FIG. **7** is a vertical section view through a lock embodiment of the present invention wherein a transmission is mounted in fixed relation over a lock-fed tank and driven by a drive chain having a weight and a float on opposite ends of the chain.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

[0022] As seen in FIG. **1**, in one embodiment, the transmission **10** includes a primary shaft **12** mounted in appropriate bearings (not shown), and an adjacent and parallel stub shaft or secondary shaft **14** also mounted in appropriate bearings (not shown). A pair of intermeshed gears **16** and **18** are mounted on shafts **12** and **14** respectively and intermeshed so that rotation of one causes rotation of the other. A pair of one-way clutches **20** and **22** are mounted onto the ends of shafts **12** and **14** respectively and in particular to the ends of those shafts which are exposed from a housing or gear box **24** as better seen by way of example in FIG. **2**. As illustrated, one-way clutches **20** and **22** are, respectively, although generally referred to herein as clutches, a clockwise overrunning clutch and sprocket, and a counter clockwise over running clutch and sprocket.

[0023] As is known in the art, in the one form of one-way clutch which is illustrated, and which is not intended to be limiting, each clutch includes an outer body in the form of a ring **20***a* and **22***a* which may be a sprocket usually having teeth or the like (not shown) for mating with an elongate flexible member such as drive chain **26**. An inner ratchet mechanism **20***b* and **22***b* are respectively mounted rotatably within rings **20***a* and **22***a*. The ratchets are each mounted rigidly to the ends of the corresponding shafts **12** and **14** and are coupled to the corresponding outer rings **20***a* and **22***a* by a radially spaced apart array of balls **20***c* and **22***c* radially spaced apart around and between rings **20***a* and **22***a*, and inner ratchet mechanisms **20***b* and **22***b*. As would be known to one skilled in the art, rotation of the outer rings relative to the inner ratchet mechanisms tend to wedge the corresponding balls between the outer ring and inner ratchet thereby effecting a coupling between the outer ring and the corresponding inner ratchet as the outer ring rotates first in a direction which compresses the balls into engagement with the ratchet mechanism and decouples the ring from the ratchet mechanism when the outer ring rotates in the opposite direction leaving thereby the outer ring to be free running with respect to the ratchet.

[0024] Thus in the embodiment of FIG. **2**, a first weighted body or weight **28** is mounted to the first end **26***a* of chain **26**, transmission **10** is mounted on or in gear box **24** which itself is mounted on a floating second body such as floating structure **30**, and a third body such as anchor **32** is mounted at the second end **26***b* of chain **26** so as to rest on sea bed **34**. Thus as the fluid mass such as ocean **36** swells or other wise hydraulically elevates floating structure **30** in direction A, weight **28** is also elevated in direction B and chain **26** runs in direction C, as seen in FIG. **1**, over one-way clutches **20** & **22**. As one-way clutch **20** is a clockwise overrunning clutch and one-way clutch **22** is a counterclockwise overrunning clutch, the corresponding rotation of the one-way clutches as chain **26** translates in direction C, causes balls **20***c* to jam between ratchet **20***b* and outer ring **20***a* to thereby cause driven rotation of shaft **12** in direction D while outer ring **22***a* of one-way clutch **22** freewheels or overruns so as to not cause rotation of shaft **14**. Rotation of shaft **12** in direction D causes a corresponding rotation of gear **16** also in direction D as gear **16** is rigidly mounted onto shaft **12**. Because gear **16** is intermeshed with gear **18**, rotation of gear **16** in direction D causes counter rotation of gear **18**. Counter rotation of gear **18** causes corresponding counter rotation of shaft **14**. Counter Rotation of shaft **14** causes counter rotation of ratchet **22***b* which is freewheeling within freely overrunning outer ring **22***a*.

[0025] As the swell of ocean **36** subsides so that floating structure **30** descends in a direction opposite to direction A, causing weight **28** to translate in a direction opposite to direction B, chain **26** runs in direction E, again as seen in FIG. **1**, over one-way shafts **20** and **22**. Running of chain **26** in direction E over the one-way clutches, causes the clutch mechanism of one-way clutch **22** to engage, that is, balls **22***c* jam between ratchet **22***b* and outer ring **22***a* so as to cause corresponding rotation in direction F of shaft **14** and gear **18**. Rotation of gear **18** in direction F also causes rotation of gear **16** in direction D which correspondingly rotates shaft **12** in direction D, thereby providing continuous unidirectional rotation of shaft **12** to allow useful work to be extracted from shaft **12** for example by the operation of reduction gears **38** electrical generation unit **40**.

[0026] In FIG. **2***a* a floating structure such as water tight pontoon **31**, that is which has a hull which is enclosed on all sides, as well as on the top and bottom. Electrical generators are housed within the pontoon. Pontoons **31** are positioned in areas where ocean swells would be the main source of vertical movement. Shafts as per the embodiments of FIGS. **1** and **2** extend from the generators through the pontoon walls to the outside. The shafts are supported by bearings **31***a*, and extend as far enough to afford clearance from contact with the wall of the structure. The walls of the hull, below the point where the shafts extend to the outside, are slanted inwardly under the hull to a degree useful to prevent the drive chain **26** or other flexible member from contacting said hull, the actions of ocean swells presumably causing rolling motions and horizontal movements of the hull or pontoon which is held in place by the anchors **32** on/in the sea bed **34**.

[0027] Total displacement of water would be the sum of the weight of the pontoon, the weight of the mechanical components **24**, **38**, **40**, and the weights **28** attached to the chains **26**. The mechanical components are mounted to platforms **33** attached along the inner sides of the walls, and braced by braces **33***a* for stability. The amount of freeboard (distance from surface of water to top of structure) is calculated to allow free access to the mechanical components, yet minimize the effect of wind moving the pontoon horizontally. Sealed hatched **30***b* located in the top of the pontoon provide access. The amount of power produced may be varied, with variable being the number and size of generators, etcetera, the draft, beam and length of the pontoon. This embodiment may be retro-fitted to other existing floating structures, such as used barges, hulls from de-commissioned ships or other existing floating structures.

[0028] Apart from the driving of transmission **10** by the operation of ocean swells, the rise and fall of the tides may also operate to drive transmission **10** thereby provide for usable work being provided by shaft **12**.

[0029] For example in an ebb tide, as the tide recedes, floating structure **30** descends and free weight **28** at end **26***a* of chain **26** pulling downwardly under the force of gravity urges one of the pair of one-way clutches to rotate its corresponding shaft while being free running over the other clutch. Another example would be during a flood tide so that as the tide changes and starts to flood floating structure **30** starts to ascend and anchor **32** on sea bed **34** then tensions chain **26** so as to cause translation of the chain in an opposite direction thereby reversing the operation of the pair of clutches. That is, the drive clutch during the descent of the floating structure becomes the returning clutch and the clutch which was the free turning clutch during the descent of the floating structure becomes the driving clutch. Thus during both the ebb tide and flood tide as the floating structure correspondingly descends and ascends, the pair of one-way clutches operate to drive shaft **12** continuously in a single rotational direction.

[0030] With respect to floating structure **30**, it may be a free floating or a tethered floating structure including such things as floating marinas or docks, barges, house boats, such examples not intending to be limiting.

[0031] In some coastal areas tidal flats occur at low tide. In order to capture the full height of a tide, as seen in FIG. **3**, instead of a power generating unit built out to sea, a long distance from the shoreline potentially creating a hazard to navigation, a shore-based system is provided for locating the power generating apparatus on the shore. Because of the slow-moving nature of the tides, equalization tank **42** may be used to increase the total vertical distanced (see FIGS. **4***a*-**4***d*). The following describes the construction process:

[0032] A hole is dug to the appropriate depth below drying level and a vertical tidal tank **44** built. The tidal tank has a first volume. Equalization tank **42** is built adjacent to the tidal tank **44**. The equalization tank has a second volume which is greater than the first volume. The two tanks are connected by a pipe **46** and water flow is controlled by a valve. A second pipe **50** is connected to the outlet of the tidal tank and extends out to open water to just past the low tide level (See FIG. **3**). The size of the tidal tank is sufficient to accept a float **52** and counterweight **54** sized to power the generating device **40** (not shown). The diameter of the horizontal pipes **46** and **50** is sufficient to allow the tidal tank and equalization tank to fill and empty at the speed of the tidal ebb and flow.

[0033] During the flood tides, as the tide floods, the float rises and the counterweight forces the chain to rotate the pair of one-way clutches **20**, **22** to thereby rotate shaft **12**. As the tidal tank fills to Level A, the valve from the sea to the tidal tank closes, preventing further ingress of sea water. The valve between the tidal tank and the equalization tank opens, allowing the water to flow from the tidal tank into the equalization tank until the level of the two tanks equalizes at Level B. This causes the float to drop in the Tidal Tank and the counterweight to rise, turning the clutches **20**, **22** in the opposite direction. This again causes shaft **12** to rotate.

[0034] Once the tank levels equalize, the equalization tank valve closes and the sea water valve opens and water continues to flow into the Tidal Tank until it reaches Level C which is higher than Level A because of the incoming tide. Then the sea water valve closes and then the equalization tank valve opens allowing the water to flow into the equalization tank until the two tanks once again equalize at Level D.

[0035] Each time the water rises or falls in the Tidal Tank it causes the shaft to rotate. The use of an equalization tank significantly increases to total vertical movement—the larger the equalization tank—the greater the increase in vertical tide movement. An equalization tank of double the surface area of the Tidal Tank almost triples the vertical distance the water rises and falls within the Tidal Tank. By of analogy then the tidal tank acts as a cylinder and the reciprocating motion of the float on the end-weighted chain as a piston reciprocating in the cylinder.

[0036] During the ebb tide, with both valves closed, the level of the water in the tidal tank lowers to a pre-determined level. The sea valve closes, then the equalization tank valve opens and water from the equalization tank moves into the Tidal Tank until the water level in both tanks equalizes. Every time the water in the Tidal Tank lowers and then rises, alternatingly ascending and descending, it causes shaft **12** to rotate.

[0037] This permits a tidal power unit to operate during times when sea ice or other severe weather conditions would make other systems difficult or impossible to continue to operate. Pure vertical tidal power (disregarding swells and waves) is predictable using this system. Time intervals between valve changes can be altered to suit the tidal profile in any chosen area. Size of equalization tank, if used, can be sized according to the tidal profile in order to optimize the activation of the generating device.

[0038] In some regions the size of the vertical tide may not be sufficient to provide sufficient rpm's to activate an electrical generating unit. As an example of tide differences, the tide characteristics of 2 locations in Canada were compared on the same day. The tidal change in the west coast location was about 6 feet per cycle, while that on the east coast location was about 20 feet.

[0039] In addition to an equalization tank, a solution would be to use springs which could be wound up to a predetermined tension, after which the power could be transferred to the shaft. Using multiple gearboxes, the springs could be wound up to be released at different times. In this way a more constant delivery of electricity could be achieved.

[0040] Where multiple units are needed to ensure a more consistent source of power, for example when springs are used to store the potential energy, and sequenced to discharge at different intervals, a single float could be used to connect the multiple units as seen in FIG. **6**.

[0041] If a tank is located ashore, the weights may be suspended outside the tank so that only the float contacts the water.

[0042] In the application shown in FIG. **6**, the structure **54** is fixed to the shore or seabed for example on pilings **54***a* or other such supports. Fixed structure **54** may include oil rigs, bridge foundations exposed to ocean swells/waves, marinas or other fixed structures supported by vertical pilings, or other structures constructed specifically for electrical generation. The buoyancy to couple the energy of a swell or wave is provided by a separate float **56** and the weight **28** hangs at the other end of the chain **26**. As the swell or wave **36***a* moves from the peak to the trough, the float moves downward, activating the clockwise overrunning clutch to move the shaft in a clockwise direction, transferring this power through the reduction gear to the electrical generating unit. As the swell or wave continues, the float moves from the trough to the peak. This moves the float upwards, causing the chain to produce counterclockwise movement in the overrunning clutches. This now causes the counterclockwise overrunning clutch to engage the device and move the shaft in a clockwise direction to drive the electrical generating unit.

[0043] In the further example of FIG. **7**, the vertical hydraulic displacement found in the operation of canal locks may be employed using the present invention to create power from the vertical movement of the water in a lock **58** as the lock empties empty and fills during its normal operation. To employ the present invention a vertical cistern **60** similar to the tidal tank of FIG. **3**, is constructed alongside the lock, to the full depth of the lock. A pipe **62** interconnects from the bottom of the lock to the bottom of the cistern.

[0044] As with tidal tank **44**, the cistern is sized to accept a float **52** and counterweight **28** on opposite ends of chain **26**, where chain **26** drives one-way clutches **20**, **22**. Since locks fill and empty relatively quickly, the time for power generation may be very short. The diameter of the connecting pipe **62** may be reduced to maximize the length of time it takes to fill and empty the cistern, thereby increasing the length of time of power generation per cycle of the lock. Thus as the lock fills, the water enters the cistern and the float rises while the counterweight descends. The weight on the chain causes the shaft **12** to rotate and thereby actuate the power generating device. Conversely, as the lock empties, the float, which again, although buoyant has a dead weight greater than that of weight **28**, descends while the weight ascends, causing the chain to move in the opposite direction, rotating the shaft and thereby continuously to actuate the power generating device.

[0045] As will be apparent to those skilled in the art in the light of the foregoing disclosure, many alterations and modifications are possible in the practice of this invention without departing from the spirit or scope thereof.

What is claimed is:

1. An apparatus for converting energy in a moving fluid mass having a vertically translating fluid surface to rotational energy driving a transmission, the apparatus comprising:

an elongate flexible member having first and second opposite ends,

first, second, and third bodies connected to in spaced apart array along said elongate flexible member,

wherein said first body is a submerged counter-weight mounted at said first end of said elongate flexible member, said counter-weight submerged in said moving fluid mass between said vertically translating fluid surface and a fixed bottom surface under said vertically translating fluid surface,

wherein one of said second or third bodies has a transmission mounted thereto, said transmission including a pair of side-by-side oppositely free-running one-way clutches over which said flexible member is entrained, said one of said second or third bodies generally situate intermediate along said flexible member between said first and second ends and above said vertically translating fluid surface,

the other of said second or third bodies at said second end of said flexible member, and having a weight which is greater than the weight of said counter-weight.

2. The apparatus of claim **1** wherein said one of said second or third bodies is a fixed structure fixedly mounted relative to, and so as to be elevated above said vertically translating fluid surface, and said other of said second or third bodies at said second end of said flexible member is a float for buoyantly floating substantially on said vertically translating fluid surface of said moving fluid mass.

3. The apparatus of claim **2** wherein said fixed structure is fixedly mounted by elevated mounting means to said fixed bottom surface.

4. The apparatus of claim **2** wherein said moving fluid mass is a tidally driven body of water and wherein said transmission is adapted to harness a tidal ascent and tidal descent of said float for said driving of said transmission.

5. The apparatus of claim 4 wherein said adapting of said transmission includes providing a first hollow container having a vertical rise, said float and said counter-weight suspended in said first container, said fixed structure mounted over, so as to cooperate with, said vertical rise of said first container, first fluid communication means communicating a fluid flow between said body of water and a lower end of said first container.

6. The apparatus of claim 5 wherein said first container is a tidal tank.

7. The apparatus of claim 6 further comprising an equalization tank in selective fluid communication with said tidal tank by a second fluid communication means.

8. The apparatus of claim 7 wherein said first and second fluid communication means are pipes, and further comprising valve means cooperating with said pipes for selectively controlling flow into and out of said tidal tank and said equalization tank.

9. The apparatus of claim 8 further comprising control means for selectively controlling actuation of said valve means, wherein said valve means includes a first valve between said tidal tank and said body of water, and a second valve between said tidal tank and said equalization tank, said control means opening said first valve and closing said first valve in controlled succession as a tide floods said body of water so as to repeatedly fill said tidal tank to a level corresponding to an ascending level of said fluid surface of said body of water, while interleaving opening and closing said second valve while said first valve is closed to gradually fill said equalization tank, and so as to reverse the process to gradually drain said equalization tank during an ebb tide lowering said fluid surface of said body of water, whereby said float and counter-weight are vertically oscillated on said flexible member at a frequency corresponding to a rate of said controlled succession and said interleaving.

10. The apparatus of claim 2 further comprising a hollow container having a vertical rise, said float and said counter-weight suspended in said container, said fixed structure mounted over so as to cooperate with said vertical rise of said container, fluid communication means communicating a fluid flow between said moving fluid mass and a lower end of said container.

11. The apparatus of claim 10 wherein said container is a cistern and said fluid mass is contained within a lock.

12. The apparatus of claim 1 wherein said one of said second or third bodies is a floating structure floating on said vertically translating fluid surface and said other of said second or third bodies at said second end of said flexible member is an anchor weight for resting on said fixed bottom surface under said vertically translating fluid surface of said moving fluid mass.

13. The apparatus of claim 12 wherein said floating structure is a watertight pontoon.

14. The apparatus of claim 13 wherein said pontoon has a top and sides extending downwardly from said top, and wherein at least one transmission shaft extends from said transmission, and wherein said transmission is mounted within said pontoon and said at least one transmission shaft extends through said sides of said pontoon above said vertically translating fluid surface, wherein said flexible member is said entrained over said at least one transmission shaft and engaged thereon.

15. The apparatus of claim 14 wherein said at least one transmission shaft has said clutches mounted thereon at distal ends thereof for engaging said flexible member.

16. The apparatus of claim 14 wherein said sides of said pontoon taper inwardly and downwardly from said top whereby said flexible member when swaying due to fluid motion of said fluid mass does not interfere with said sides.

17. The apparatus of claim 15 wherein said at least one transmission shaft is a pain of transmission shafts and wherein said clutches are mounted on said pair of transmission shafts.

18. The apparatus of claim 17 wherein said pair of transmission shafts are substantially parallel.

19. The apparatus of claim 16 wherein said transmission includes a plurality of transmissions, and further comprises a plurality of generators wherein each said transmission of said plurality of transmissions cooperates with a corresponding generator of said plurality of generators, and wherein said each transmission includes a corresponding said transmission shaft and corresponding said flexible member having corresponding said anchor weight and said counter-weight.

20. The apparatus of claim 19 wherein said plurality of said transmission shafts extend from said sides of said pontoon on opposite said sides of said pontoon.

21. The apparatus of claim 20 wherein said anchor weights are aligned substantially vertically below said at least one transmission shaft.

22. A method for converting energy in a moving fluid mass having a vertically translating fluid surface to rotational energy driving a transmission, the method comprising the steps of:

providing an elongate flexible member having first and second opposite ends,

providing first, second, and third bodies connected to in spaced apart array along said elongate flexible member,

providing a transmission including a pair of side-by-side oppositely free-running one-way clutches over which said flexible member is entrained wherein said clutches drive counter-rotatable inter-meshed gears for converting reciprocatingly driven rotation of said clutches to uni-directional rotation of an output shaft of said transmission,

wherein said first body is a counter-weight mounted at said first end of said elongate flexible member,

wherein one of said second or third bodies has said transmission mounted thereto, said one of said second or third bodies generally situate intermediate along said flexible member between said first and second ends and above said vertically translating fluid surface,

the other of said second or third bodies at said second end of said flexible member, and having a weight which is greater than the weight of said counter-weight,

submerging said counter-weight in said moving fluid mass between said vertically translating fluid surface and a fixed bottom surface under said vertically translating fluid surface,

allowing vertical translation of said fluid surface of said fluid mass to cause relative movement between said first, second and third bodies so as to cause said flexible member to drive rotation of said one-way clutches to thereby drive said transmission.

23. The method of claim 13 wherein said one of said second or third bodies is a fixed structure fixedly mounted relative to, and so as to be elevated above said vertically translating fluid

surface, and said other of said second or third bodies at said second end of said flexible member is a float for buoyantly floating substantially on said vertically translating fluid surface of said moving fluid mass.

24. The method of claim **14** wherein said fixed structure is fixedly mounted by elevated mounting means to said fixed bottom surface.

25. The method of claim **14** wherein said moving fluid mass is a tidally driven body of water and wherein said transmission is adapted to harness a tidal ascent and tidal descent of said float for said driving of said transmission.

26. The method of claim **16** wherein said adapting of said transmission includes providing a first hollow container having a vertical rise, said float and said counter-weight suspended in said first container, said fixed structure mounted over, so as to cooperate with, said vertical rise of said first container, first fluid communication means communicating a fluid flow between said body of water and a lower end of said first container.

27. The method of claim **17** wherein said first container is a tidal tank.

28. The method of claim **18** further comprising an equalization tank in selective fluid communication with said tidal tank by a second fluid communication means.

29. The method of claim **19** wherein said first and second fluid communication means are pipes, and further comprising valve means cooperating with said pipes for selectively controlling flow into and out of said tidal tank and said equalization tank.

30. The method of claim **20** further comprising control means for selectively controlling actuation of said valve means, wherein said valve means includes a first valve between said tidal tank and said body of water, and a second valve between said tidal tank and said equalization tank, said control means opening said first valve and closing said first valve in controlled succession as a tide floods said body of water so as to repeatedly fill said tidal tank to a level corresponding to an ascending level of said fluid surface of said body of water, while interleaving opening and closing said second valve while said first valve is closed to gradually fill said equalization tank, and so as to reverse the process to gradually drain said equalization tank during an ebb tide lowering said fluid surface of said body of water, whereby said float and counter-weight are vertically oscillated on said flexible member at a frequency corresponding to a rate of said controlled succession and said interleaving.

31. The method of claim **14** further comprising a hollow container having a vertical rise, said float and said counter-weight suspended in said container, said fixed structure mounted over so as to cooperate with said vertical rise of said container, fluid communication means communicating a fluid flow between said moving fluid mass and a lower end of said container.

32. The method of claim **22** wherein said container is a cistern and said fluid mass is contained within a lock.

33. The method of claim **13** wherein said one of said second or third bodies is a floating structure floating on said vertically translating fluid surface and said other of said second or third bodies at said second end of said flexible member is an anchor weight for resting on said fixed bottom surface under said vertically translating fluid surface of said moving fluid mass.

* * * * *

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Mesa

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(45) **Date of Patent: Oct. 11, 2011**

(54) **SYSTEM TO OBTAIN ENERGY FROM WATER WAVES**

(75) Inventor: **Manuel Constanzo Mesa**, Miami, FL (US)

(73) Assignee: **Matter Wave Technologies, LLC.**, Miami, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 407 days.

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(51) **Int. Cl.**
F03B 13/10 (2006.01)
F03B 13/12 (2006.01)

(52) **U.S. Cl.** **290/53**; 290/42; 60/495; 60/497; 60/502; 60/503

(58) **Field of Classification Search** 60/495–497, 60/500–506; 290/42–43, 48, 53–54; 417/331–333
See application file for complete search history.

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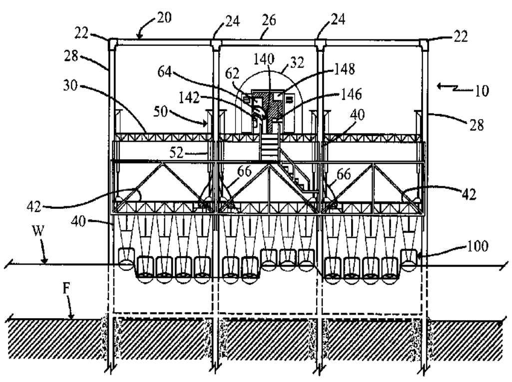
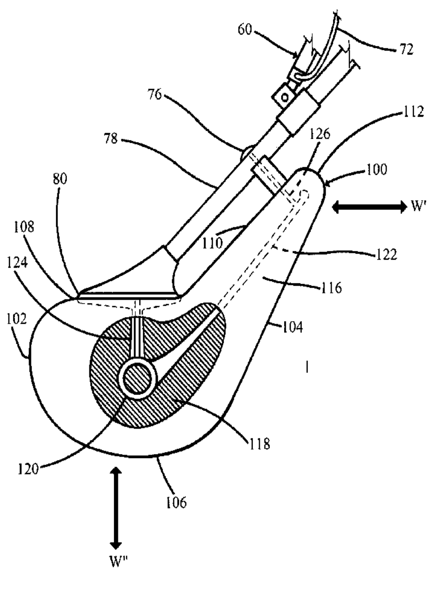
Primary Examiner — Tran Nguyen
(74) *Attorney, Agent, or Firm* — Albert Bordas, P.A.

(57) **ABSTRACT**

A system to harness energy from water waves, comprising a frame assembly, first and second hydraulic systems, at least one float assembly, and an electrical assembly. The float assembly comprises front, rear, bottom, top, and first and second lateral faces. The float assembly further comprises a trailing face. The trailing face and the rear face merge to define an edge. The float assembly is mounted onto the mounting plate. The float assembly is placed in a body of water that comprises wave forces. The electrical system comprises a generator. The generator produces electricity when driven by the hydraulic motor when hydraulic fluid is displaced and pressurized within a hydraulic system when the wave forces cause the float assembly to move when in the body of water.

20 Claims, 13 Drawing Sheets





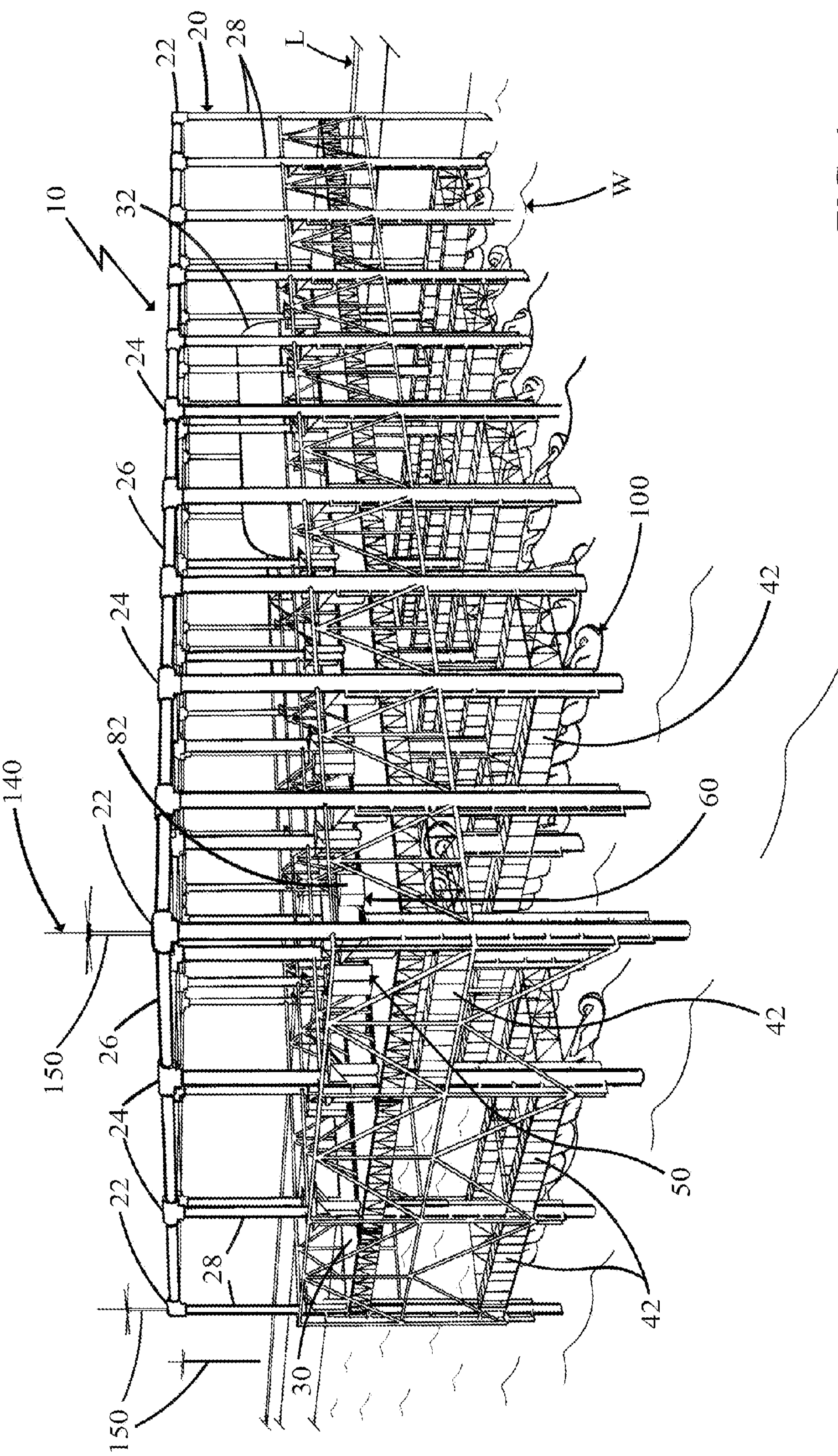


FIG. 1

FIG. 2

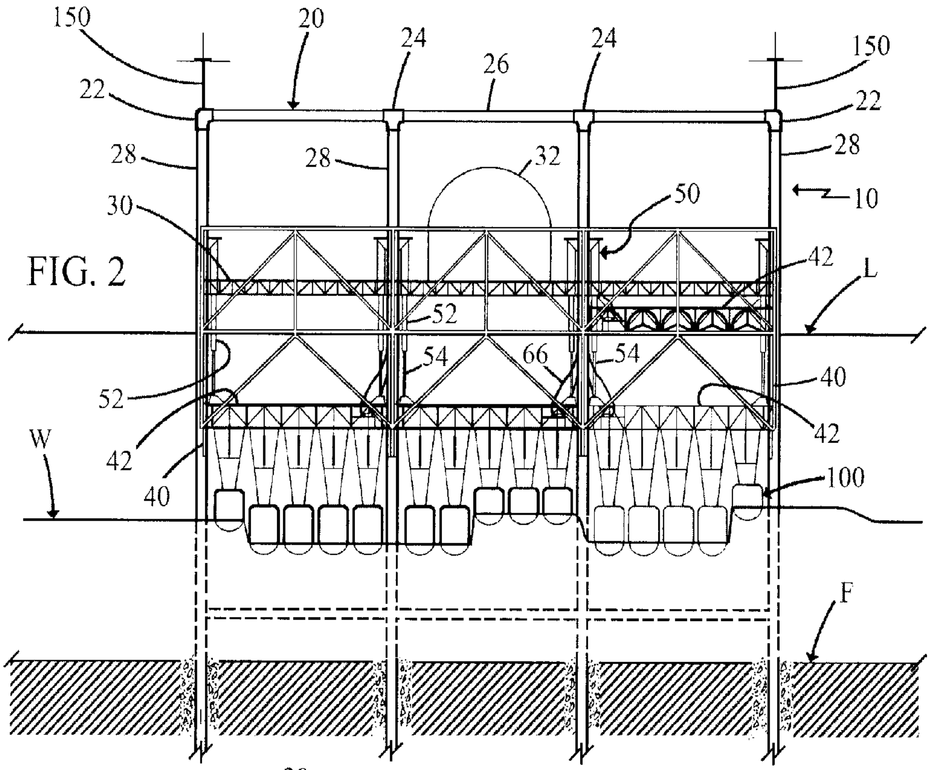

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FIG. 3

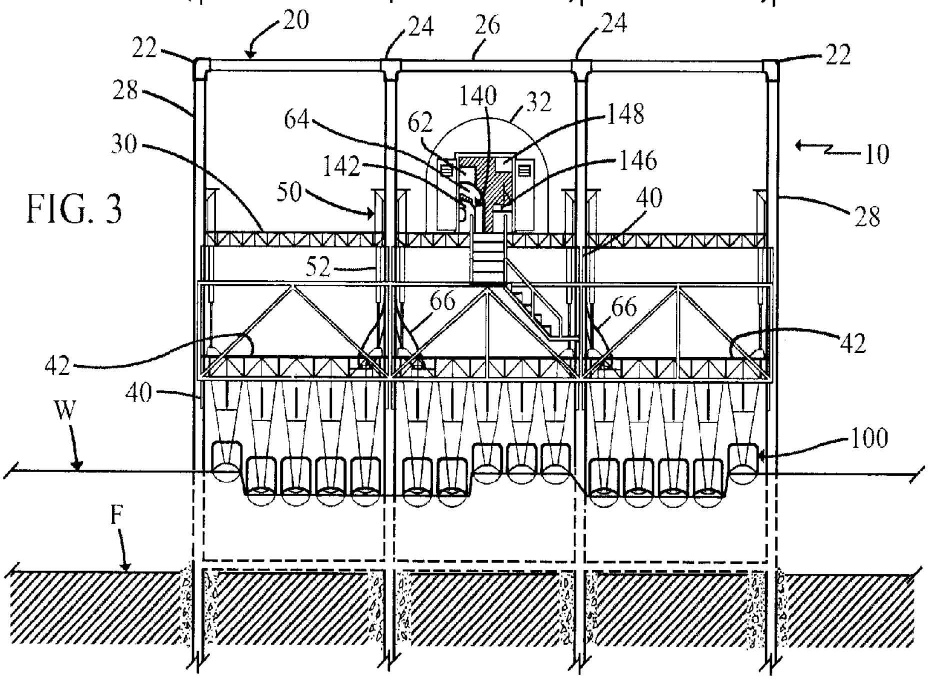
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FIG. 4A

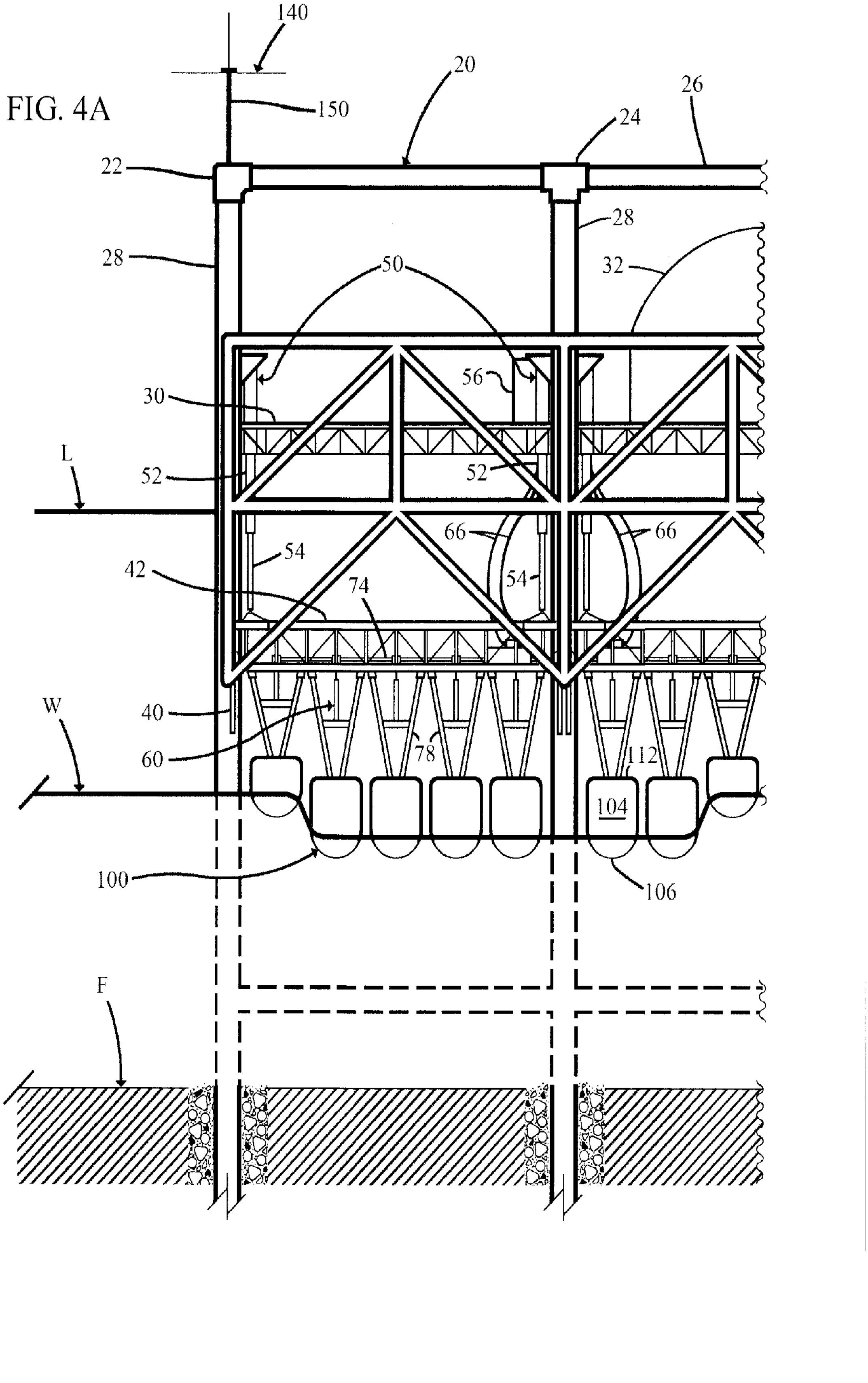

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FIG. 4B

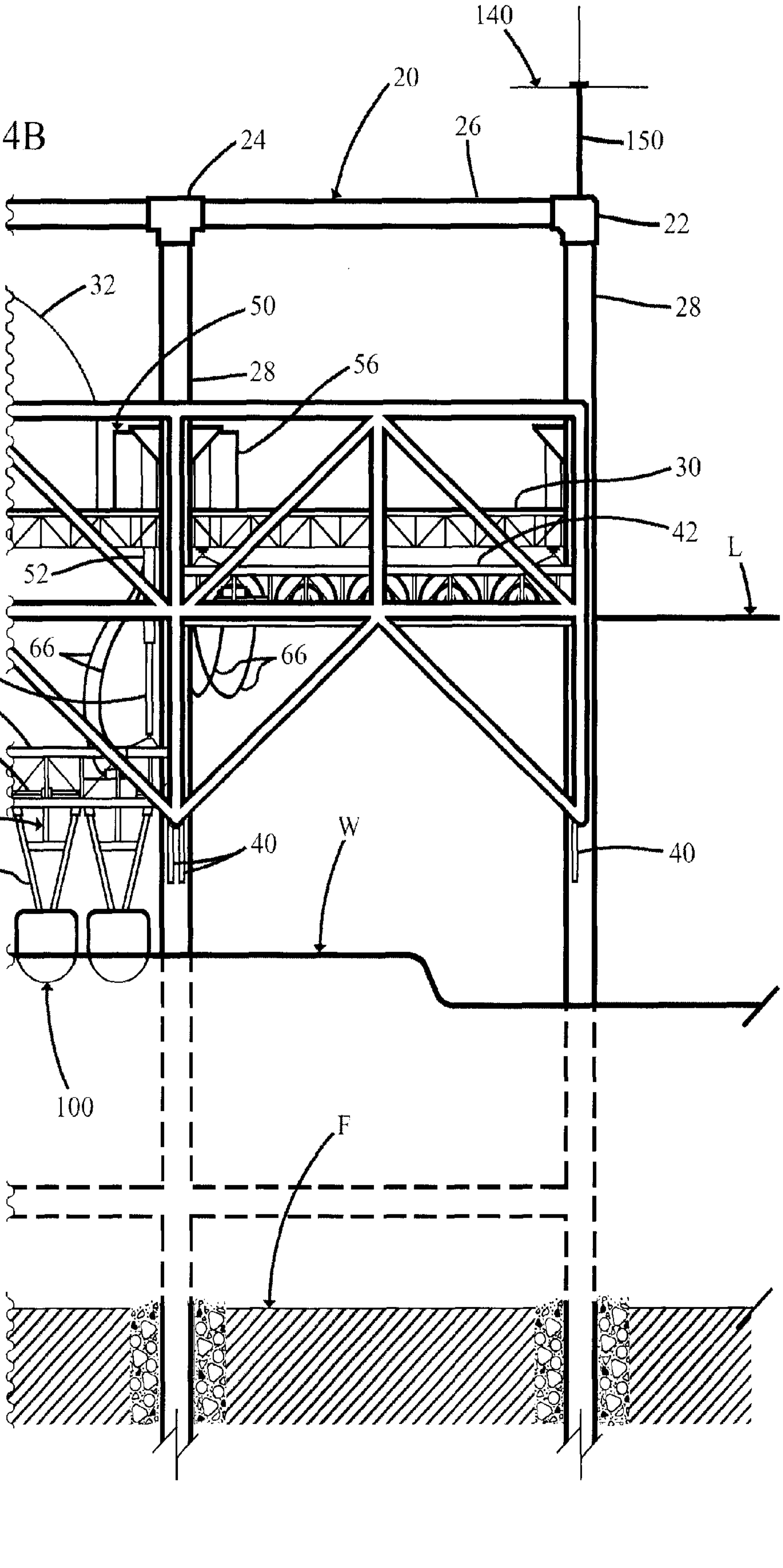

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FIG. 5A

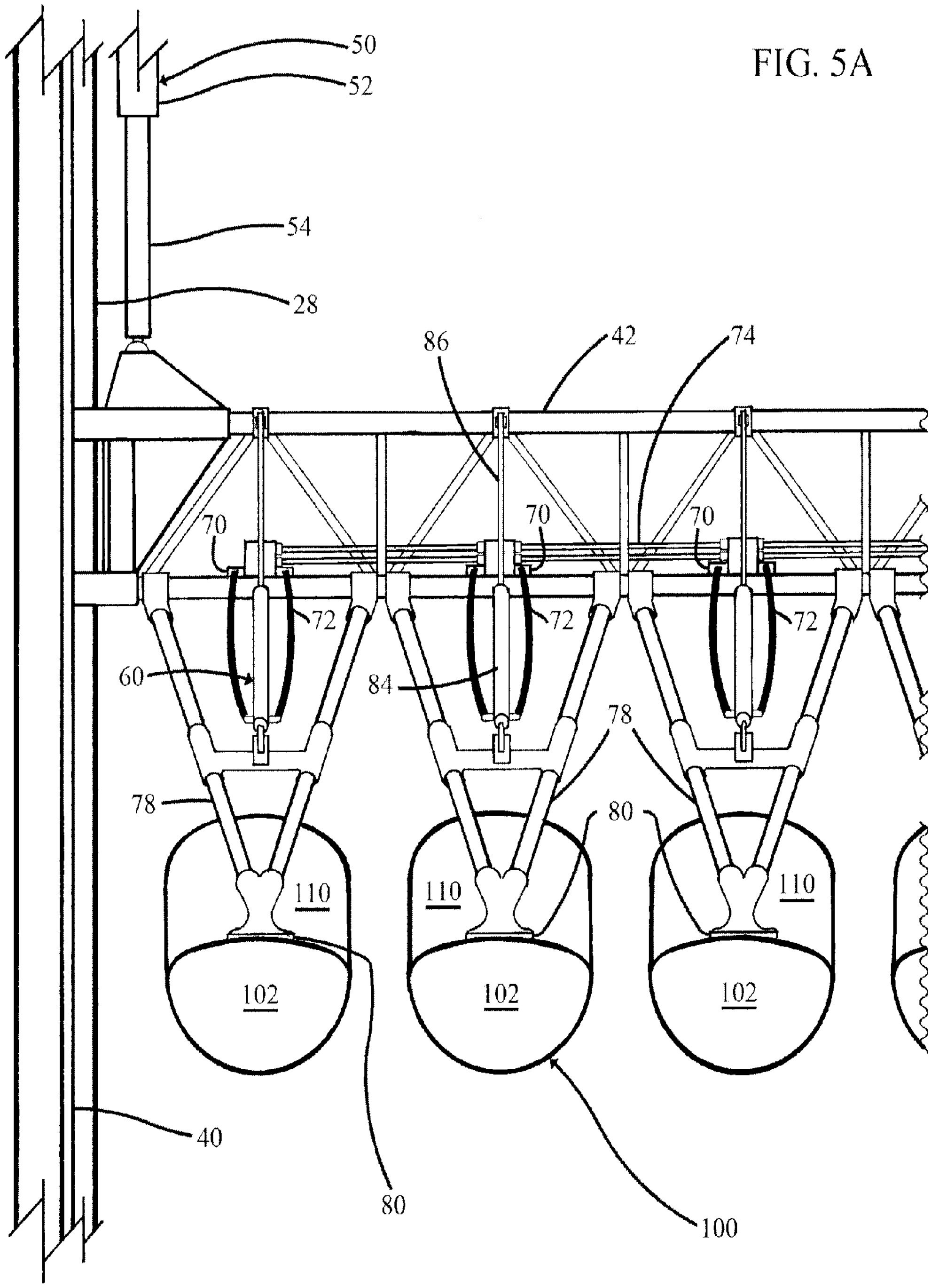
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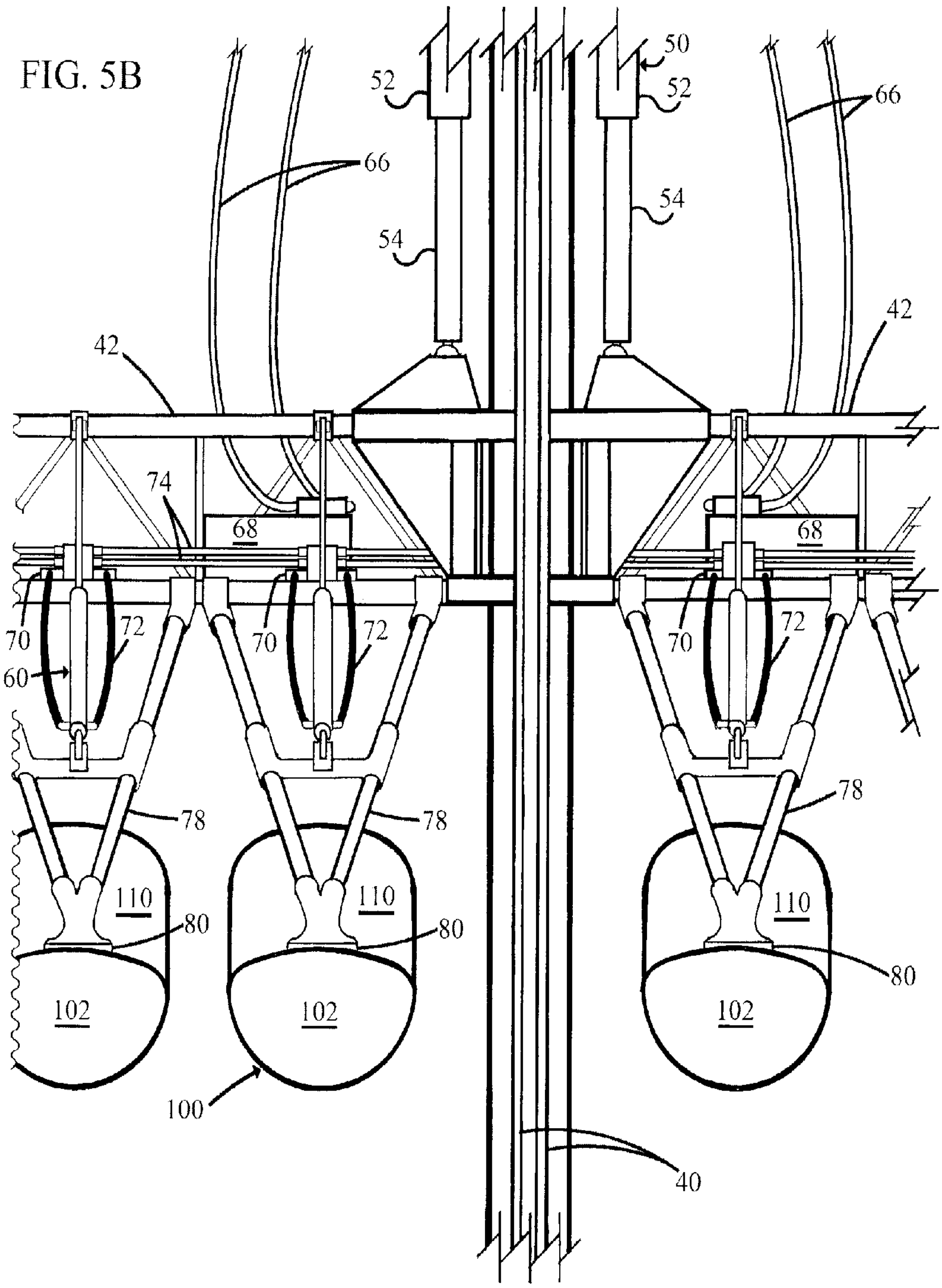
FIG. 5B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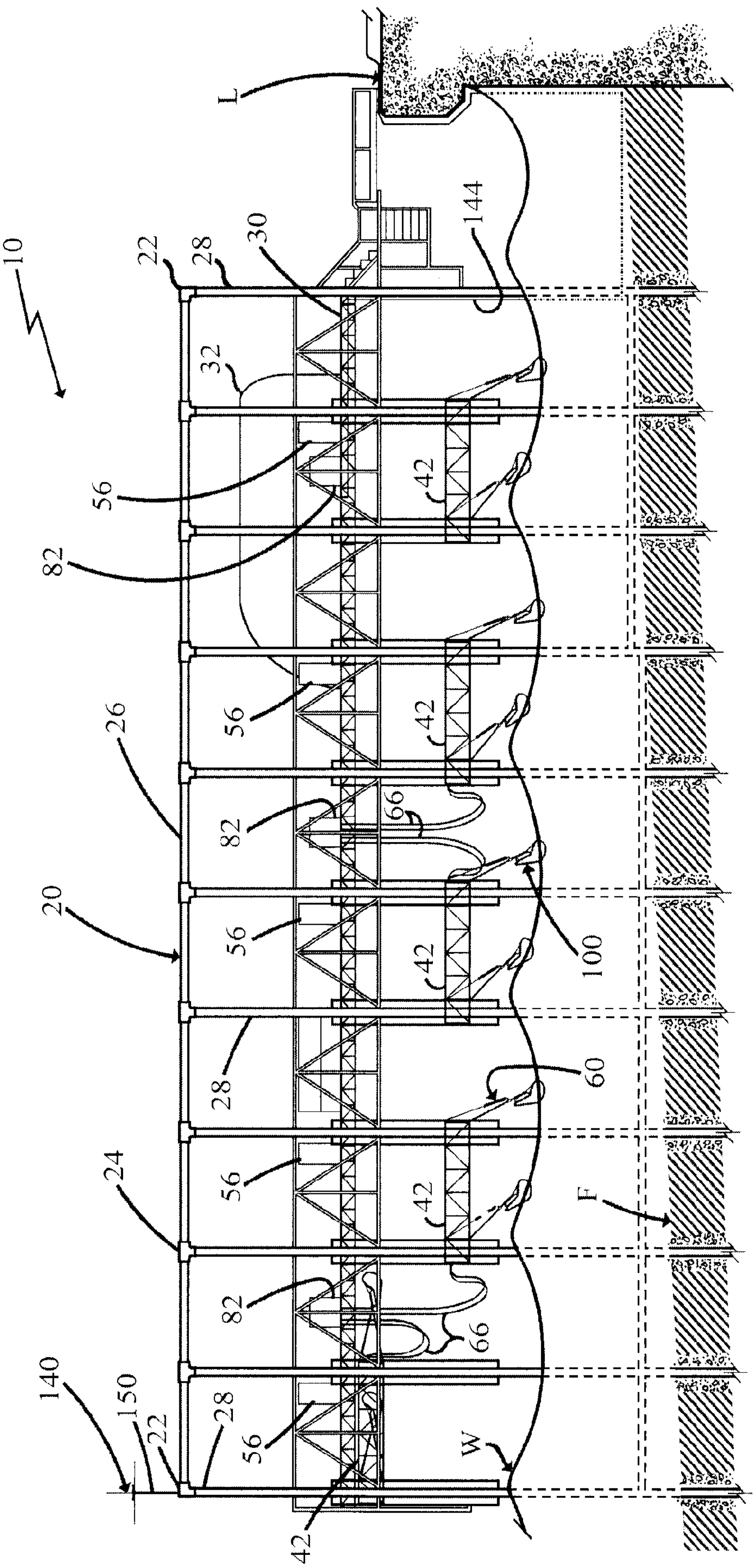
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FIG. 6

FIG. 7A

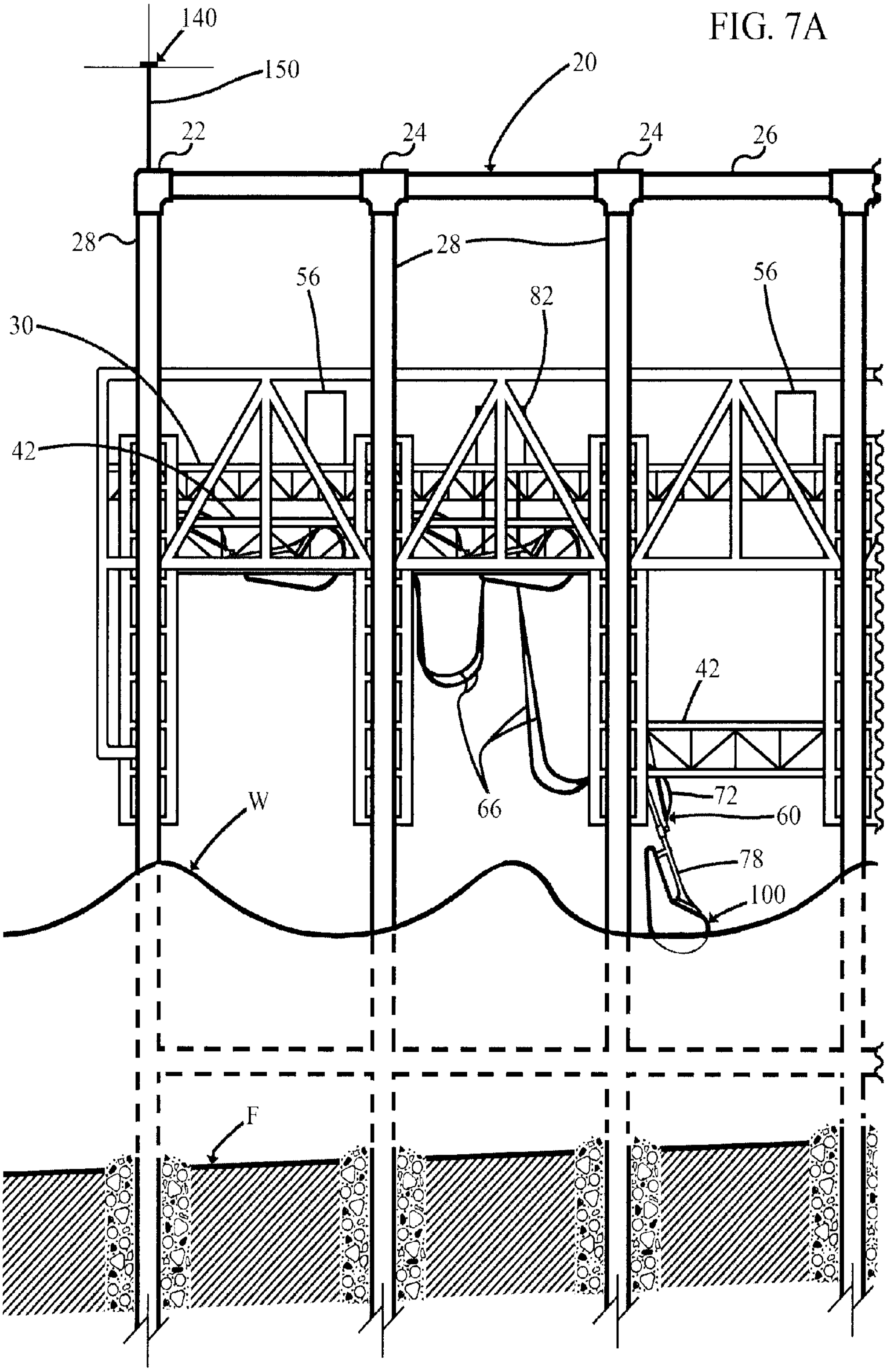

FIG. 7B

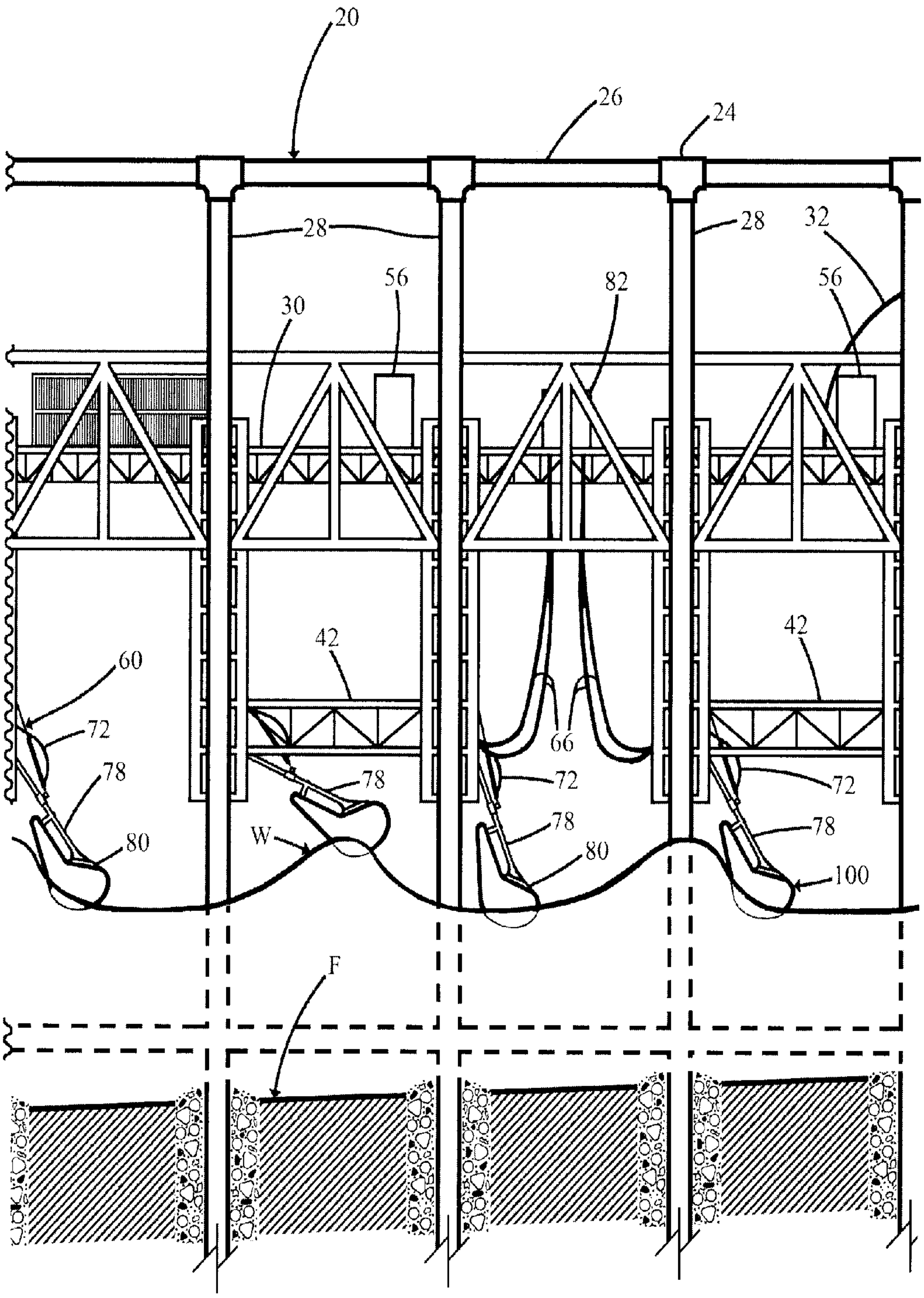
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FIG. 8

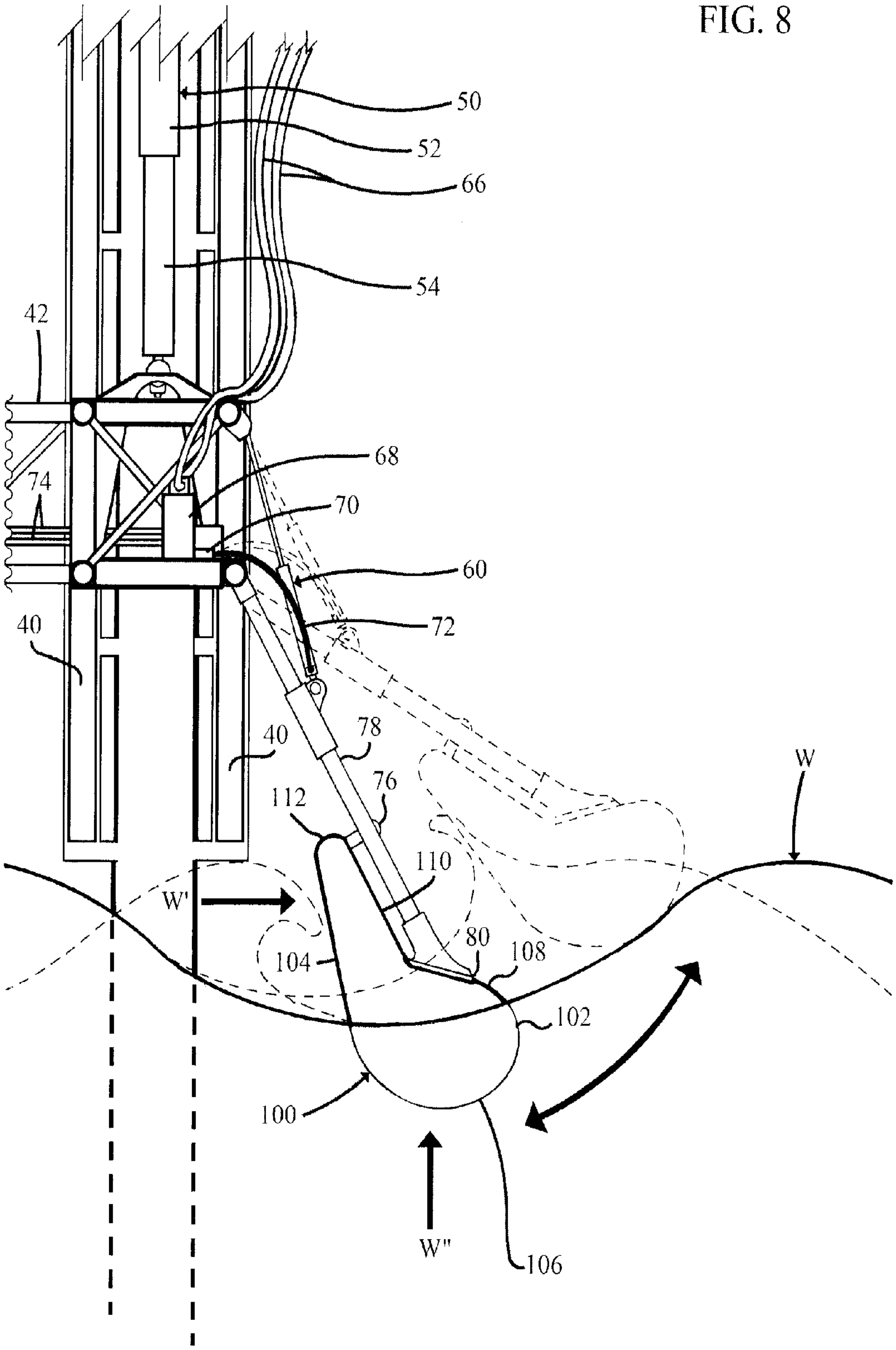
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FIG. 9A

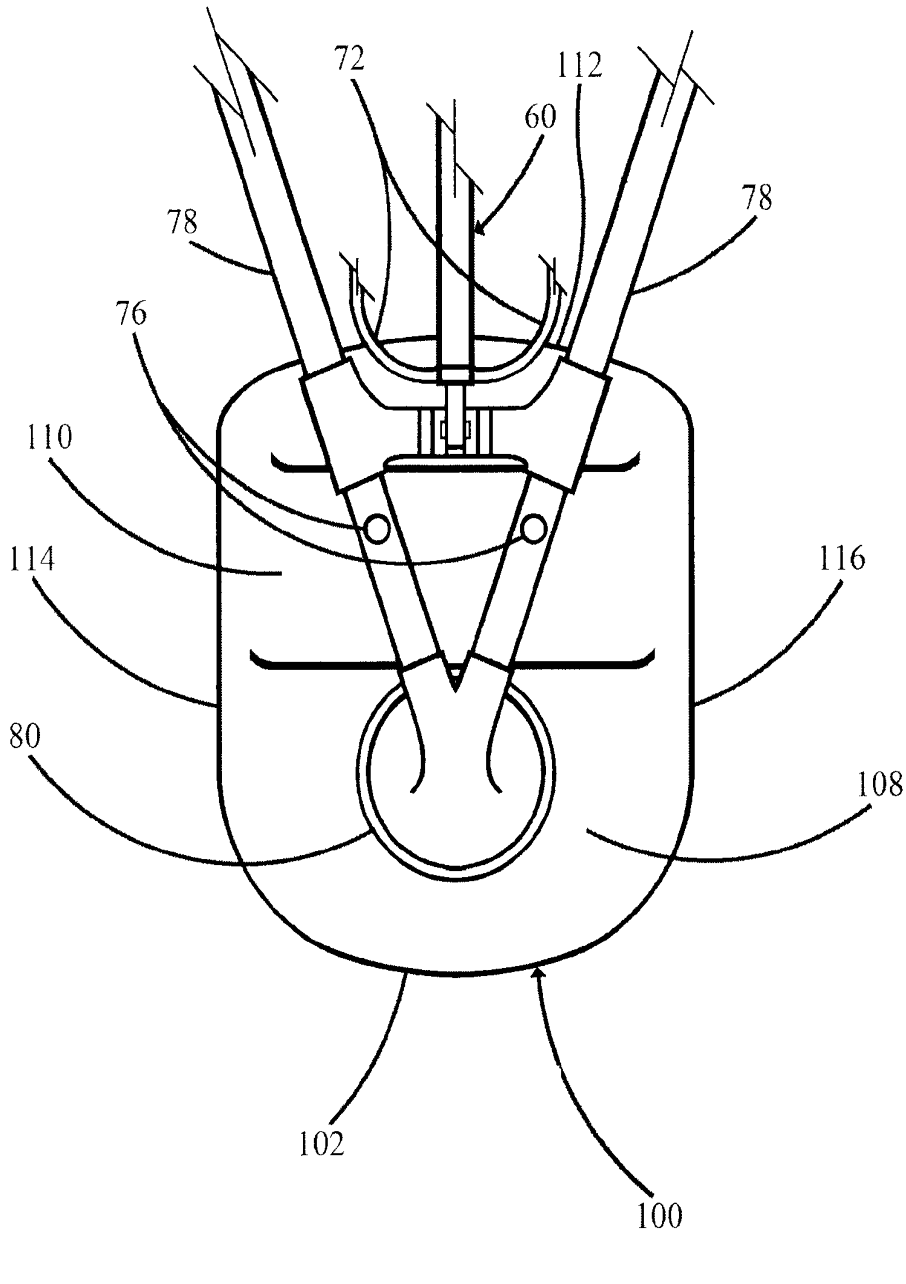
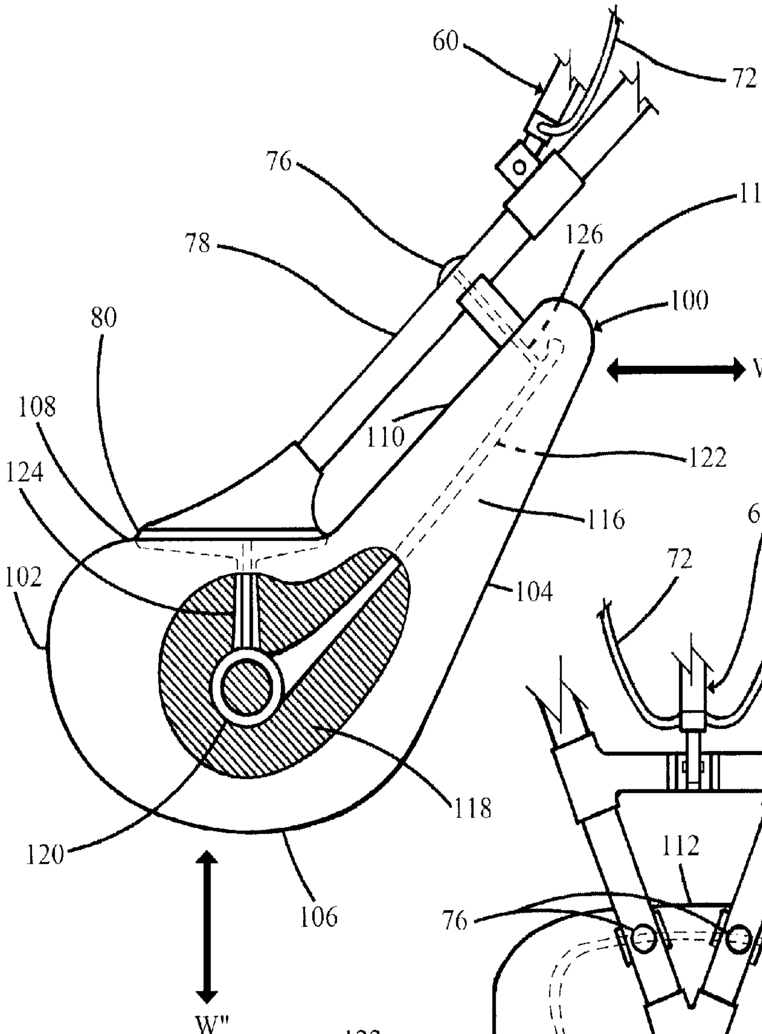


FIG. 9B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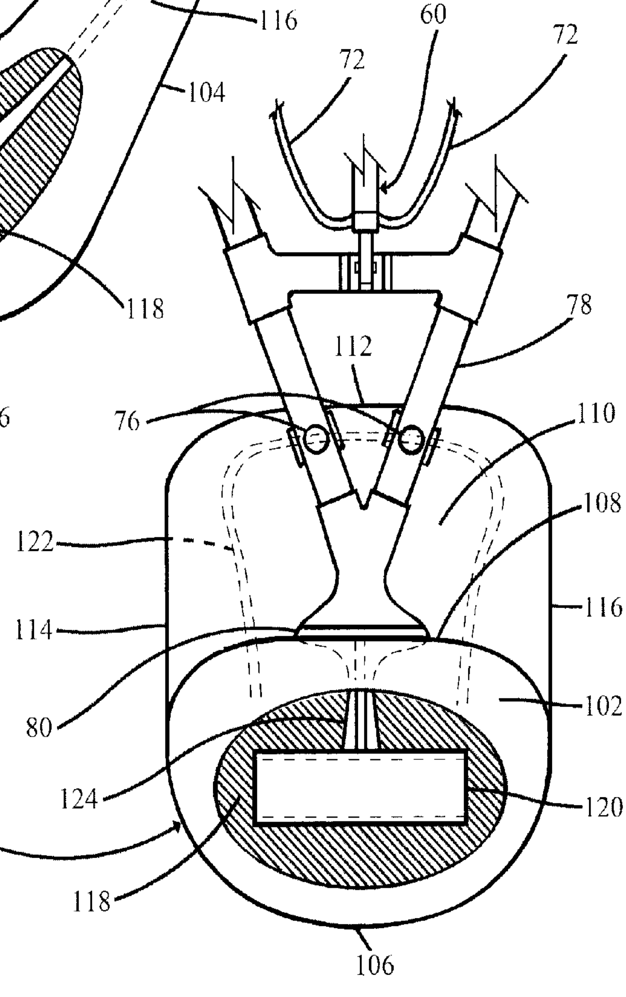
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FIG. 9C

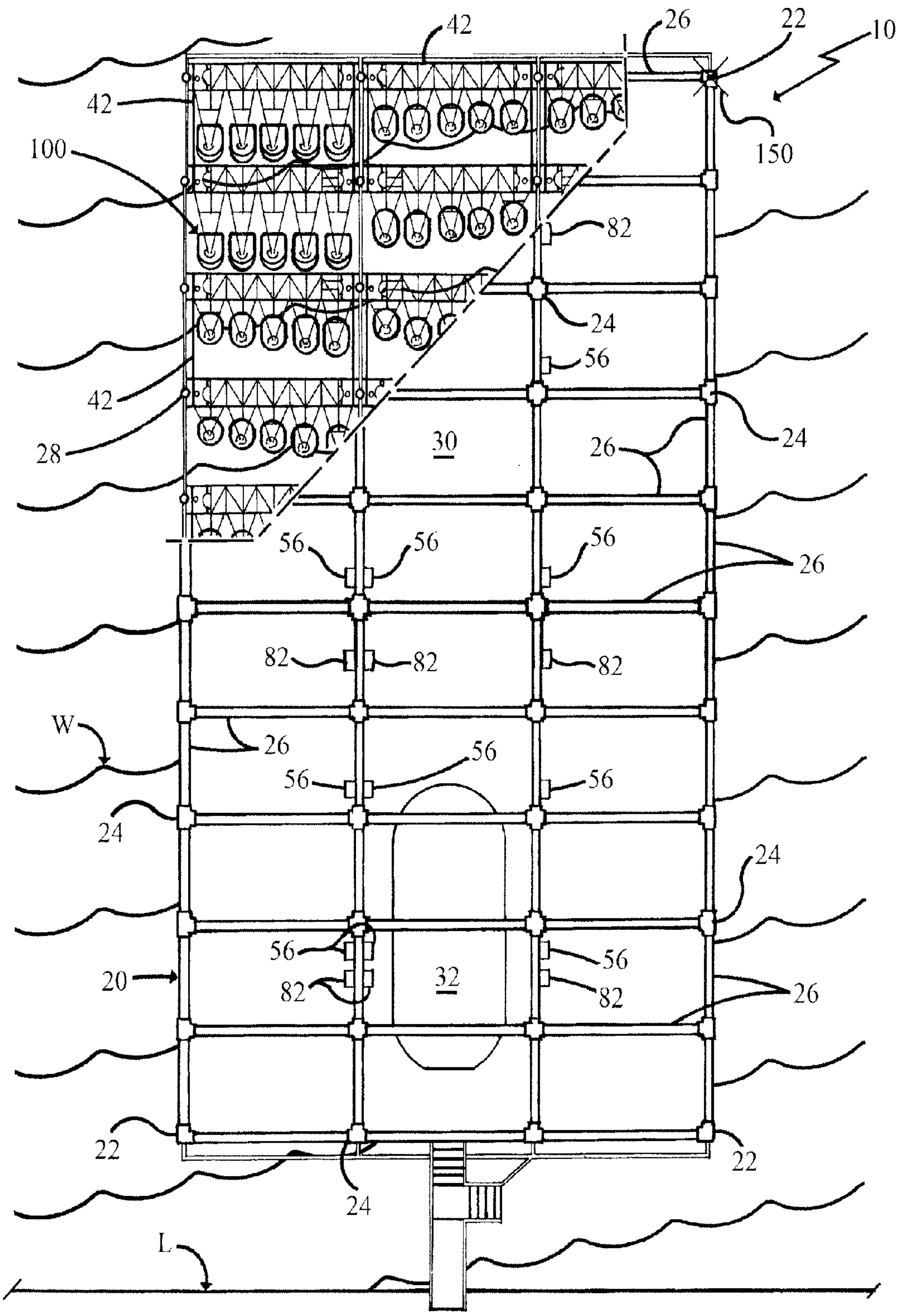
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FIG. 10

SYSTEM TO OBTAIN ENERGY FROM WATER WAVES

II. BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to energy systems, and more particularly, to an energy system for harnessing energy from water waves.

2. Description of the Related Art

Mechanical waves are waves that propagate through a material medium (solid, liquid, or gas) at a wave speed, which depend on the elastic and inertial properties of that medium. There are two basic types of wave motion for mechanical waves: longitudinal waves and transverse waves. Water waves are an example of waves that involve a combination of both longitudinal and transverse motions. As a wave travels through the water, particles travel in clockwise circles. The radius of the circles decreases as the depth into the water increases.

Ocean waves are produced by an amount of energy transferred from wind speed over a sea surface, and are commonly mentioned as wave phenomena. Physicists and mathematicians prove a variety of intrinsic properties of waves. Such scientists divided and named a body of water waves to search, understand, and create exact models of them. Those parts include: the crest, which is the highest point of the wave; the trough, which is the lowest point of the wave; the height, which is the vertical distance between a crest and trough and where the energy is; the wave length, which is the horizontal distance between a crests or troughs of two consecutive waves; wave period, which is the time it takes for two consecutive crests or troughs to pass a fixed point; and the frequency, which is the number of waves that passed at a fixed point per unit of time.

Several machines to harness water wave energy have been considered in the past. Applicant believes that one of the closest references corresponds to U.S. Pat. No. 6,925,800 issued to Hansen, et al. on Aug. 9, 2005 for Wave Power Machine. However, it differs from the present invention because Hansen, et al. teach a wave force machine that is capable of utilizing an upward force from waves with a force from a float and rocker arm via rocker arm pipe, wherein one or more lock bearings are provided, which transfer the upward force causing the driving force shaft to rotate in the same direction. On each driving force shaft may be one after the other of mounted float, rocker arm and rocker arm pipe with lock bearings after the other, and several driving force shafts may be interconnected both horizontally and vertically to a toothed wheel with four driving force shafts. The total force from the driving force shafts may be brought to a gearbox and electric generator, and may be used in electricity production. Three wave force machines may be interconnected to form a star, so that the force from the three wave force machines may be gathered in a star point, wherein a gearbox and electric generator are positioned. Alternatively, several star points are interconnected to from a hexagon. In addition, Hansen, et al. teaches use of an upward force only, whereas the present invention considers additional forces, not only upward. Specifically, the present invention teaches horizontal wave forces and vertical wave forces that cause each float assembly to move when in a body of water.

Applicant believes that another reference corresponds to U.S. Pat. No. 597,833 issued to John M. Palmeron on Jan. 25, 1898 for Wave Power. However, it differs from the present invention because Palmer teaches a movable float that is employed to actuate a piston, which forces fluid through a

suitable mechanism to a conduit or receiver. A hollow buffer piston rod carries pistons on its ends that are adapted to operate, respectively, in a pressure-cylinder and the buffer-cylinder. Fluid is forced by the pressure-piston through the hollow buffer-piston rod into the buffer-cylinder and from thence to the conduit or receiver.

Applicant believes that another reference corresponds to U.S. Pat. No. 675,039 issued to Justin J. Graff on May 28, 1901 for Wave-Motor. However, it differs from the present invention because Graff teaches wave-motors, and more particularly to a type in which an oncoming motion of wave or surf furnishes a motive power as distinguished from those in which a float is lifted vertically. Graff employs a float, not to secure a lifting action, but to form a buoyant part of an oscillating device, which buoyant part is the resistance to the wave and is self-adjusting to the height of the latter by reason of its buoyancy.

Applicant believes that another reference corresponds to U.S. Pat. No. 7,331,174 issued to Welch, Jr. on Feb. 19, 2008 for Buoyancy Pump Power System. However, it differs from the present invention because Welch, Jr. teaches a system for generating electricity that includes a pump operable to convert wave motion from a body of water into mechanical energy. The pump includes an input port through which an operating fluid can enter the pump and an output port through which the operating fluid can exit the pump. A first outlet line and a second outlet line are fluidly coupled to the output port of the pump. A first reservoir is fluidly connected to the first outlet line, and a second reservoir is fluidly connected to the second outlet line, both reservoirs being selectively capable of receiving operating fluid driven through the output port.

Applicant believes that another reference corresponds to U.S. Pat. No. 7,305,823 issued to Stewart, et al. on Dec. 11, 2007 for Active Impedance Matching Systems and Methods for Wave Energy Converter. However, it differs from the present invention because Stewart, et al. teaches an active impedance matching systems (AIMS) and methods for increasing the efficiency of a wave energy converter (WEC) having a shaft and a shell intended to be placed in a body of water and to move relative to each other in response to forces applied to the WEC by the body of water. The system includes apparatus for: (a) extracting energy from the WEC and producing output electric energy as a function of the movement of the shell (shaft) relative to the shaft (shell); and (b) for selectively imparting energy to one of the shell and shaft for causing an increase in the displacement and velocity (or acceleration) of one of the shell and shaft relative to the other, whereby the net amount of output electrical energy produced is increased. The apparatus may be implemented using a single device capable of being operated bi-directionally, in terms of both direction and force, or may be implemented by different devices.

Applicant believes that another reference corresponds to U.S. Pat. No. 6,857,266 issued to Dick on Feb. 22, 2005 for Wave Energy Converter. However, it differs from the present invention because Dick teaches a wave energy conversion apparatus. It comprises at least two devices, each comprising a surface float; at least one of the surface floats being rigidly attached to a submerged body. The movement of the two devices in response to a passing wave may be used to effect an energy transfer.

Applicant believes that another reference corresponds to U.S. Pat. No. 6,747,363 issued to Sanchez Gomez on Jun. 8, 2004 for Floating Platform Harvesting Sea Wave Energy for Electric Power Generation. However, it differs from the present invention because Sanchez Gomez teaches a floating platform harvesting sea wave energy comprising a helix or a turbine arranged at the bottom of a containment tube on a horizontal plane and devices to maintain the platform on the valley of the waves when the tide raises the sea level.

Applicant believes that another reference corresponds to U.S. Pat. No. 6,644,027 issued to Kelly on Nov. 11, 2003 for Apparatus for Protecting a Wave Energy Converter. However, it differs from the present invention because Kelly teaches an apparatus for converting the motion of sea waves to electrical energy. It comprises at least one vertically oriented linear generator, relatively reciprocating motion of the armature and stator of which is driven by a float immersed in the sea directly below the motor armature. To protect the generator against unfavorable sea conditions, on the onset or occurrence of same, the float is moved to and held in a position in which it is clear of, or submerged, in the sea. This movement may be achieved in whole or in part by operating the linear generator as a linear motor.

Applicant believes that another reference corresponds to U.S. Pat. No. 6,328,539 issued to Hung on Dec. 11, 2001 for Hydraulic Device Powered by Wave. However, it differs from the present invention because Hung teaches a hydraulic device powered by a wave having one or more posts secured on a sea floor, a float buoyant on the wave, a housing secured to the posts and having a slidable piston for separating the interior of the housing into two chambers. Four pipes are coupled to the chambers of the housing with four check valves, for allowing the fluid to be drawn into the chambers from two of the pipes and to be forced out of the chambers into the other pipes step by step in order to generate a hydraulic power or energy and for powering or actuating the other facilities.

Applicant believes that another reference corresponds to U.S. Pat. No. 6,045,339 issued to Berg on Apr. 4, 2000 for Wave Motor. However, it differs from the present invention because Berg teaches a wave energy harvesting apparatus of the type employing laterally spaced-apart floats arranged so that up and down movements of the floats in response to the wave motion are out of phase with each other and can be used to drive one or more pumps. It is configured to maintain a fixed orientation with respect to the direction of wave motion and is adapted, on the basis of local wave characteristics, to maximize the average power output. This adaptation may be provided by means including initial selection of the overall size of the apparatus and subsequent adjustments made to the pumping mechanism. The preferred pumping arrangement employs three pumps, each having a piston with one end removably pivotally attached to a pumping arm near one of the floats. Each piston reciprocates, with a stroke much longer than its diameter, within a respective neutrally buoyant cylinder that is pivotally attached to a body float.

Applicant believes that another reference corresponds to U.S. Pat. No. 6,020,653 issued to Woodbridge, et al. on Feb. 1, 2000 for Submerged Reciprocating Electric Generator. However, it differs from the present invention because Woodbridge, et al. teaches a submerged reciprocating electric generator placed below the ocean surface and creates electric power from the surface ocean swells. The generator coil reciprocates linearly in response to an external force acting on a float by passing ocean swells. A cable connects the float on the ocean surface with the reciprocating coil of the submerged generator. A magnetic field is focused through the coil as it reciprocates, creating an electromotive force in the coil. The magnetic field is created in such a manner as to provide uniform field of a single magnetic orientation throughout the entire length of motion of the reciprocating coil. The generator includes a base formed on the ocean floor supporting magnetic core having a generator coil movably mounted therein and connected to a float with a cable passing through cable alignment bearings. Electromagnetic windings are mounted at the closed end of the generator magnetic flux core.

Applicant believes that another reference corresponds to U.S. Pat. No. 5,921,082 issued to Berling on Jul. 13, 1999 for Magnetically Powered Hydro-Buoyant Electric Power Generating Plant. However, it differs from the present invention because Berling teaches a hydro-buoyant electrical power generating plant that generates electricity from a source of hydraulic pressure. The energy that pressurizes the hydraulic fluid is derived from movements of a crane-like class II lever that has its fulcrum fixed to a stationary land mass so that the fulcrum's position is fixed relative to the lever's opposite "movable" end where the applied load is established. The movable end of the lever is attached to an "applied force vessel" that alternatively can be filled with water (or other liquid) so as to sink due to gravity, and then can be evacuated of water so as to rise due to buoyancy. When the applied force vessel is at its position of greatest elevation, the interior chamber of the vessel initially would be filled with air, typically at atmospheric pressure. Valves mounted to the bottom and top of the vessel are then opened to allow liquid to enter the vessel from beneath the vessel, thereby allowing the vessel (and its attached lever) to sink to its point of least elevation. At its uppermost position, the vessel of the preferred embodiment is floating, and thereby displacing its own weight. While the vessel is sinking, the mechanical motion of the attached lever creates power that will be used to drive linear hydraulic actuators (e.g., double acting single ended actuators) that in turn will be used to displace and pressurize a hydraulic fluid. This hydraulic fluid can then be taken directly to a hydraulic motor, which can be used to drive an electrical generator, or the pressurized fluid can be stored indefinitely in hydraulic accumulators. Once the applied force vessel reaches its bottom-most position, the valves below and above the vessel are closed, and multiple submersible pumps attached around the vessel's bottom surface periphery begin to pump the liquid that is presently contained within the vessel out to the surrounding medium (i.e., the infinite liquid). As the liquid is pumped out of the vessel, the vessel becomes buoyant, and a buoyancy stroke can now be started and the entire lever and vessel structure begins to rise in the vertical direction. While the vessel is rising, the mechanical motion of the attached lever creates power that again will be used to drive the double acting linear hydraulic actuators.

Applicant believes that another reference corresponds to U.S. Pat. No. 5,710,464 issued to Kao, et al. on Jan. 20, 1998 for Power Drive System for Converting Natural Potential Energy into a Driving Power to Drive a Power Generator. However, it differs from the present invention because Kao, et al. teaches a power drive system, which includes a water collecting barrel vertically fastened to the oceanic crust under the sea level and having a reduced top end connected to the power input port of a power generator; a plurality of water tubes radially connected to the water collecting barrel for guiding sea water to the power input port of the power generator to move it into operation; a plurality of rockers respectively pivoted to the water collecting barrel; a plurality of floating devices floating on the sea level; a plurality of connecting rods connected between the floating devices and the rocker; and water pump means driven by the rockers to pump water into the water tubes and the water collecting barrel to force the power generator into operation.

Applicant believes that another reference corresponds to U.S. Pat. No. 4,672,222 issued to Ames on Jun. 9, 1987 for Ocean wave energy converter. However, it differs from the present invention because Ames teaches a self-stabilized and modularly expandable system of independently operative point absorbers with respective drive transmissions and electrical generators that produces electricity from wave motion on a body of water.

Applicant believes that another reference corresponds to U.S. Pat. No. 5,461,862 issued to Ovadia on Oct. 31, 1995 for System for Conversion of Sea Wave Energy. However, it differs from the present invention because Ovadia teaches a system for the conversion of sea wave energy including a breakwater structure including a wave energy collector integrally formed within the breakwater structure. The energy collector collects and directs oncoming waves to an upwardly extending duct having hydraulic oil separated from seawater by a membrane for converting the wave energy into oil pressure. The wave energy collector incorporates a plurality of control valves, which are electronically coupled through a computerized control system, which regulate the control valves so that the optimum wave pressure is collected and transferred to the hydraulic oil. A piping system conducts the pressurized hydraulic oil to a pressure tank, which is connected to a hydraulic motor, which is mechanically coupled to an electric generator. The system may be combined with a solar distillation apparatus.

Applicant believes that another reference corresponds to U.S. Pat. No. 4,363,213 issued to Paleologos on Dec. 14, 1982 for Combined Body and Power Generating System. However, it differs from the present invention because Paleologos teaches a system for converting a standard buoy design into an electrical power producing apparatus. The vertical arms slide in sleeves attached to the buoy body and terminate in feet in the form of flat discs. As the buoy bobs and pivots in the water, the resistance of the feet to motion causes the arms to reciprocate, operating pneumatic piston pumps within the buoy. These piston pumps power pneumatic turbines, which activate generators for producing electrical power. The moving parts of the linkages connecting the arms to the pumps are protected by a plastic casing, which keeps out seawater. The casing includes facets, which act as sails. Annular wipers are provided between the arms and sleeves within which the arms reciprocate, so as to prevent seawater from seeping therebetween.

Applicant believes that another reference corresponds to U.S. Pat. No. 4,242,593 issued to Quilico, et al. on Dec. 30, 1980 for Device for Converting Sea Wave Energy into Electrical Energy. However, it differs from the present invention because Quilico, et al. teaches a device for converting sea wave energy into electrical energy that comprises a floating platform carrying a pulley, which is connected through a free-wheel coupling and a speed multiplier to a drive shaft of an electrical generator, on which a flywheel is mounted. An anchor cable passes over the pulley and suspends at its free end an immersed counterweight so that vertical motion of the platform in the sea causes rotation of the pulley and drives the generator continuously.

Applicant believes that another reference corresponds to U.S. Pat. No. 4,232,230 issued to Ames on Nov. 4, 1980 for Ocean Wave Energy Converter. However, it differs from the present invention because Ames teaches a modular assembly of reciprocating electric generators with respective movable floats and a common submerged damper plate and buoyancy chamber that produces electricity from wave motion on a body of water.

Applicant believes that another reference corresponds to U.S. Pat. No. 4,203,294 issued to Budal, et al. on May 20, 1980 for System for the Conversion of Sea Wave Energy. However, it differs from the present invention because Budal, et al. teaches a system for conversion of sea wave energy to useful energy comprising a water displacing member adapted to be at least in part submerged in the sea and mechanically secured to solid ground and provided with means to so control the movement of the water displacing member that it is locked relative to the ground during selected time periods of each cycle of such waves to which the water displacing member is subjected, for the purpose of thereby controlling the rotational movement of an electric generator through at least one fluid under controlled circulation within the water displacing member.

Applicant believes that another reference corresponds to U.S. Pat. No. 4,078,871 issued to Perkins, Jr. on Mar. 14, 1978 for Sea Wave Energy Conversion. However, it differs from the present invention because Perkins, Jr. teaches a fixed structure that encloses a vertically spaced plurality of superimposed channels that are open at one end of the sea to receive deep sea waves approaching a shoreline. Each of the channels has an entrance ramp that slopes upwardly shorewardly to induce breaking of a wave at and over an apex of trailer service ramp that merges into a shorewardly downwardly sloping convergent conduit having fluid communication with a pressure chamber of the structure through a one-way valve controlled aperture at which the wave energy is concentrated. A portion of each ramp is overlain by a roof, which may comprise the underside of a superimposed ramp of another channel. Each of the ramps is of upwardly convex configuration, transversely to the wave direction, and at opposite sides is provided with re-entrant scuppers for draining backwash from a receding wave. Wave focusing vanes or walls diverge seawardly from the open end of the fixed structure along an axis bisecting a submerged transverse wall member embedded on the sea floor, of a lens configuration for bending and focusing a given linear wave length into the convergent walls. Water is directed from the pressure chamber of the structure into energy recovery devices utilizing the kinetic, hydrostatic and pneumatic energy contained in the pressure chamber, which acts as an accumulator.

Applicant believes that another reference corresponds to U.S. Pat. No. 3,970,415 issued to Widecrantz, et al. on Jul. 20, 1976 for One Way Valve Pressure Pump Turbine Generator Station. However, it differs from the present invention because Widecrantz, et al. teaches a power generating plant that utilizes the motion of ocean waves to drive turbine generators in a power station; the plant including a series of underwater units each of which includes a hollow sphere that floats upon the water so that it rises and falls as waves move by, the ball being mounted on an end of a pivoting arm to which there is connected a piston slidable in a cylinder so to pump ocean water through a duct to the turbines in the power station.

Applicant believes that another reference corresponds to U.S. Pat. No. 1,223,184 issued to Larson on Apr. 17, 1917 for Wave Motor. However, it differs from the present invention because Larson teaches a wave motor including a float having direct connection with a compressor and vertically adjustable means for pivotally supporting the pump and float.

Applicant believes that another reference corresponds to European Patent No. 1682776(A1) issued to Resen, et al. in July 2007 for a Wave Power Apparatus Comprising a Plurality of Arms Arranged to Pivot With a Mutual Phase Shift. However, it differs from the present invention because Resen, et al. teach a wave power apparatus that has at least one arm (**122**), the arm being rotationally supported at one end by a pair of pre-stressed, essentially slack-free bearings (**142**) and carrying a float (**124**) at its other end, so that a translational movement of the float caused by a wave results in rotation of the arm. Power conversion means convert power transmitted from the wave to the arms into useful power. The bearing may comprise a flexible material (**149**) of flat spring (**342**; **352**; **362**; **372**; **374**) allowing rotation or wriggling of the arm (**122**) around a supporting shaft (**126**). The apparatus may comprise a plurality of arms, which are supported by individual pairs of bearings.

Applicant believes that another reference corresponds to WIPO Publication No. WO/2006/100436 published to Aquamarine Power Limited, et al. on Sep. 28, 2006 for Apparatus and Control System for Generating Power From Wave Energy. However, it differs from the present invention because Aquamarine Power Limited, et al. teach a wave energy conversion device (**1**), for use in relatively shallow water, which has a base portion (**2**) for anchoring to the bed of a body of water (**6**) and an upstanding flap portion (**8**) pivotally connected (**12**) to the base portion. The flap portion is biased to the vertical and oscillates backwards and forwards about the vertical in response to wave motion acting on its faces. Power extraction means extract energy from the movement of the flap portion. When the base portion (**2**) is anchored to the bed of a body of water (**6**) with the flap portion (**8**) facing the wave motion, the base portion (**2**) and the flap portion (**8**) extend vertically through at least the entire depth of the water, to present a substantial. Other patents describing the closest subject matter provide for a number of more or less complicated features that fail to solve the problem in an efficient and economical way. None of these patents suggest the novel features of the present invention.

III. SUMMARY OF THE INVENTION

The present invention provides for an onshore hydrokinetic system that is capable of harnessing energy from water waves by employing a plurality of specially designed floats, whereby a summation of intrinsic water wave forces is exploited. This is achieved by their combined functions and advantages, which are constituted by their body-mass, shape, arrangement, movable parts, and method of use within the system. A correctly proportioned body-mass of a traditional float will always achieve net-upward buoyancy by nature. However, the plurality of specially designed floats are designed and arranged to absorb energy from water waves while taking into consideration their force and speed, even when traveling into shallow waters. This also includes great volumes of inland bodies of water where wind may provoke significant waves.

More specifically, the instant invention is a system to harness energy from water waves, comprising a frame assembly. The frame assembly has a moving frame assembly mounted upon vertical guide rails. The moving frame assembly comprises at least first and second arms rotatably mounted thereon. The first and second arms terminate at a mounting plate. The moving frame assembly travels upon the vertical guide rails. A first hydraulic system comprises at least one first cylinder and respective first piston. The first cylinder is fixedly mounted onto the frame assembly and the respective first piston is fixedly mounted onto the moving frame assembly. A second hydraulic system comprises a hydraulic motor, and at least one second cylinder and respective second piston. The second cylinder is rotatably mounted onto the first and second arms and the respective second piston is rotatably mounted onto the moving frame assembly. At least one float assembly comprises front, rear, bottom, top, and first and second lateral faces. The float assembly further comprises a trailing face. The front face extends upwardly from the bottom face at a first predetermined angle. The trailing face extends upwardly from the top face at a second predetermined angle. The trailing face and the rear face merge to define an edge. The float assembly is mounted onto the mounting plate. The float assembly is placed in a body of water that comprises wave forces. An electrical system comprises a generator. The generator produces electricity when driven by the hydraulic motor when hydraulic fluid is displaced and pressurized within the second hydraulic system when the wave forces cause the float assembly to move when in the body of water.

The float assembly further comprises a central body that is buoyant. The float assembly further comprises a compact mass internally housed within the central body. The float assembly further comprises a frame to secure the compact mass to the first and second arms. The float assembly further comprises a plate connector that extends from the compact mass to the mounting plate. The float assembly further comprises a pin connector that extends from the frame to the first and second arms.

The first hydraulic system comprises a control valve. The moving frame assembly is placed in a raised position to lift the float assembly from the body of water with the first hydraulic system, and is placed in a lowered position to lower the float assembly into the body of water also with the first hydraulic system. The frame assembly comprises a platform having doors to access the moving frame assembly. The platform is positioned above the moving frame assembly. The frame assembly comprises a housing assembly fixed upon the platform. In a preferred embodiment, the housing assembly houses the hydraulic motor and the generator. The electrical system comprises weather-monitoring equipment, and the frame assembly is anchored to floor of the body of water.

It is therefore one of the main objects of the present invention to provide a system for harnessing energy from water waves.

It is another object of this invention to provide a system to obtain energy from water waves that is eco-friendly.

It is yet another object of this invention to provide such a system that is inexpensive to manufacture and maintain while retaining its effectiveness.

Further objects of the invention will be brought out in the following part of the specification, wherein detailed description is for the purpose of fully disclosing the invention without placing limitations thereon.

IV. BRIEF DESCRIPTION OF THE DRAWINGS

With the above and other related objects in view, the invention consists in the details of construction and combination of parts as will be more fully understood from the following description, when read in conjunction with the accompanying drawings in which:

FIG. **1** is a perspective view of the system to obtain energy from water waves, object of the instant application.

FIG. **2** is a front view of the present invention.

FIG. **3** is a rear view of the present invention.

FIG. **4**A shows a first partial front view of the present invention as shown in FIG. **2**.

FIG. **4**B shows a second partial front view of the present invention as shown in FIG. **2**.

FIG. **5**A shows a first partial rear view of the present invention as shown in FIG. **3**.

FIG. **5**B shows a second partial rear view of the present invention as shown in FIG. **3**.

FIG. **6** is a side view of the instant invention.

FIG. **7**A shows a first partial side view of the present invention as shown in FIG. **6**.

FIG. 7B shows a second partial side view of the present invention as shown in FIG. 6.

FIG. 8 shows a side view of a float assembly in operation.

FIG. 9A is a top view of the float assembly.

FIG. 9B is a side elevation view of the float assembly represented in FIG. 9A, which has been partially cross-sectioned.

FIG. 9C is a rear elevation view of the float assembly represented in FIG. 9A, which has been partially cross-sectioned.

FIG. 10 is a top plan view of the present invention, which has been partially cross-sectioned to show the disposition of the float assemblies.

V. DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawings, the present invention is generally referred to with numeral **10**. It can be observed that it basically includes frame assembly **20**, moving frame assembly hydraulic system **50**, hydraulic system **60**, float assembly **100**, and electrical system **140**.

As seen in FIGS. **1**, **2**, and **3**, present invention **10** is a system to harness energy from water waves W. Frame assembly **20** is anchored to floor F of a body of water. In one configuration, frame assembly **20** defines a rectangular shape as seen in this illustration. However, it is noted that frame assembly **20** may define various shapes and not necessarily rectangular. Frame assembly **20** comprises a plurality of horizontal frame members **26** that are connected to one another by connecting joints **24**. At the corners of frame assembly **20**, horizontal frame members **26** connect to one another by corner joints **22**. Frame assembly **20** further comprises a plurality of vertical frame members **28** that are connected to one another by connecting joints **24**. At the corners of frame assembly **20**, vertical frame members **28** connect to one another by corner joints **22**. Frame assembly **20** further comprises platform **30** that is positioned above moving frame assembly **42**. Although not illustrated, platform **30** has access doors to access moving frame assembly **42**. Platform **30** may be grated to prevent water accumulation, and provide minimal wind resistance. Frame assembly **20** also comprises housing assembly **32** that is fixed upon platform **30**. Housing assembly **32** houses hydraulic motor **64** and generator **142**. In a preferred embodiment, frame assembly **20** is made of non-corrosive materials, which are strong enough to resist extreme weather conditions. It is noted that frame assembly **20** provides minimal wind resistance.

Electrical system **140** comprises generator **142**. In addition, electrical system **140** comprises weather-monitoring equipment. Such weather-monitoring equipment includes computer system **146**, high-frequency radar **148**, and antennas **150**. Although not illustrated, it is noted that electrical system **140** also comprises means to operate and power instant invention **10**. Such means may include computers having computer programs as an example. Generator **142** produces electricity when driven by hydraulic motor **64** when hydraulic fluid is displaced and pressurized within hydraulic system **60** when horizontal wave forces W' and vertical wave forces W", best seen in FIG. **8**, cause each float assembly **100** to move when in the body of water. Such a body of water can be any significant accumulation of water having waves W. The term body of water most often refers to large accumulations of water, such as oceans, seas, and lakes but it may also include smaller accumulations of water. Some bodies of water can be man-made (artificial), such as reservoirs or harbors.

As seen in FIGS. **4**A and **4**B, and **5**A and **5**B, a first hydraulic system is defined as moving frame assembly hydraulic system **50**. Moving frame assembly hydraulic system **50** comprises cylinders **52** having respective pistons **54**. Cylinders **52** are fixedly mounted onto frame assembly **20** and pistons **54** are fixedly mounted onto moving frame assembly **42**. Moving frame assembly hydraulic system **50** further comprises control valves **56**.

As best seen in FIG. **4**B, a section of moving frame assembly **42** is placed in a raised position to lift float assemblies **100** from the body of water with moving frame assembly hydraulic system **50**. Float assemblies **100** may be raised from the body of water in the event of foul weather, or for maintenance as an example. As mentioned above, platform **30** has the access doors to access moving frame assembly **42** to inspect or otherwise perform maintenance of the moving frame assembly **42**, float assemblies **100**, or other surrounding equipment. In the same illustration, another section of moving frame assembly **42** is in a lowered position to lower float assemblies **100** into the body of water.

Moving frame assemblies **42**, cylinders **52**, and corresponding float assemblies **100** are independently enumerated to be identifiable by a computer program, not seen. When any specific cylinder **52** or corresponding float assembly **100** switch is pressed, not seen, a related analog sensor emits a signal with data work to a computer, not seen, where its activity is analyzed. The activity analyzed is for detecting a possible malfunction, or if abnormal conditions are detected as an example. In the event of either above, frame assemblies **42** are automatically placed in the raised position, and a program emits an assistance required alert with an exact location for maintenance. The computer also has means to record the activity of each float assembly **100**. Furthermore, the computer system is programmed with tidal information of the body of water to adjust the elevation of the float assemblies thereon for variations in high tides, low tides, and in between same.

As best seen in FIGS. **5**A and **5**B, moving frame assembly **42** is mounted upon vertical guide rails **40**. Moving frame assembly **42** comprises arms **78** rotatably mounted thereon. Arms **78** terminate at mounting plate **80**. Moving frame assembly **42** travels upon vertical guide rails **40**.

A second hydraulic system is defined as hydraulic system **60**. Hydraulic system **60** comprises hydraulic motor **64**, and cylinders **84** having respective pistons **86**. Cylinders **84** are rotatably mounted onto arms **78** and pistons **86** are rotatably mounted onto moving frame assembly **42**. Hydraulic system **60** further comprises hoses **72** that extend from cylinders **84** to check valves **70**. Metal tubing **74** connects check valves **70** and transports hydraulic fluid to pressure control valves **68**. Hydraulic hoses **66** extend from pressure control valves **68** and are routed to transport the hydraulic fluid to control valves **82**, seen in FIG. **6**. Additional hydraulic hoses, not seen, extend from control valves **82** and are routed to transport the hydraulic fluid to master control valve **62**, seen in FIG. **3**.

As best seen in FIG. **6**, instant invention **10** may comprise a plurality of moving frame assemblies **42** mounted upon vertical guide rails **40**, which are mounted onto frame assembly **20**, and each moving frame assembly **42** may comprise a plurality of float assemblies **100**. Instant invention **10** in a preferred embodiment is positioned near land L. Electrical system **140** further comprises electrical cables **144** to transmit the electricity produced by generator **142**. The elevation of moving frame assembly **42**, and consequently float assemblies **100**, is predetermined based on tidal history and weather record valuation of the body of water.

It is noted that cylinders **84** have a sufficient internal hydraulic pressure force so as to keep each float assembly **100** partially submerged into the body of water as seen in this illustration. However, that internal hydraulic pressure force is less than an upward buoyancy force created by the buoyancy of float assembly **100**.

As seen in FIGS. **7**A and **7**B, moving frame assemblies **42** are independent from each other, meaning that some moving frame assemblies **42** may be in a raised positioned to raise float assemblies **100** from the body of water, and some moving frame assemblies **42** may be in a lowered positioned to lower float assemblies **100** into the body of water.

As best seen in FIG. **8**, generator **142** produces electricity when driven by hydraulic motor **64** when hydraulic fluid is displaced and pressurized within hydraulic system **60** when horizontal wave forces W' and vertical wave forces W" cause each float assembly **100** to move when in the body of water. Although not illustrated, waves W may comprise additional directional forces affecting horizontal wave forces W' and vertical wave forces W" that also cause each float assembly **100** to move when in the body of water. In the preferred embodiment, float assemblies **100** move vertically.

As best seen in FIGS. **9**A, **9**B, and **9**C, float assembly **100** comprises front face **104**, rear face **102**, bottom face **106**, top face **108**, and first and second lateral faces **114** and **116**. Float assembly **100** further comprises trailing face **110**. Front face **104** extends upwardly from bottom face **106** at a first predetermined angle. Trailing face **110** extends upwardly from top face **108** at a second predetermined angle. Front face **104** and trailing face **110** merge to define edge **112**. Float assembly **100** is mounted onto mounting plate **80**. Float assembly **100** further comprises foam central body **118**, which is buoyant. Float assembly **100** further comprises compact internal mass **120** housed within foam central body **118**. Frame **122** is rigid and secures float assembly **100** to arms **78** with pin connector **126** and pin **76**, whereby pin connector **126** extends from frame **122** to arms **78**. Plate connector **124** extends from compact internal mass **120** to mounting plate **80**.

Float assemblies **100** are designed with special shape and materials selection. Foam central body **118** is made of closed-cell urethane foam. Compact internal mass **120** can be an antirust-treated encapsulated steel core-anchor epoxy coated or hot-dipped galvanized. The exterior surface of front face **104**, rear face **102**, bottom face **106**, top face **108**, first and second lateral faces **114** and **116**, trailing face **110**, and edge **112** are preferably made of synthetic polymer filament reinforced with polyurethane. The shapes of bottom face **106** and top face **108** create a surface where water is not retained. Furthermore, the shape of float assembly **100** achieves a hi-net upward buoyancy force. Specifically, front face **104** extends upwardly from bottom face **106** at the first predetermined angle to optimize the impact of horizontal wave forces W' and vertical wave forces W" and the additional directional forces affecting horizontal wave forces W' and vertical wave forces W".

As seen in FIG. **10**, frame assembly **20** may comprise a plurality of rows and columns to increase the number of moving frame assemblies **42** that comprise a plurality of float assemblies **100** for increased production of electricity. In operation, instant invention **10** produces large amounts of electrical power.

The foregoing description conveys the best understanding of the objectives and advantages of the present invention. Different embodiments may be made of the inventive concept of this invention. It is to be understood that all matter disclosed herein is to be interpreted merely as illustrative, and not in a limiting sense.

What is claimed is:

1. A system to harness energy from water waves, comprising:

A) a frame assembly comprising a moving frame assembly mounted upon vertical guide rails, said moving frame assembly comprising at least first and second arms rotatably mounted thereon, said at least first and second arms terminate at a mounting plate, said moving frame assembly travels upon said vertical guide rails;

B) a first hydraulic system comprising at least one first cylinder and respective first piston, said at least one first cylinder is fixedly mounted onto said frame assembly and said respective first piston is fixedly mounted onto said moving frame assembly;

C) a second hydraulic system comprising a hydraulic motor, and at least one second cylinder and respective second piston, said at least one second cylinder is rotatably mounted onto said at least first and second arms and said respective second piston is rotatably mounted onto said moving frame assembly;

D) at least one float assembly comprising front, rear, bottom, top, and first and second lateral faces, said at least one float assembly further comprising a trailing face, said front face extends upwardly from said bottom face at a first predetermined angle, said trailing face extends upwardly from said top face at a second predetermined angle, said front face and said trailing face merge to define an edge, said at least one float assembly is mounted onto said mounting plate, said at least one float assembly is placed in a body of water that comprise wave forces; and

E) an electrical system comprising a generator, said generator produces electricity when driven by said hydraulic motor when hydraulic fluid is displaced and pressurized within said second hydraulic system when said wave forces cause said at least one float assembly to move when in said body of water.

2. The system to harness energy from water waves set forth in claim **1**, further characterized in that said at least one float assembly further comprises a central body.

3. The system to harness energy from water waves set forth in claim **2**, further characterized in that said central body is buoyant.

4. The system to harness energy from water waves set forth in claim **3**, further characterized in that said at least one float assembly further comprises a compact mass internally housed within said central body.

5. The system to harness energy from water waves set forth in claim **4**, further characterized in that said at least one float assembly further comprises a frame to secure to said first and second arms.

6. The system to harness energy from water waves set forth in claim **4**, further characterized in that said at least one float assembly further comprises a plate connector that extends from said compact mass to said mounting plate.

7. The system to harness energy from water waves set forth in claim **5**, further characterized in that said at least one float assembly further comprises a pin connector that extends from said frame to said first and second arms.

8. The system to harness energy from water waves set forth in claim **1**, further characterized in that said first hydraulic system further comprises a control valve, said moving frame assembly is placed in a raised position to lift said at least one float assembly from said body of water with said first hydraulic system.

9. The system to harness energy from water waves set forth in claim **1**, further characterized in that said first hydraulic system further comprises a control valve, said moving frame assembly is placed in a lowered position to lower said at least one float assembly into said body of water with said first hydraulic system.

10. The system to harness energy from water waves set forth in claim **1**, further characterized in that said frame assembly comprises a platform positioned above said moving frame assembly, said platform having doors to access said moving frame assembly.

11. The system to harness energy from water waves set forth in claim **10**, further characterized in that said frame assembly comprises a housing assembly fixed upon said platform, said housing assembly houses said hydraulic motor and said generator.

12. The system to harness energy from water waves set forth in claim **1**, further characterized in that said electrical system comprises weather-monitoring equipment.

13. The system to harness energy from water waves set forth in claim **1**, further characterized in that said frame assembly is anchored to floor of said body of water.

14. A system to harness energy from water waves, comprising:

A) a frame assembly comprising a moving frame assembly mounted upon vertical guide rails, said moving frame assembly comprising at least first and second arms rotatably mounted thereon, said at least first and second arms terminate at a mounting plate, said moving frame assembly travels upon said vertical guide rails;

B) a first hydraulic system comprising at least one first cylinder and respective first piston, said at least one first cylinder is fixedly mounted onto said frame assembly and said respective first piston is fixedly mounted onto said moving frame assembly;

C) a second hydraulic system comprising a hydraulic motor, and at least one second cylinder and respective second piston, said at least one second cylinder is rotatably mounted onto said at least first and second arms and said respective second piston is rotatably mounted onto said moving frame assembly;

D) at least one float assembly comprising front, rear, bottom, top, and first and second lateral faces, said at least one float assembly further comprising a trailing face, said front face extends upwardly from said bottom face at a first predetermined angle, said trailing face extends upwardly from said top face at a second predetermined angle, said front face and said trailing face merge to define an edge, said at least one float assembly is mounted onto said mounting plate, said at least one float assembly further comprises a buoyant central body, said at least one float assembly is placed in a body of water that comprise wave forces; and

E) an electrical system comprising a generator, said generator produces electricity when driven by said hydraulic motor when hydraulic fluid is displaced and pressurized within said second hydraulic system when said wave forces cause said at least one float assembly to move when in said body of water.

15. The system to harness energy from water waves set forth in claim **14**, further characterized in that said central body is made of foam.

16. The system to harness energy from water waves set forth in claim **15**, further characterized in that said at least one float assembly further comprises a compact mass internally housed within said central body.

17. The system to harness energy from water waves set forth in claim **16**, further characterized in that said at least one float assembly further comprises a frame to secure to said first and second arms.

18. The system to harness energy from water waves set forth in claim **17**, further characterized in that said at least one float assembly further comprises a plate connector that extends from said compact mass to said mounting plate, and said at least one float assembly further comprises a pin connector that extends from said frame to said first and second arms.

19. The system to harness energy from water waves set forth in claim **14**, further characterized in that said first hydraulic system further comprises a control valve, said moving frame assembly is placed in a raised position to lift said at least one float assembly from said body of water with said first hydraulic system, and said moving frame assembly is placed in a lowered position to lower said at least one float assembly into said body of water with said first hydraulic system.

20. The system to harness energy from water waves set forth in claim **19**, further characterized in that said frame assembly comprises a platform having doors to access said moving frame assembly, said platform positioned above said moving frame assembly, said frame assembly comprises a housing assembly fixed upon said platform, said housing assembly houses said hydraulic motor and said generator, said electrical system comprises weather-monitoring equipment, and said frame assembly is anchored to floor of said body of water.

* * * * *

US005424582A

United States Patent [19]

Trepl, II et al.

[11] **Patent Number: 5,424,582**

[45] **Date of Patent: Jun. 13, 1995**

[54] **CUSHIONED DUAL-ACTION CONSTANT SPEED WAVE POWER GENERATOR**

[75] Inventors: **John A. Trepl, II; Farhad Bashardoust,** both of Placentia, Calif.

[73] Assignee: **Elektra Power Industries, Inc.,** Fallbrook, Calif.

[21] Appl. No.: **902,701**

[22] Filed: **Jun. 23, 1993**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 590,121, Sep. 28, 1990, abandoned, which is a continuation-in-part of Ser. No. 453,049, Dec. 13, 1989, abandoned, which is a continuation-in-part of Ser. No. 885,864, Jul. 15, 1986, abandoned, which is a continuation-in-part of Ser. No. 614,459, May 24, 1984, abandoned.

[51] **Int. Cl.**[6] **F03B 13/12**; F03B 13/14

[52] **U.S. Cl.** **290/53**; 60/503; 60/506; 60/507; 290/42

[58] **Field of Search** 60/503, 506, 507; 290/42, 53

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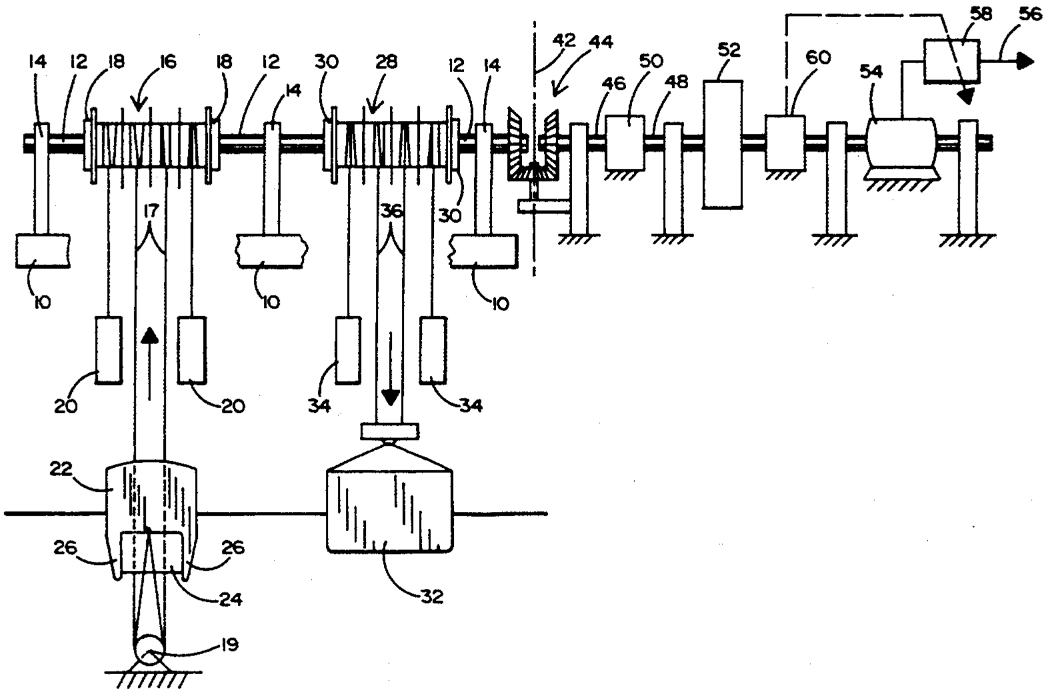
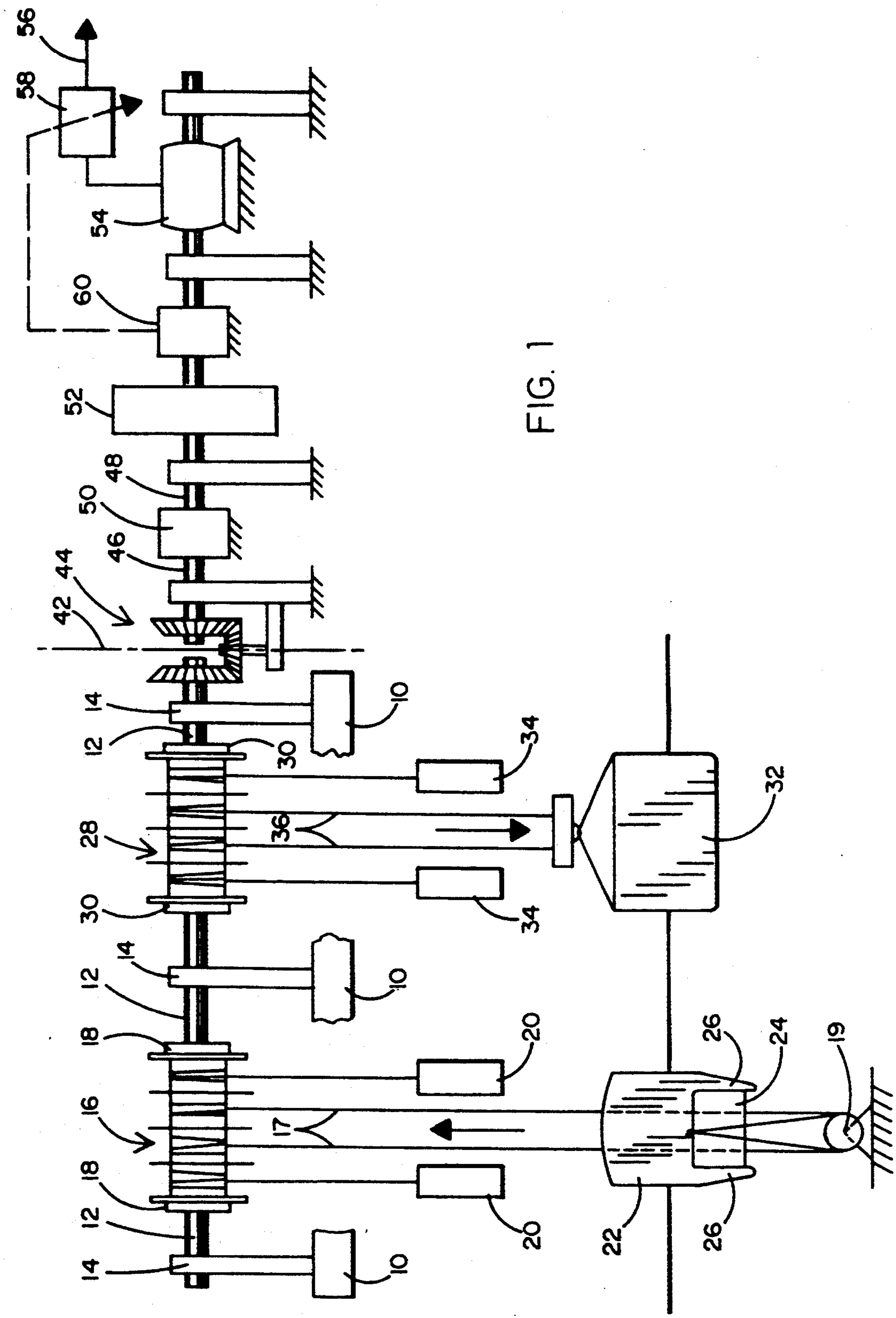
Primary Examiner—A. D. Pellinen
Assistant Examiner—Robert Lloyd Hoover
Attorney, Agent, or Firm—Harry G. Weissenberger

[57] **ABSTRACT**

A wave power generator is substantially continuously driven by a pair of floats connected to a common drive shaft and positioned side by side along a line perpendicular to the direction of wave motion, one float being specifically designed to efficiently drive the shaft during the rising portion of a wave, the other to efficiently drive the shaft during the falling portion of a wave. The generator's flywheel is maintained at a constant speed by an automatic load control throughout a range of wave patterns sufficient to encompass over 70% of the statistically expected wave patterns at the generator location. An inclined-bottom float is used for the rising wave drive, and a bottom-weighted float is disclosed for the falling wave drive. The floats may be disposed one above the other and may have mating conical surfaces for cushioning occasional contact between the floats. In accordance with another feature of the invention, the efficiency of the inventive apparatus is increased by holding the descending float against movement until it is substantially out of the water, and then releasing it for a substantially free fall.

12 Claims, 8 Drawing Sheets

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58
54
60
52
48
50
46
44
42
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28
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18
16
17
20
26
24
19
22

FIG. 1

FIG. 2

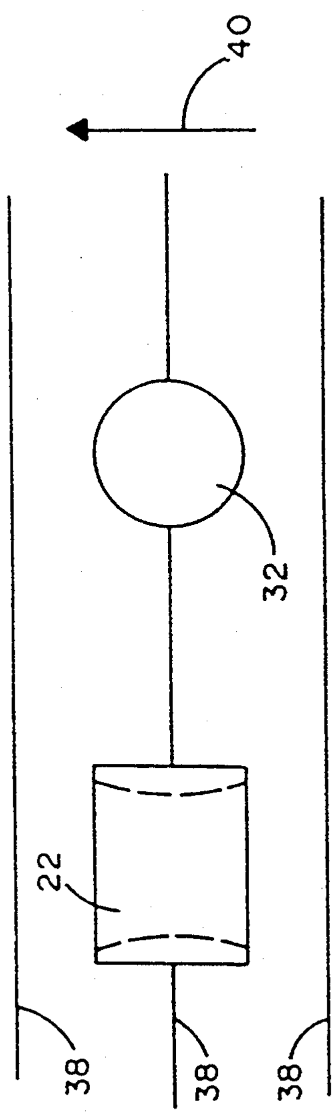
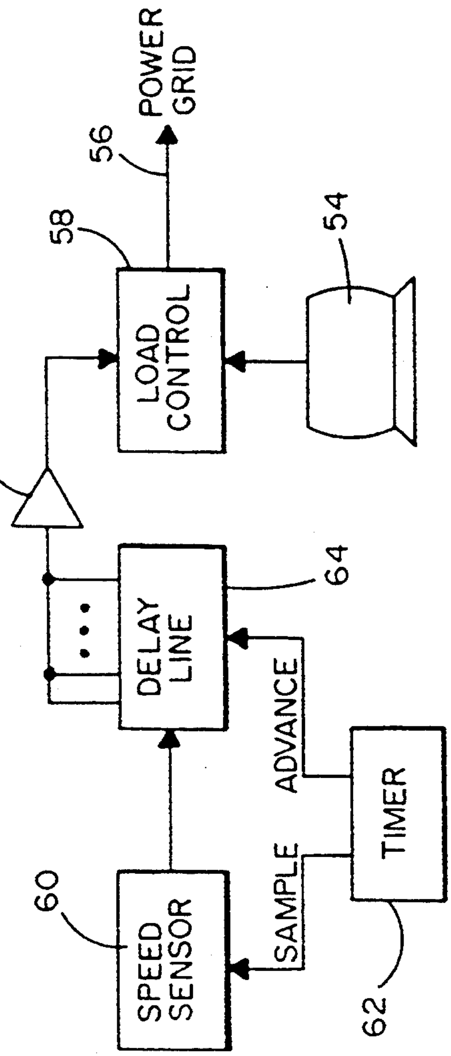

40
32
22
38
38
38

FIG. 3


POWER GRID
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LOAD CONTROL
54
66
DELAY LINE
64
ADVANCE
TIMER
SAMPLE
SPEED SENSOR
60
62

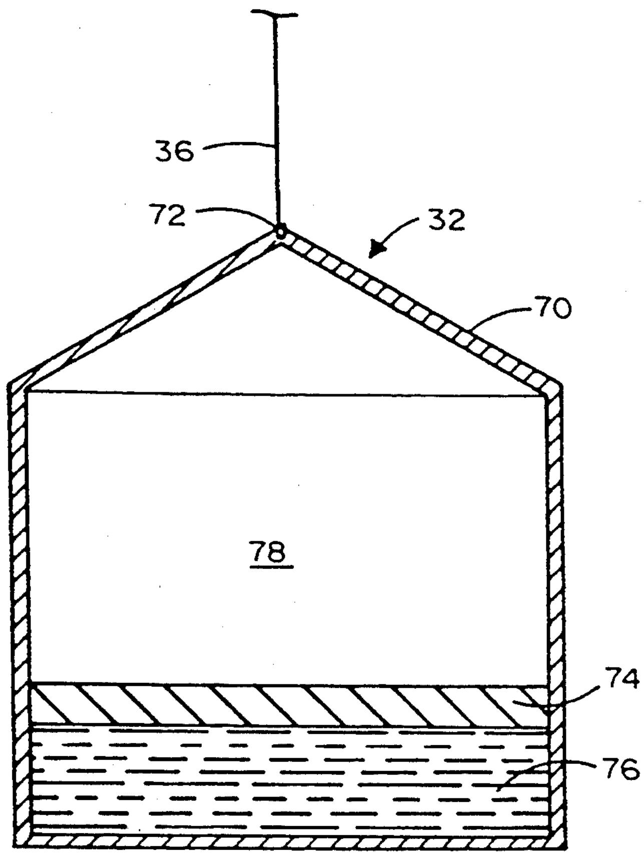


FIG. 4

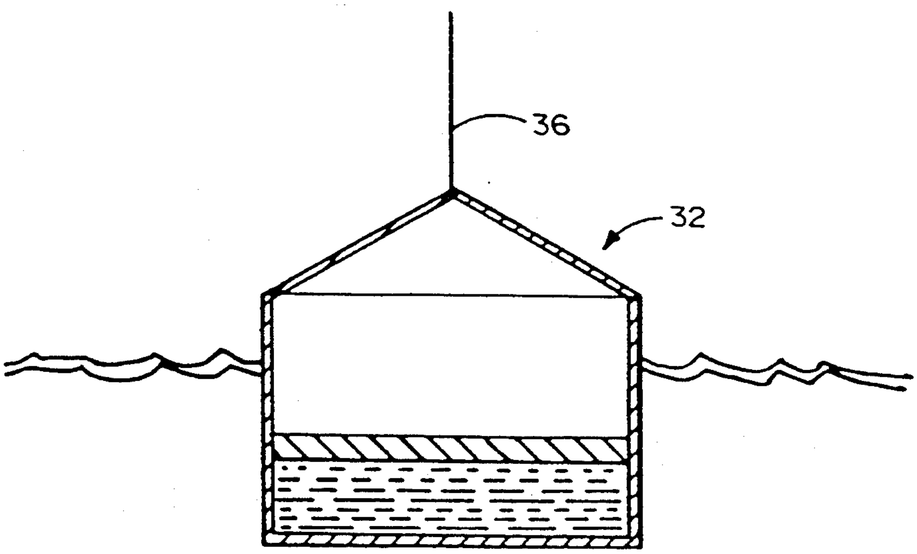


FIG. 5a

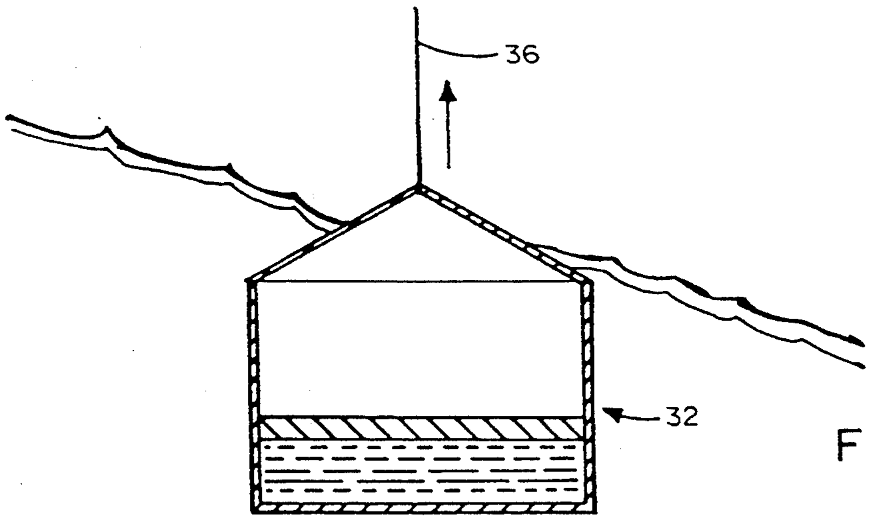


FIG. 5b

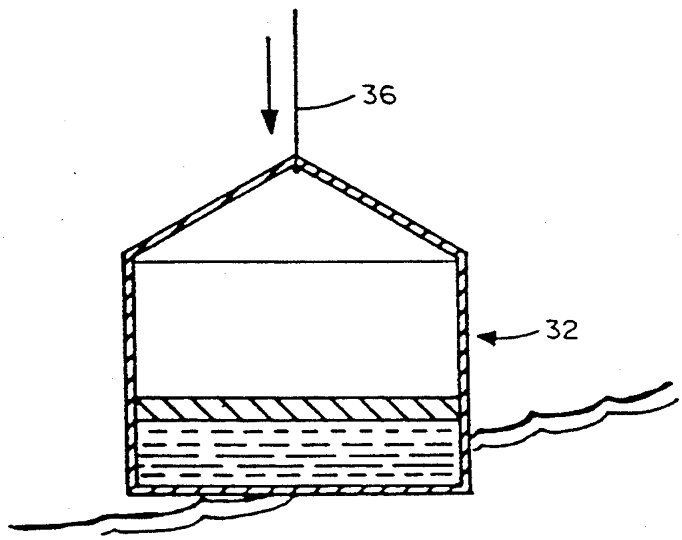


FIG. 5c

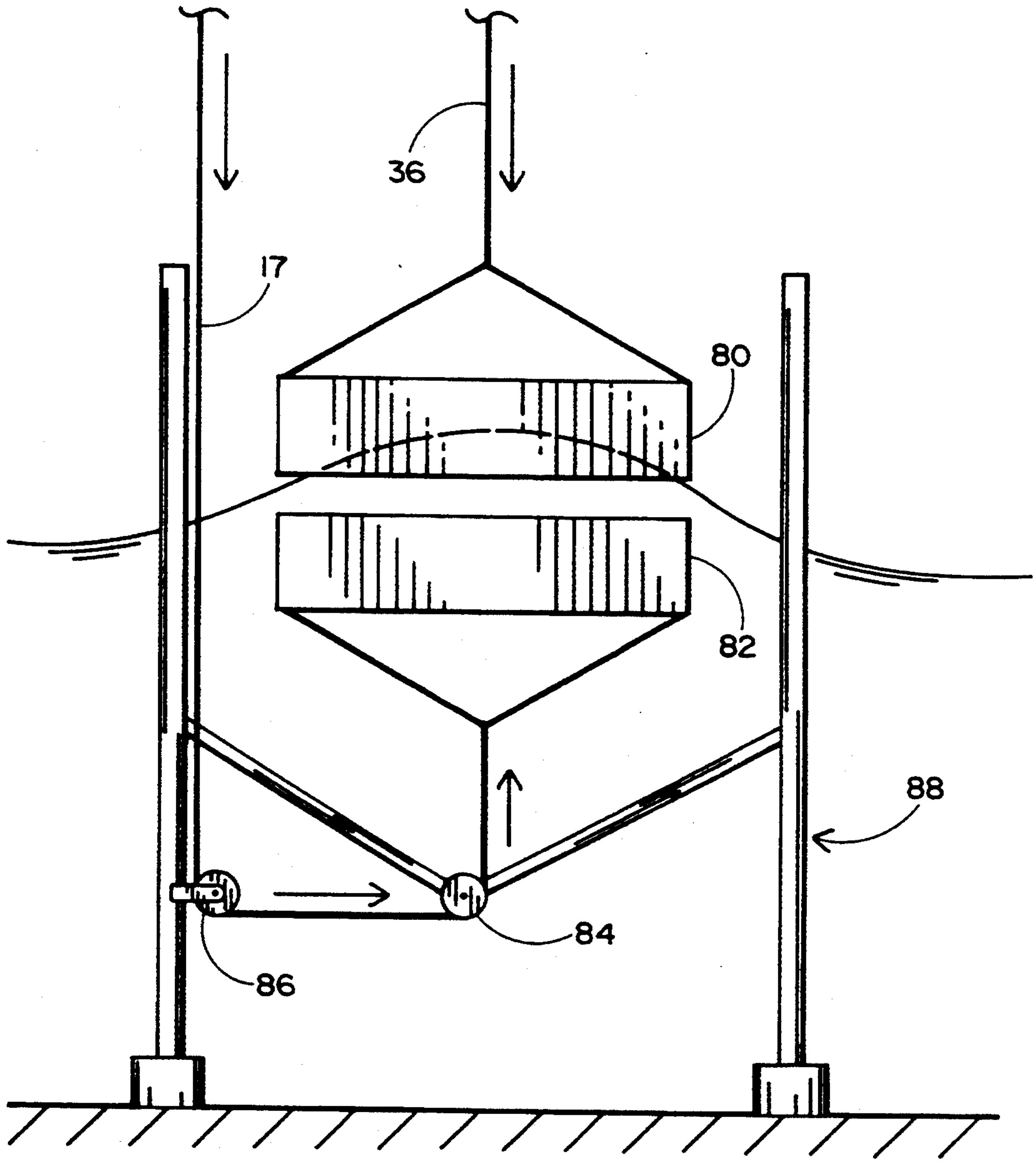


FIG. 6

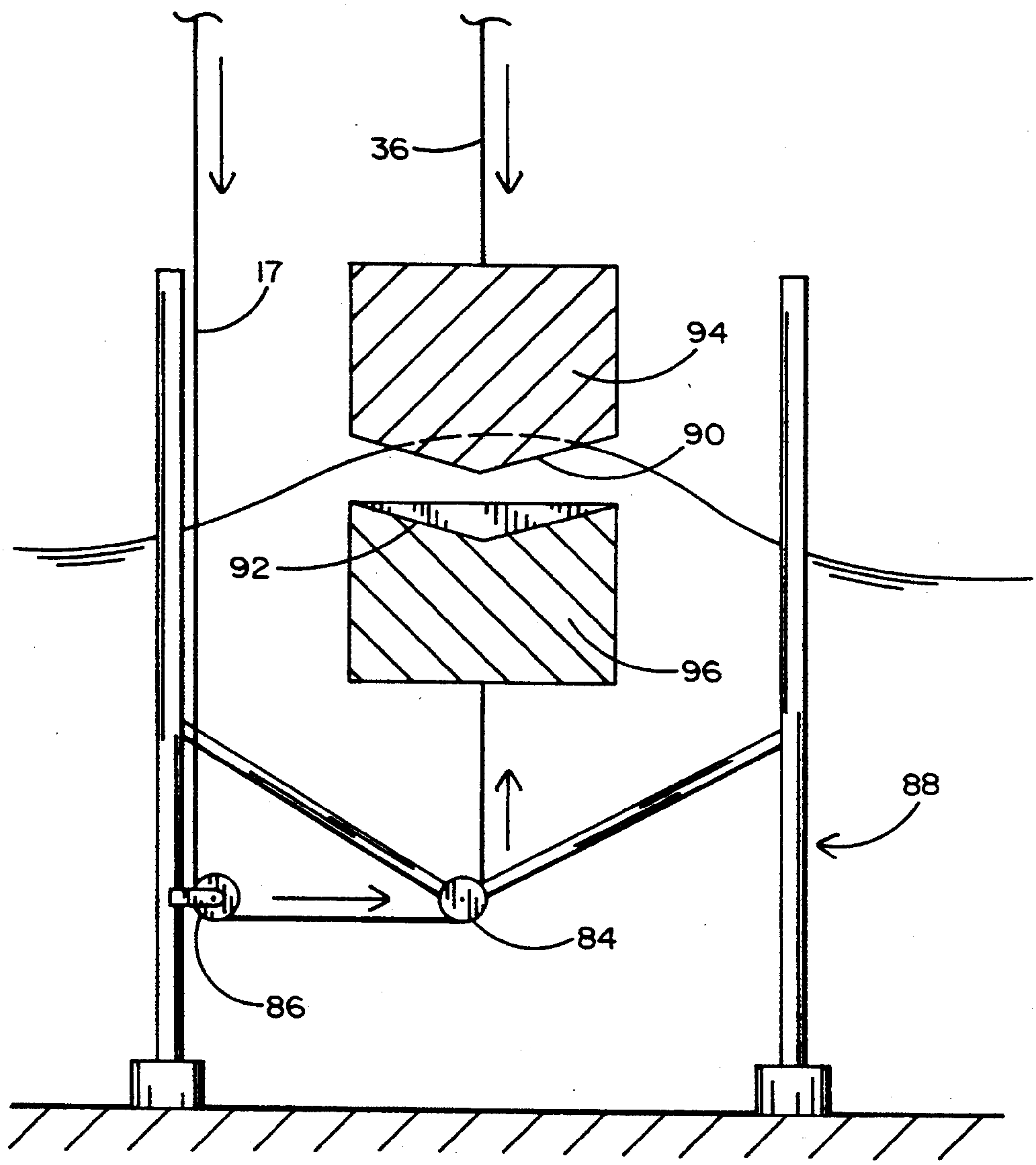


FIG. 7

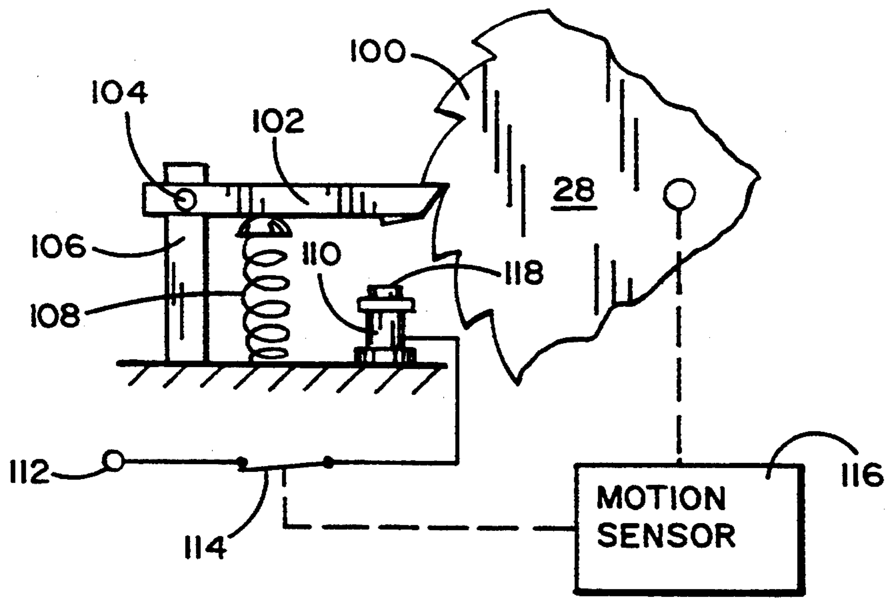
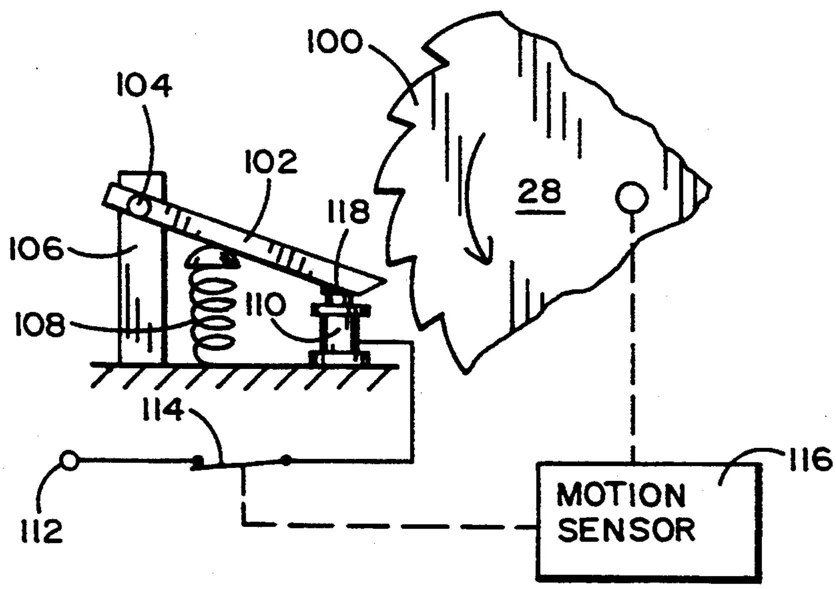

100
104
102
28
106
110
118
108
112
114
116
MOTION SENSOR

FIG. 8a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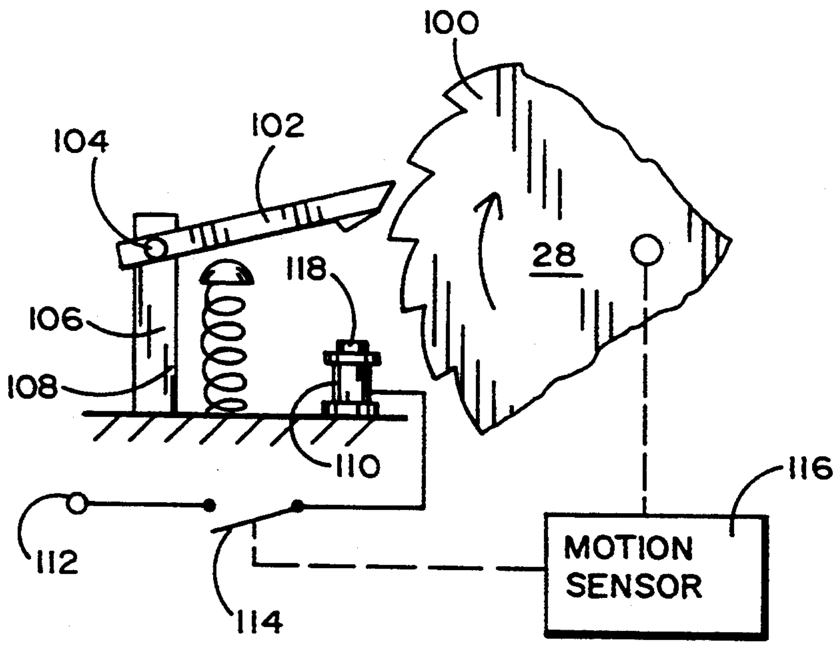
108
114
116
MOTION SENSOR
112

FIG. 8b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102
104
106
108
118
28
110
116
112
MOTION SENSOR
114

FIG. 8c

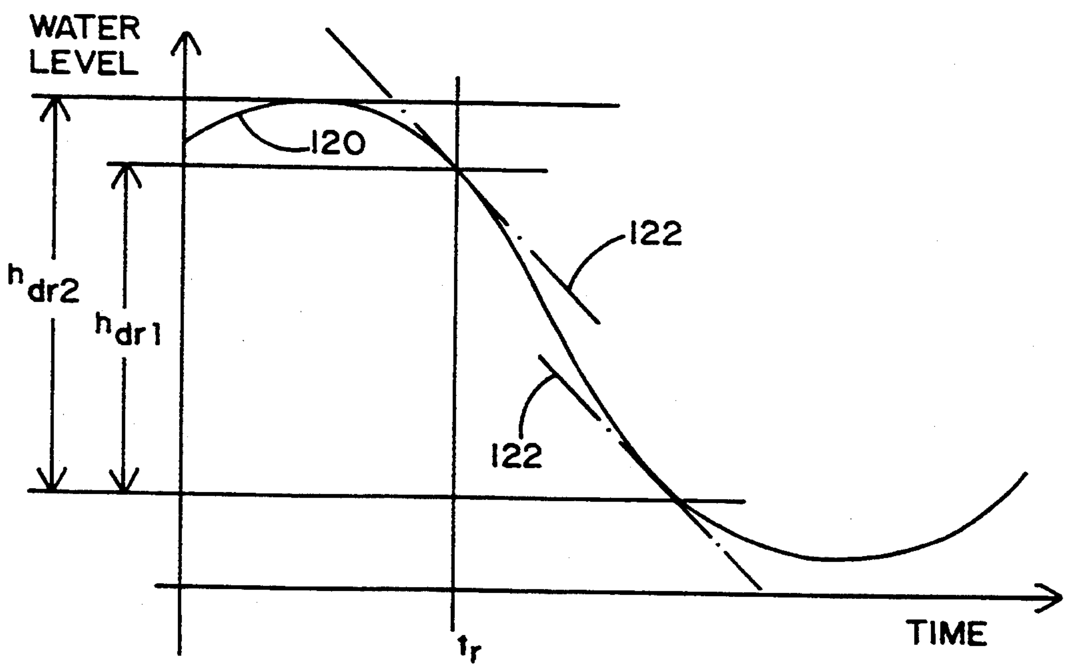
WATER LEVEL
120
122
h_{dr2}
h_{dr1}
122
t_r
TIME

FIG. 9

CUSHIONED DUAL-ACTION CONSTANT SPEED WAVE POWER GENERATOR

STATEMENT OF RELATED CASES

This case is a continuation-in-part of application Ser. No. 590,121 filed 28 Sep. 1990, now abandoned, which is itself a continuation-in-part of application Ser. No. 453,049 filed 13 Dec. 1989, now abandoned, which is itself a continuation-in-part of application Ser. No. 885,864 filed 15 Jul. 1986, entitled "Dual-Action Constant Speed Wave Power Generator", now abandoned, which in turn is a continuation-in-part of application Ser. No. 614,459, filed 24 May 1984 and entitled "Wave Power Generator With Weighted Float", now abandoned.

FIELD OF THE INVENTION

This invention relates to wave power generators, and more particularly to a double-action, constant-speed system which utilizes a maximum of the wave energy for power generation.

BACKGROUND OF THE INVENTION

Application Ser. No. 590,121 and U.S. Pat. Nos. 4,379,235 and 4,469,955 disclose two types of float systems specifically adapted to efficiently generate power during the fall of a wave and the rise of a wave, respectively. The drawback of both systems is that in each case, one half of the wave period is not used to drive the flywheel. As a result, not only does half the wave energy remain unutilized, but the flywheel has to be quite sizable to avoid excessive speed variations within long wave periods. Also, neither system is equally efficient with all types of waves, the system of application Ser. No. 590,121 being more efficient with shorter period waves, and the system of U.S. Pat. No. 4,379,235 being more efficient with longer period waves.

The prior art has proposed using generator drive mechanisms which utilize both directions of movement of a float to generate power. This is not a good solution, however, because the drag produced by the power-generating load slows the travel of the float and prevents it from making a full stroke in either direction.

Another problem of the prior art was the inability of wave power generating systems to adequately accommodate the wide variety of wave heights and periods which occur in practice on both a daily and a seasonal basis.

SUMMARY OF THE INVENTION

In one aspect of the invention, a float for falling-wave power is provided which has a lower, normally immersed portion filled with a relatively heavy substance such as water, or lead, and a normally floating portion filled, for example, with air. The combination of these two portions results in a float which is very stable yet responds very quickly to a rising wave front and remains essentially on top of the wave during its rapid rise. Then, when the wave recedes, the weight of the float does the work as the drag caused by the power generating load causes the float to rise at least partially out of the water.

In another aspect, the present invention makes full use of both the rising and falling movement of the wave by providing separate rising-wave and falling-wave drives for the generator flywheel. Each drive is idle during its return motion and is therefore capable of returning to the full extent of its stroke. In accordance with one embodiment of the invention, the system is adapted to be positioned so that the two floats are disposed along a line perpendicular to the wave front for maximum regularity of drive power.

In accordance with a further aspect of the invention, the flywheel transmission is so arranged that the wave heights and period necessary to produce rated flywheel rpm at full load (long-period, high waves) and rated flywheel rpm at minimum load (short-period, shallow waves) lie within a range encompassing the vast majority of the wave conditions statistically expected to be encountered at the location of the apparatus. Within this range, the invention provides automatic power output adjusting means to maintain the flywheel rpm essentially constant with varying wave patterns.

It is therefore the object of the invention to provide a highly efficient wave power generating system capable of effectively utilizing a wide range of wave patterns to produce alternating-current power at an essentially constant frequency.

In still another aspect of the invention, the efficiency of the float drive is enhanced by providing a mechanism which latches the descending float against descending movement when it reaches the crest of the wave, and then releases it when its weight reaches a predetermined amount as the wave recedes from beneath it. This arrangement makes it possible to utilize a greater portion of the static energy gathered by the float, because the float is not coupled to the flywheel drive below a certain minimum speed of descent, and the static energy released by any float movement below that speed is lost for power generation purposes.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic front elevation of a wave power system constructed in accordance with the invention;

FIG. **2** is a plan view of the float arrangement of the system of FIG. **1**;

FIG. **3** is a block diagram of the flywheel speed control used in the invention;

FIG. **4** is a vertical section of the preferred falling-wave float of FIG. **1**;

FIGS. **5***a, b* and *c* are vertical sections illustrating the operation of the float of FIG. **4**;

FIG. **6** is a fragmentary, partially schematic elevational view of another embodiment of the invention; and

FIG. **7** is a fragmentary elevational view showing a specific float construction particularly adapted for use in the embodiment of FIG. **6**.

FIGS. **8***a* through **8***c* are schematic views illustrating the operation of an efficiency-enhancing addition to the system of FIG. **1**; and

FIG. **9** is a amplitude-time diagram showing the effect of the apparatus of FIGS. **8***a–c.*

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIG. **1** shows a wave power generating system according to this invention in somewhat schematic form. A platform **10** supports a drive shaft **12** in bearings **14**. A drum **16** coaxial with the shaft **12** is connected to the shaft **12** by overrunning clutches **18** in such a way that the drum **16** drives the shaft whenever the drum **16** rotates under the influence of the pull of cable **17** which is looped over a sheave **19** attached to the ocean floor.

The rising of float **22** pulls the cable **17**. During the descent of float **22** on a falling wave, counterweights **20** keep the cable **17** taut.

The float **22** is preferably of the type described in my U.S. Pat. Nos. 4,379,235 and 4,469,955, i.e. a body with a rearwardly inclined bottom surface **24** and guide flanges **26** which assist in maintaining the float **22** in a position facing the oncoming waves. The purpose of the inclined bottom surface **24** is to use the forward motion of the wave to increase the lift applied to the float **22**.

A second drum **28** is coaxially mounted on drive shaft **12** and connected to it by overrunning clutches **30** in such a way as to drive the shaft **12** (in the same direction as drum **16**) whenever the drum **28** is rotated by the descent of float **32**. Counterweights **34** are provided on drum **28** to keep the cables **36** taut as float **32** rises.

It will be seen that the shaft **12** in this invention is driven essentially continuously: by float **22** during a rising wave, and by float **32** during a falling wave. The use of two floats with unidirectional drives rather than one float with a bidirectional drive has several advantages. For one, a float which must do work in both directions of movement never gets a chance to use the full height of the wave (for example, on a falling wave, the float, because of the drag of the drive shaft, will already encounter a new rise in the wave before it can reach the bottom of the wave trough); and for another, the use of separate rising and falling floats allows the use of the most efficient float construction for each of the rising and falling motions.

In order for floats **22** and **32** to drive the shaft **12** without overlap, it is necessary to dispose the two floats side by side along a line parallel to the wave fronts **38** (FIG. 2), i.e. perpendicular to the direction **40** of wave motion. For this purpose, it may be advantageous to journal the platform **10** for pivotal movement about an axis **42** (FIG. 1), or to pivot the entire system, so that varying directions of forward wave motion may be accommodated.

A bevel gear set **44** may be used to transmit rotation from the drive shaft **12** to a transmission shaft **46** which drives the flywheel shaft **48** through an appropriate transmission **50**. A flywheel **52** fixedly mounted on shaft **48** is dimensioned to store sufficient energy to maintain the rotational speed of flywheel shaft **48** within a narrow tolerance of its rated speed as long as sufficient wave power is present.

Electrical power is produced in the system of this invention by an alternator **54** driven from flywheel shaft **48**. In order to be compatible with a commercial power grid, the alternator **54** must run at a speed sufficiently constant to produce an output **56** at a frequency equal to the power grid frequency ±1 Hz.

Because wave power varies considerably from day to day and season to season, as hereinafter discussed in more detail, it is necessary to provide appropriate means for maintaining the speed of flywheel **52** constant regardless of the drive power produced by floats **22** and **32**. This can be accomplished by slip clutches or other mechanical means, but those expedients are necessarily wasteful because the more energy is produced by the floats, the more is dissipated.

In accordance with the invention, a power output controller **58** is provided to regulate the amount of current (and hence power) which can be drawn by the commercial power grid from the alternator **54**. The load controller **58** is itself controlled by a speed sensor **60** in an appropriate manner.

FIG. 3 shows one type of arrangement which may be used for load control. A timer **62** samples the output of speed sensor **60** at regular intervals (e.g. every 9 seconds) and loads the sample into a delay line **64** which is advanced one step by timer **62** at the same intervals. An accumulator **66** continuously provides an averaged value of a plurality of samples as the input signal to the load controller **58**. The load controller **58** may limit the output current of alternator **54** continuously or in a stepped manner by any appropriate means well known to power engineers.

In accordance with the invention, the transmission **50** is so geared as to drive the flywheel **52** at at least the minimum acceptable speed with no electrical load under wave height and period conditions lying below the line **53** in Table I below. Wave conditions above the line **53** are too weak to produce usable power. The maximum power output of the alternator **54** is so chosen that the flywheel **52** will not exceed its maximum acceptable speed under the maximum reasonably expected wave height and period conditions.

Table I shows the statistical distribution of wave patterns by wave heights and periods at a typical offshore test location during a typical year.

TABLE I

	Distribution of Occurrence						
	Wave Period in Seconds						
Wave Height In Feet	4 6	6 8	8 10	10 12	12 14	14 16	16 +
0–1.64	.06%	.64%	.21%	.26%	1.43%	.41%	.06%
1.64–3.28	10.59%	1.72%	.50%	1.43%	6.32%	1.78%	.24%
3.28–4.92	17.82%	3.24%	.60%	.68%	3.12%	3.62%	.81%
4.92–6.56	8.37%	9.89%	.58%	.20%	.56%	.96%	.84%
6.56–8.20	.10%	11.39%	.32%	.04%	.10%	.26%	.44%
8.20–9.84	ø	5.74%	.07%	.07%	.03%	ø	.09%
9.84–13.12	ø	1.44%	2.27%	.01%	.04%	ø	.03%
13.12–16.40	ø	ø	.51%	.01%	ø	ø	ø
16.40–19.68	ø	ø	ø	.06%	ø	ø	ø
19.68–22.96	ø	ø	ø	ø	ø	ø	ø
22.96–+	ø	ø	ø	ø	ø	ø	ø
	55						53

In a preferred embodiment, the system of this invention is designed to produce power in the wave conditions encompassed by the line **55** in Table I. It will be noted that approximately 70% of the wave patterns which can be statistically expected to occur in the course of a year can be used for power production, the remaining 30% being too weak to maintain the flywheel **52** within the rated speed range even with no electrical load. The small percentage of wave patterns in which the power output required to maintain the flywheel **52** is greater than the maximum power output of the alternator **54** is still usable for the production of power, but the excess power would then have to be dissipated by mechanical means. In the alternative, the system may be disconnected in the rare excessively high wave patterns.

The range of wave patterns capable of maintaining at least minimal rated flywheel speed with no load can be expanded by increasing the size of the floats or varying the transmission ratio; on the other hand, this causes overspeed conditions to occur earlier. The invention teaches that maximum efficiency with minimum equipment complexity can be obtained by proportioning the equipment to make use of the largest percentage of statistically expected wave patterns at the system location.

FIG. **4** shows the cross section of a preferred embodiment of the falling-wave float **32**. The float **32** preferably includes a thick, corrosion-resistant water-tight casing **70** to which the cables **36** are attached by an appropriate securing device **72**. The majority of the weight of the float is concentrated in its lower, normally submerged portion, and may consist, for example, of a layer of lead **74** and a volume **76** of liquid (preferably distilled water or oil to prevent internal corrosion). The weights **74** and **76** are so positioned within the body of the float **32** as to place its center of gravity below the water line in a position to provide maximum stability to the float **32**. An air space **78** is provided within the float **32** above the weight layers **74**, **76**.

FIGS. **5***a* through *c* illustrate the operation of the float **32** of this invention. In FIG. **5***a*, the float is shown in quiescent water. Because the weight of the float **32** is concentrated below the water line, it not only rides in a stable manner but its gross weight is also reduced by the volume of water it displaces.

In a rising wave front as shown in FIG. **5***b*, the float **32** rises with the wave, the submersion of the float **32** increasing only enough to provide the extra buoyancy necessary to accelerate the mass of the float **32** in an upward direction. Due to the action of overrunning clutches **30** (FIG. **1**), the float **32** is operatively disconnected from the drive shaft **12** during its upward motion and therefore encounters no resistance therefrom. The wave is therefore able to freely lift the float **32** to its crest.

When the wave now recedes as shown in FIG. **5***c*, the float **32** begins to drop. As it does so, overrunning clutches **30** engage the drive shaft **12**. It will be understood that the drive shaft **12** is loaded by the alternator **54** to rotate very slowly, i.e. at a speed slightly less than that dictated by the downward movement of the float **32** in synchronization with the receding wave of FIG. **5***c*. Consequently, the float **32** begins to rise out of the water as the wave recedes. As it does so, the weight portions of the float **32** are no longer supported by the wave, and the total weight of the float **32** pulls against the inertia of the drive shaft **12** and tries to accelerate it. By properly balancing the parameters of the apparatus, the float can be so adjusted so as to utilize essentially the whole height of the wave, particularly if the wave has a sharp crest followed by a long trough.

FIG. **6** illustrates an alternative float arrangement which also provides the independent action of two opposing-direction floats detailed above in connection with FIG. **1**, wherein the two floats are substantially coaxially with each other. In the arrangement of FIG. **6**, a gravity drive float **80** is disposed directly above a buoyancy float **82**. The counterweighted drive cable **17** connects the buoyancy float **82** to the drum **16** of FIG. **1** after passing over cable guides **84**, **86** mounted on a support structure **88** anchored on the ocean floor. Similarly, the counterweighted cable **36** connects the gravity drive float **80** to drive **28** as on FIG. **1**.

The operation of the floats in the embodiment of FIG. **6** is as follows: During the rising part of the wave, the gravity drive float **80** moves rapidly upward because it is not doing any work during its upward motion. At the same time, the buoyancy float **82** rises slowly because of the load imposed upon it by the flywheel **52** (FIG. **1**). During this period, the vertical separation between the floats **80**, **82** increases.

As the wave crests and begins to fall, the gravity drive float **80** goes into the working mode and descends slowly. As the buoyancy float **82** is still submerged, it continues to rise, and for a short time, the floats **80**, **82** move toward each other. However, because the gravity drive float **80** is unable to follow the rapid fall of the wave, it comes out of the water. When the wave level reaches and passes the level of the buoyancy float so that it surfaces, the buoyancy float **82** ceases doing work and descends rapidly with the wave, again increasing the distance between the floats. The reverse situation occurs as the wave once again starts to rise.

Because ocean waves are not of uniform height and usually come in sets of a large wave followed by several smaller ones, the floats **80**, **82** will occasionally move in such a way as to contact each other. However, as best shown in FIG. **7**, the hydraulic action of the water between them can be utilized to cushion such a contact, and the frequency and duration of the contacts is usually small enough not to interfere with the operation of the floats **80**, **82**.

Where contacts are a problem, the float construction of FIG. **7** is advantageous. The flat mating surfaces of floats **80**, **82** as shown in FIG. **6** are susceptible to meet without adequate cushioning if the floats **80**, **82** become slightly tilted with respect to each other. By contrast, the concavo-convex shape of the mating surfaces **90**, **92** of floats **94**, **96** in FIG. **7** tend to move them into alignment due to the hydraulic action of the water as it exits from between the surfaces **90**, **92** as the floats **94**, **96** approach each other. The surfaces **90**, **92** may be conical or pyramidal in shape without departing from the invention.

In practice, the arrangement of FIG. **6** may be advantageous in some situations because it requires a smaller platform than the embodiment of FIG. **1** and is not sensitive to wave direction.

FIGS. **8** and **9** illustrate a way in which the structures of FIGS. **1**, **2** and **4** through **7** (or, for that matter, any gravity float) can be enhanced to provide substantially more drive power by increasing their efficiency. In accordance with the invention, this is accomplished by holding the gravity float after the cresting of the wave, in its topmost position until it is almost completely out of the water, and then allowing it to free-fall into its normal floating position.

The mathematical rationale for this is as follows: If the float shaft **12** in FIG. **1** rotates at a speed w, and the wave motion is sinusoidal (which it typically is), then there will be a certain distance h_F through which the gravity float has to drop before the wave is dropping fast enough for the overrunning clutch **30** to engage anbd deliver drive power to the shaft **12**.

The motion of the float **32** can be expressed by the equation

$$h_w = h_F + h_D + h_{drop}$$

in which

h_w is the wave height;

h_D is the draft of the float;

h_F is the distance the float drops slower than the vertical movement of the wave, w; and

h_{drop} is the distance the float tries to drop faster than the vertical movement of the wave, w.

Inasmuch as h_w and h_d are constants, h drop (the distance through which the fall of the float **32** does usable work) can be maximized only by minimizing h_F.

In accordance with the invention, h_F is minimized by latching the float **32** against downward movement, once it has reached the crest of the wave, until its weight, no longer reduced by buoyancy, becomes sufficient to release the latch.

A suitable mechanism for accomplishing this purpose is schematically shown in FIGS. *8a–c*. A ratchet gear **100** is carried by the drum **28** and rotates therewith. A lever **102** pivoted at **104** on a support **106** is biased into a generally horizontal position in FIG. *8a* by a spring **108**. An electromagnet **110** connected to a power source **112** through a switch **114** operated by a motion sensor **116** is provided for a purpose hereinafter described.

The strength of the spring **108** is such that it holds the lever **102** in a position to normally prevent rotation of the drum **28** in a counterclockwise direction. However, as the wave level drops while the drum **28** prevents the float **32** from falling with it, the weight of the float **32** increases, and the teeth of the drum **28** start pushing the lever **102** downward against the bias of spring **108**. Eventually, the lever **102** is pushed far enough toward the electromagnet **110** for its magnetic field to capture the lever **102** and draw it against the armature **118** of electromagnet **110** (FIG. *8b*). The drum **28** is thereby released and can turn freely. The float **32**, being now essentially suspended in air, accelerates to a free-fall velocity great enough to positively drive the shaft **12**. By the time the float **32** resumes its normal floating position, the wave level is falling rapidly enough to maintain the driving relationship of shaft **12** until the float **32** reaches the trough of the wave.

The motion sensor **116**, which may be any of a number of devices commercially available for that purpose, detects the direction of motion of the drum **28**. As soon as the wave starts rising again, and the motion of the drum **28** becomes clockwise, the motion sensor **116** operates switch **114** to de-energize electromagnet **110** and release lever **102** until the next fall of the wave causes the drum **28** to resume counterclockwise movement. During the clockwise movement of drum **28**, the lever **102** simply ratchets on the teeth of drum **28** (FIG. *8c*).

FIG. **9** illustrates the operation of the invention. If the float **32** simply follows the sinusoidal movement of the wave **120**, and if the shaft **12** speed w is such that the float **32** can do work only when its rate of fall is steeper than the slope **122**, of the only usable static energy of the float usable for power production is the weight less its buoyancy of the float **32** times h_{dr1}. On the other hand, if the float **32** is held until time t_r when it is essentially out of the water, the usable energy is the weight times the height of h_{dr2} above h_{dr1} plus the weight less its buoyancy times h_{dr1}. The percentage of energy utilization improvement achieved by the invention depends upon the shaft speed w and the periodicity of the wave (i.e. the steepness of its sides), but in a typical ocean installation for the generation of commercial power, the improvement would be on the order of 20%.

It will be seen that the present invention provides a highly effective wave power generating system which affords maximum utilization of the statistically expected wave patterns at any given location.

We claim:

1. A wave power generating system, comprising:

a) a platform positioned over a body of water exhibiting wave motion;

b) a drive shaft mounted on said platform;

c) first float means for driving said draft shaft only during the rising portion of a wave;

d) second float means for driving said drive shaft only during the falling portion of a wave;

e) a flywheel operatively connected to said drive shaft to be driven thereby; and

f) generating means operatively connected to said flywheel for generating electrical power when driven by said flywheel;

g) said first and second float means being positioned side by side along a line substantially perpendicular to the motion of the waves so as to drive said flywheel with maximum regularity and without overlap in order to achieve a substantially constant operating speed for said generating means;

h) whereby the constancy of speed necessary for commercially usable power generation is achieved with a substantially less massive flywheel.

2. The system of claim **1**, in which said first float means include an inclined bottom surface so oriented as to derive lift from the forward motion of said wave, and said second float means has a substantial majority of its weight concentrated in its lower half.

3. The system of claim **1**, further comprising:

i) load controller means for controlling the amount of electrical power generated by said generating means;

j) speed sensing means operatively connected to said flywheel for sensing its speed; and

k) control means connected to said speed sensing means and said load controller means for varying the power output of said generating means in such a manner as to maintain the speed of said flywheel substantially constant.

4. The system of claim **3**, in which said generating means is an alternator, and said flywheel maintains the output of said alternator at a substantially constant frequency.

5. The system of claim **1**, in which said second float means include:

a) a body having an upper portion and a lower portion;

b) weight means in said lower portion sufficient to concentrate the bulk of the weight of said float in said lower portion; and

c) suspension means attached to said upper portion for floatingly suspending said float in a body of water.

6. The system of claim **5**, in which said suspension means are operatively connected to power generating apparatus in such a manner as to allow said float to rise freely during the rising portion of a wave, but to drive said power generating apparatus by virtue of its weight during the falling portion of a wave.

7. A wave power generating system, comprising:

a) a platform positioned over a body of water exhibiting wave motion, said wave motion exhibiting variable wave heights and wave periods forming a plurality of wave patterns, each of said patterns having a statistical probability of occurrence in said body of water;

b) a drive shaft mounted on said platform;

c) first float means for driving said drive shaft only during the rising portion of a wave;

d) second float means for driving said drive shaft only during the falling portion of a wave, said first and second float means being positioned side by side along a line substantially perpendicular to the motion of the waves;

e) a flywheel operatively connected to said drive shaft to be driven thereby;

f) generating means operatively connected to said flywheel for generating electrical power when driven by said flywheel;

g) load controller means for controlling the amount of electrical power generated by said generating means;

h) speed sensing means operatively connected to said flywheel for sensing its speed; and

i) control means connected to said speed sensing means and said load controller means for varying the power output of said generating means in such a manner as to maintain the speed of said flywheel substantially constant;

j) said generating means being an alternator, and said flywheel maintaining the output of said alternator at a substantially constant frequency;

k) said flywheel having a narrow allowable speed range, the speed of said flywheel being a function of wave height, wave period, and alternator load; and

l) the range of wave heights and periods lying between the minimum height and maximum period required to drive said flywheel at the minimum allowable speed with no load, and the maximum heights and minimum period required to drive said flywheel at the maximum allowable speed with maximum load, encompassing in excess of 70% of the statistically expected wave patterns at the location of the system.

8. A wave power generating system, comprising:

a) a platform positioned over a body of water exhibiting wave motion;

b) a drive shaft mounted on said platform;

c) first float means for driving said drive shaft only during the rising portion of a wave;

d) second float means independent of said first float means for driving said drive shaft only during the falling portion of a wave;

e) a flywheel operatively connected to said drive shaft to be driven thereby; and

f) generating means operatively connected to said flywheel for generating electrical power when driven by said flywheel;

g) said first and second float means being positioned in substantially vertical alignment with each other so as to drive said flywheel with maximum regularity in order to achieve a substantially constant operating speed for said generating means;

h) whereby the constancy of speed necessary for commercially usable power generation is achieved with a substantially less massive flywheel.

9. The wave power generating system of claim **8**, in which said first and second float means have mating concavo-convex surfaces facing each other, whereby the water entrapped therebetween cushions contacts between said first and second float means.

10. The wave power generating means of claim **9**, in which said mating surfaces are conical in shape.

11. The wave power generating means of claim **10**, in which the mating surface of the upper float is convex and the mating surface of the lower float is concave.

12. A float arrangement for converting wave motion into work, comprising:

a) a pair of floats disposed substantially coaxially with each other, said floats being disposed for movement toward and away from each other in a fluid in response to wave motion in said fluid, said floats being capable of contacting each other at times during said movement;

b) said floats having mating surfaces facing each other, one of said mating surfaces being concave and the other convex,

c) whereby the fluid between said surfaces tends to cushion said contact while tending to coaxially align said floats with each other as they enter into contact with each other.

* * * * *

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Stansby et al.

(54) **WAVE ENERGY APPARATUS**

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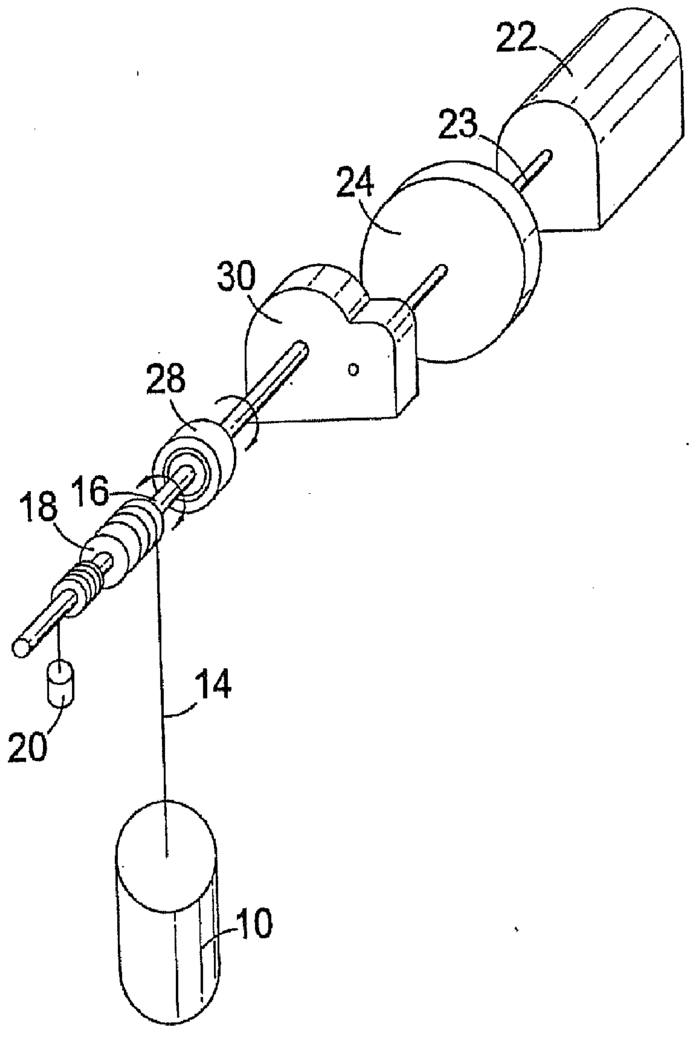
H02P 9/04 (2006.01)

(52) **U.S. Cl.** **290/42**; 290/53

(57) **ABSTRACT**

In a wave energy apparatus vertical movement of a float suspended in a body of water drives a power generator. Motion of the float is controlled by taking advantage of the movement of water on the upper surface of the float body. The upper surface can be used to generate hydrodynamic forces acting downwardly against the upward forces acting on the lower surface of the float body, effectively damping its movement in the presence of waves that might otherwise provoke undesirably large vertical movement of the float. The movement of water onto the upper surface can be controlled by adjusting the depth at which the float is suspended.



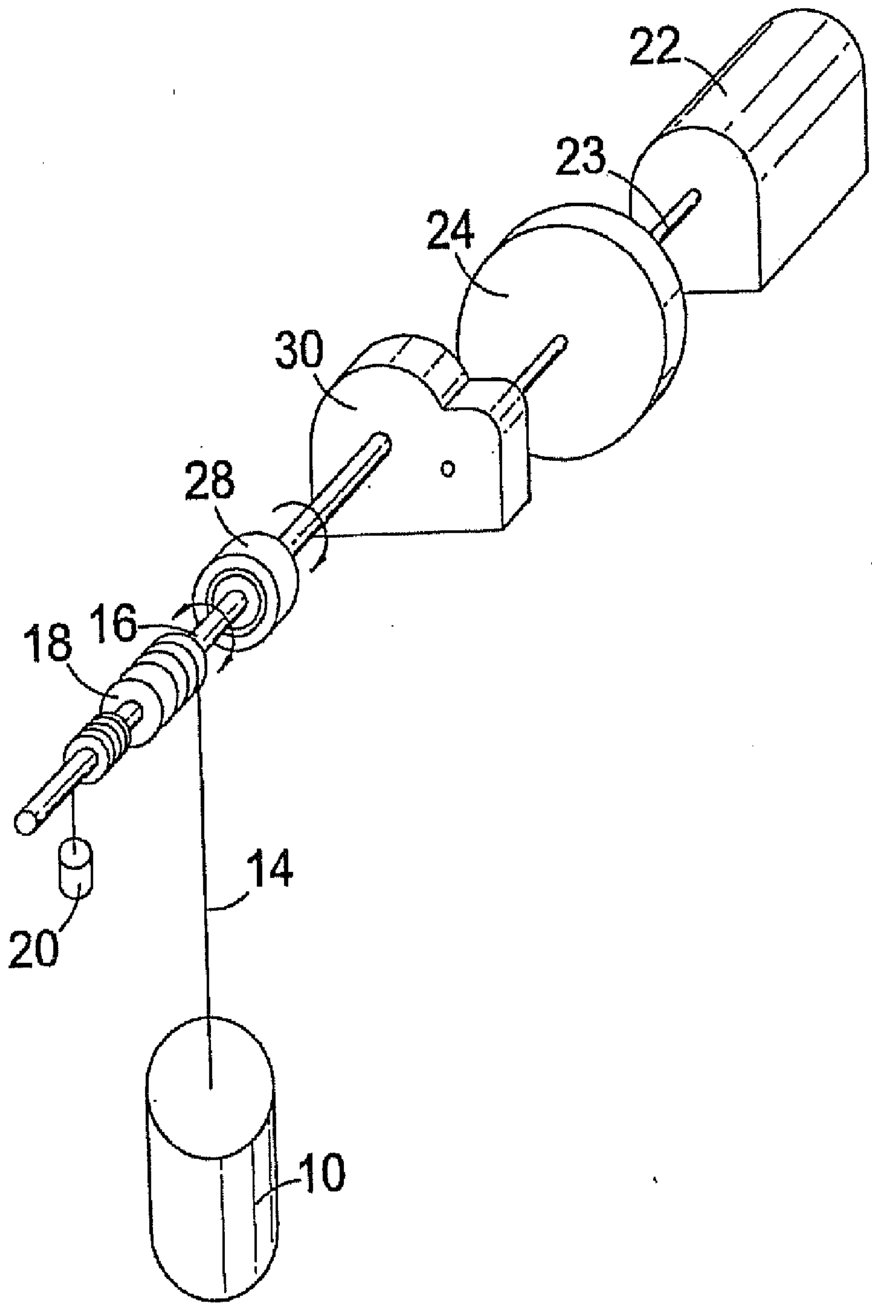


Fig. 1

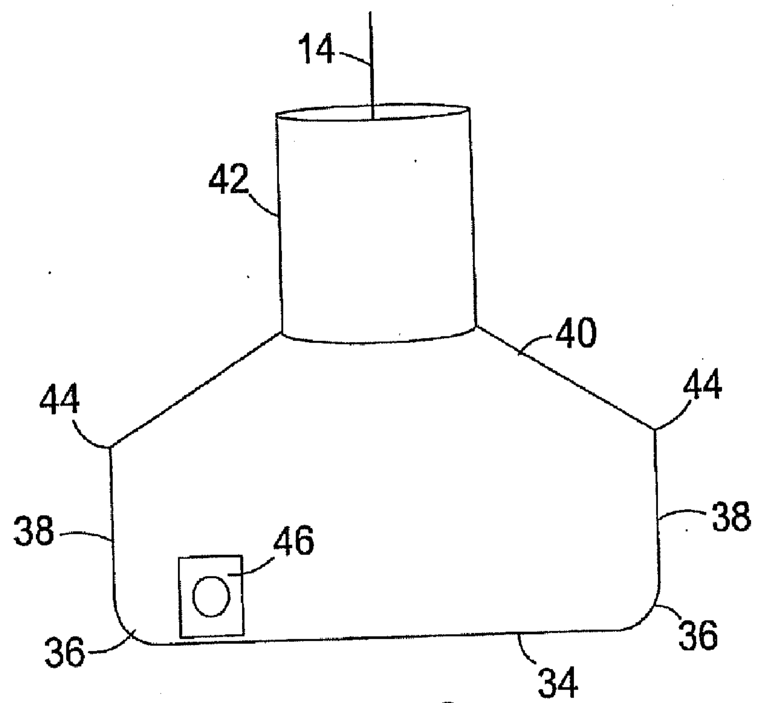


Fig. 2

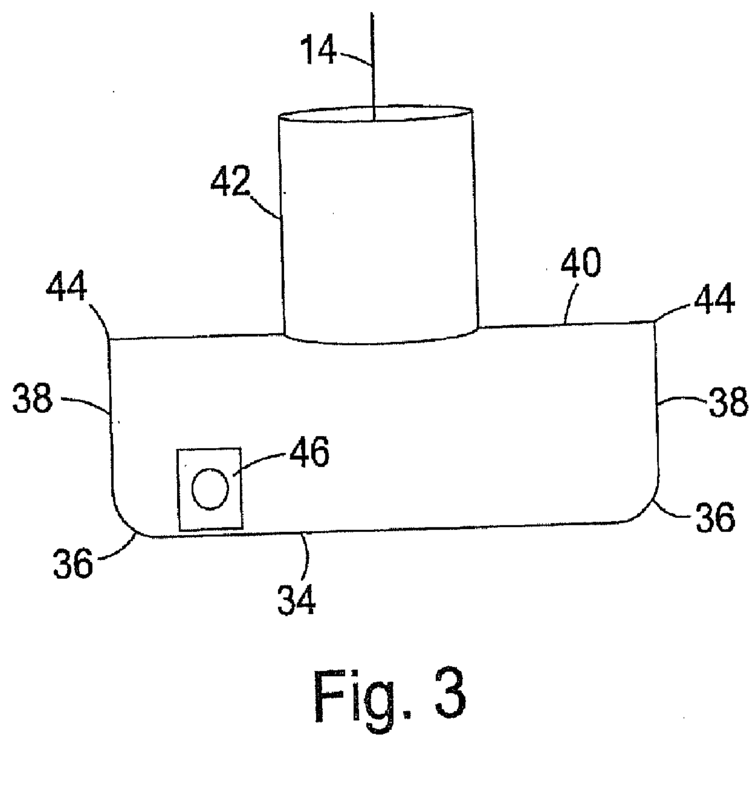


Fig. 3

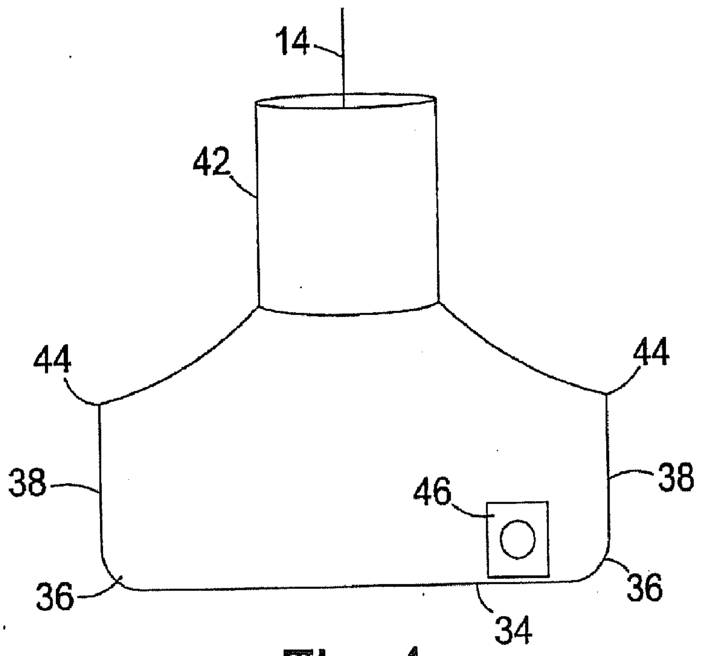


Fig. 4

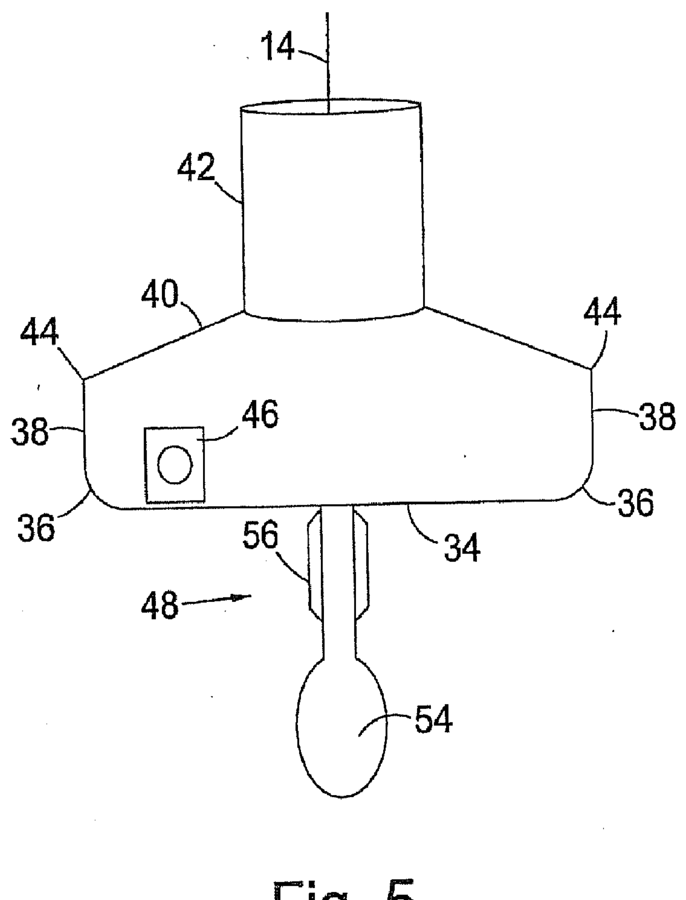


Fig. 5

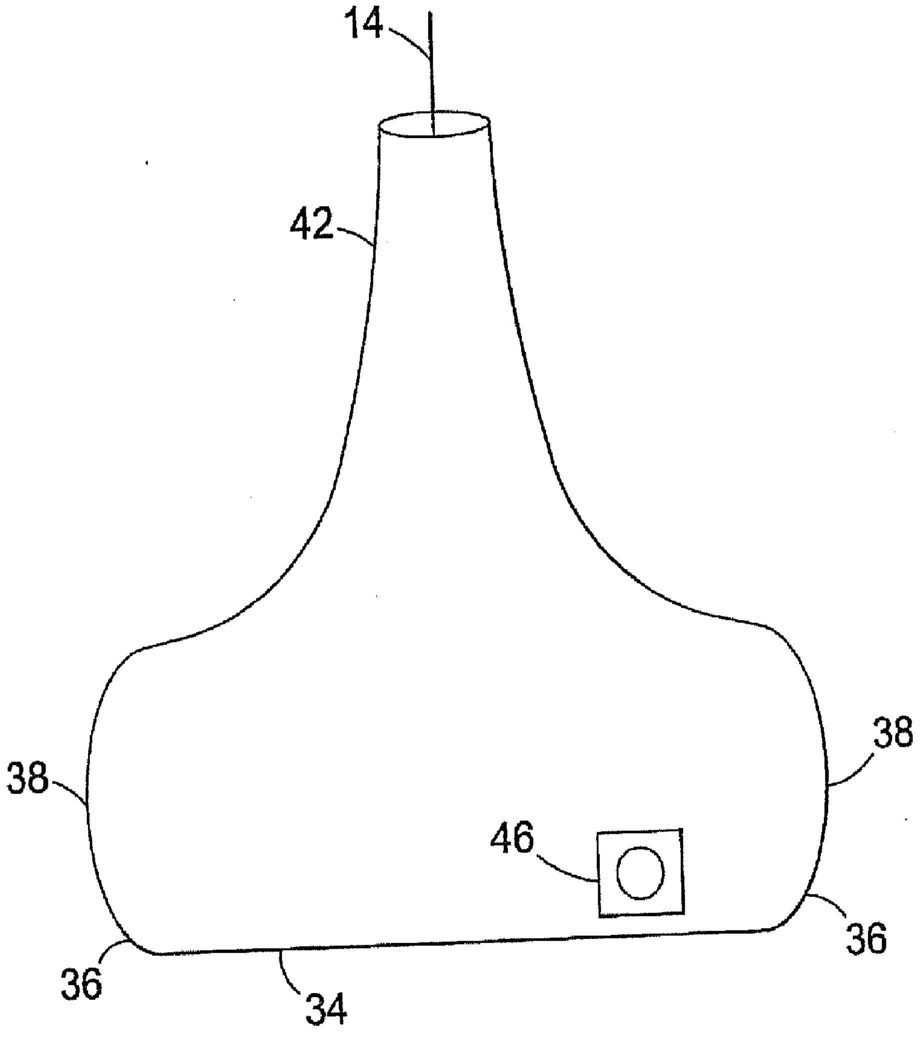
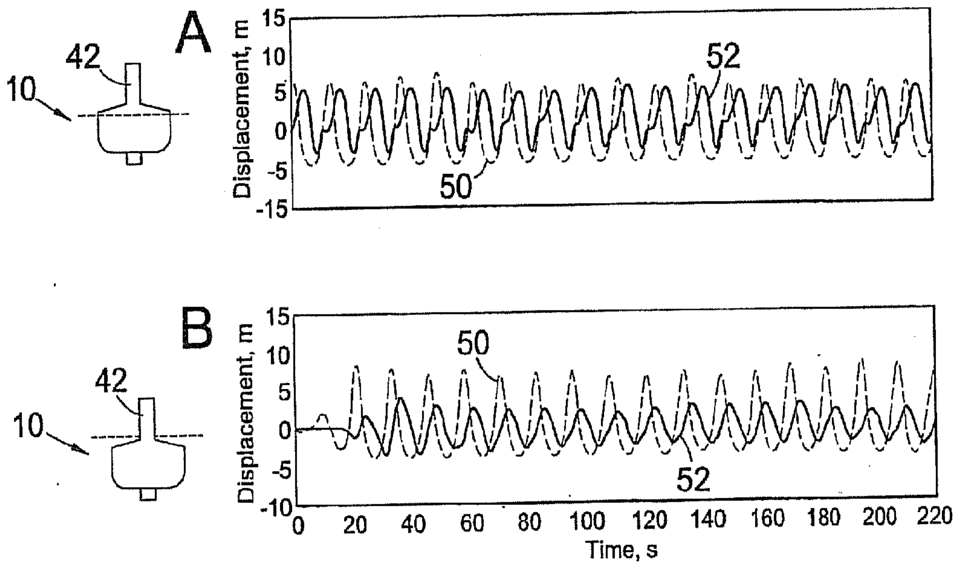


Fig. 6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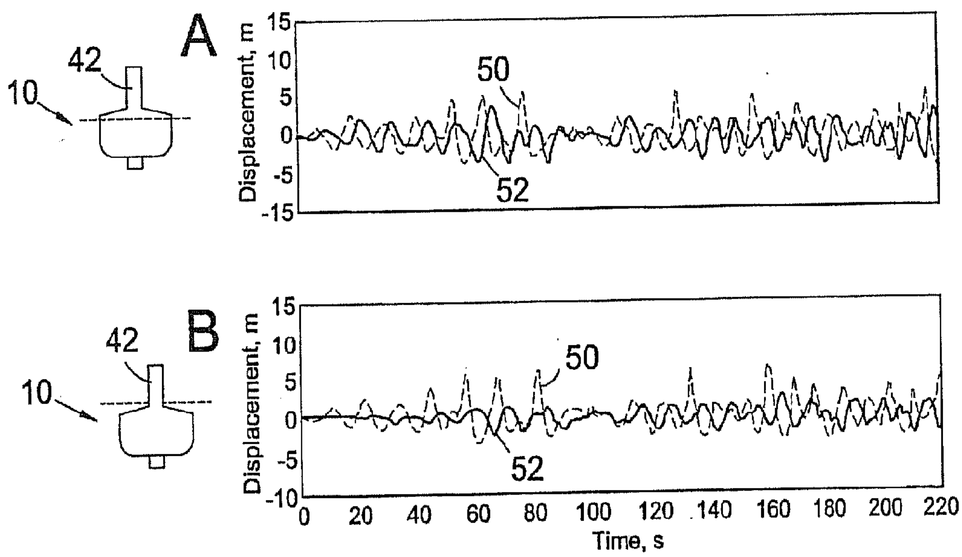
Time, s

Fig. 7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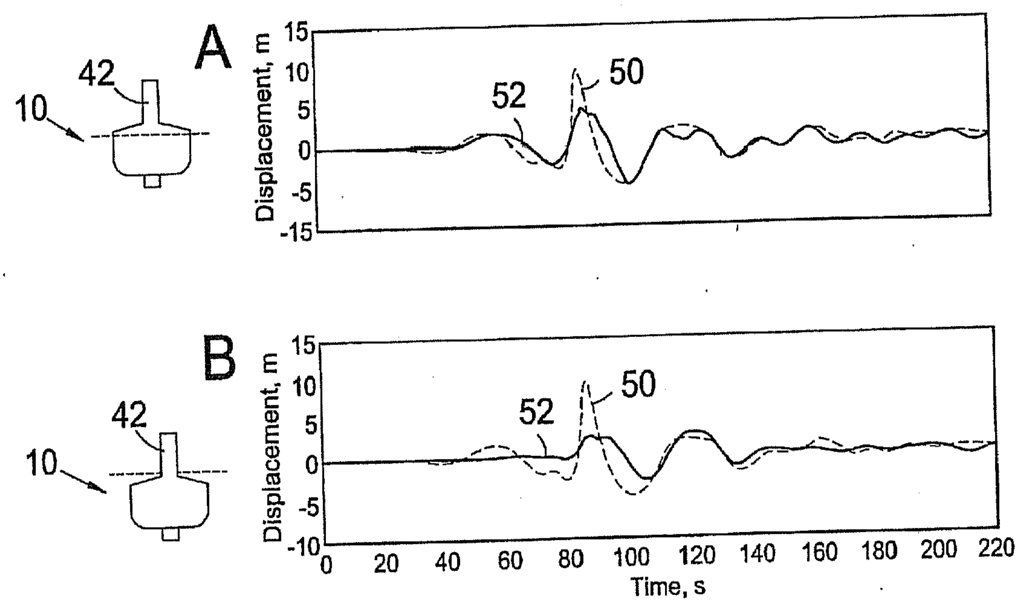
Time, s

Fig. 8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Time, s

Fig. 9

WAVE ENERGY APPARATUS

[0001] This invention relates to the extraction of energy from waves, particularly to wave energy apparatus in which vertical movement of a float suspended in a body of water drives a power generator. Such apparatus are disclosed in International Patent Publication Nos: WO 2005/038244 and WO 2006/109024, the disclosures whereof are hereby incorporated by reference. The present invention is concerned with the movement of the float of such apparatus in the water, in different wave conditions.

[0002] The movement of a float in sea water can be of undesirably large extent, as the nature and size of waves in the water vary. The patent publications referred to above address issues relating to the lateral stability of floats. The present invention is directed primarily at controlling the float's vertical motion.

[0003] According to the present invention, the float motion in wave energy apparatus of the kind described above is controlled by taking advantage of the movement of water on the upper surface of the float body. The upper surface can be used to generate hydrodynamic forces acting downwardly against the upward forces acting on the lower surface of the float body, effectively damping its movement in the presence of waves that might otherwise provoke undesirably large vertical movement of the float. The movement of water onto the upper surface can be controlled by adjusting the depth at which the float is suspended. In most embodiments of the invention therefore, the upper surface of the float body is designed such that its area when resolved parallel to the lower surface is less than that of the lower surface. This can be very easily achieved by including an element or stem projecting from the upper surface of the float body which pierces the water surface when the upper surface of the float is submerged. It can also be achieved by shaping the upper surface of the float such that a part thereof projects upwardly to pierce the water surface when the float is immersed or when suspended in still water. When suspended in still water the cross section of the element or stem, or the projecting part of the float upper surface at the water surface is preferably in the range 0.01 to 0.2 times the mean cross section of the float body. If at least the stem cross section is circular, this sets the minimum diameter of the stem or of the projecting row at the surface at around 0.1, and a maximum of around 0.4, times the float body diameter. Preferably it is 0.2 to 0.3 times the float diameter. Generally, the larger the cross-section of the stem, the larger the changes of mass that are required to alter the behaviour of the float in the waves. The float body cross section will normally be constant, and usually circular, although variations are possible. Such variations will typically include shapes which taper toward the top of the float.

[0004] The upper surface of the float body may take any suitable shape, including flat, convex or conical. We have found that a conical upper surface has provided effective damping, the cone angle being in the range 90 to 150°. A cone angle of 120° is particularly preferred.

[0005] Where the upper surface meets the side of the float, it is preferred that a sharp corner or edge is created. This enhances the sloshing effect, generates turbulence around the periphery, and downwardly directed hydrodynamic forces on the float upper surface. However, floats without such a sharp edge can be useful. In this variant the float has the overall shape of a teardrop with the float upper surface merging with and into a continuous sidewall of the float body. An element or stem can extend from the upper surface, but can be perceived as no more than a continuation of the upper surface. The float can of course be suspended directly from the apex of the upper surface.

[0006] Typically the float base will be substantially flat with a chamfered periphery joining with a cylindrical outer shape. Preferred base shapes have a flat central section of area at least one fourth of the cross-section of the float at its base. Other convex shapes such as dome can also be used, one such option being a base cross-section defining an ellipse. Concave shapes for the base would not normally be used. The cylindrical side of the float will normally be of constant diameter, but can converge towards the top.

[0007] The depth at which the float is suspended in the water can be adjusted by altering its effective weight. This can be accomplished either directly by shifting ballast to or from the float, and the ballast can be water from the body in which the float is suspended. A pump mechanism can be installed within the float to take on or remove water, but it can also be taken or removed through an element or stem of the kind referred to above extending from the upper surface of the float. As in the practice of the invention the float will normally be suspended from a gantry of some kind, taking ballast to or from the float, or power to a suitably located pump mechanism in the float will be a relatively straightforward exercise. However, because the float will normally be suspended in the water by a mechanism including a counterweight for the float, the effective weight of the float can also be easily adjusted by altering the weight of the counterweight.

[0008] Adjusting the effective weight of the float alters the natural frequency of the float. The natural period of the float is mainly determined by the system mass and wetted diameter and in the method of the invention the natural period of the float system is preferably less than that of the prominent wave. When the upper surface of the float is submerged for part of the wave cycle, the vertical oscillation of the float will be reduced. This is the desired configuration in seas with medium to large waves.

[0009] In some circumstances it is beneficial to lower the centre of gravity of the float body and this can be accomplished by suspending a keel from the float body. The keel should be shaped to offer least resistance to vertical motion through the water, but can be adapted to resist lateral oscillatory motion by bearing fins or ribs. It would normally be elliptical, spherical or otherwise bulbous in general outline, and could be spaced from the float body by means of a rigid element that could itself bear fins or ribs, or even by a flexible elongate element such as a chain. A keel could also be in the form of a solid cylindrical mass, attached to the float base and concentric with the float, having a diameter small in relation to the float diameter. In some embodiments the mass of the float as a whole can be concentrated in the keel. This will provide maximum stability while at the same time provide for maximum response of the float as a whole to moving waves at the surface. The lower surface of the float body will be as large as is reasonably possible to maximise its response.

[0010] All the surfaces of the float will normally be substantially smooth or at least uninterrupted. However, some surface profiling can be used if appropriate. Ribs or grooves can be formed on the upper surface of the float to channel water flowing thereover. Ribs or grooves can also be formed on the side wall of the float to channel water as the float rises and falls.

[0011] The invention will now be described by way of example and with reference to the accompanying schematic drawings wherein:

[0012] FIG. **1** is a perspective view of a wave energy apparatus of the kind disclosed in International patent publication No. WO 2005/038244; and

[0013] FIGS. **2** to **6** are cross-sectional views of different floats that can be used in accordance with the invention in the apparatus of FIG. **1**.

[0014] FIGS. **7**, **8** and **9** illustrate how the movement of a float of the kind shown in FIG. **2** can be modulated by lowering it in the body of water.

[0015] In the apparatus shown in FIG. **1**, a float **10** is suspended from a structure (not shown) by a cable **14** which extends around a pulley **18** mounted on a drive shaft **16**. The float **10** is adapted to be suspended in a body of water subject to movement, and adapted to rise and fall with such movement. It does not though, have to be on or immersed in the water at all times. As the float **10** rises, slack in the cable **14** is taken up by a counterweight **20** also mounted on the shaft **16**, but on a cable around a pulley in the opposite sense to the cable **14** supporting the float **10**. The drive shaft **16** is connected to an electricity generator **22** through clutch/free wheel device **28** and a gearbox **30**. The clutch **28** is caused to engage and disengage the connection of the drive shaft **16** with the generator **22** by means of a clutch and/or a freewheel device. By this means, vertical movement of the float in the body of water is converted into rotational movement of the shaft which is used to generate electricity in the generator. A separate flywheel **24** on the shaft **23** between the gearbox **30** and the generator **22** provides momentum to maintain rotation of the shaft when it is not being driven by the movement of the float **10**. Reference is directed to Patent Application No: WO 2005/038244, incorporated herein by reference, for further discussion of the operation of apparatus of the kind illustrated in FIG. **1**.

[0016] The present invention is concerned particularly with the manner in which the moving water imparts movement to the float **10** in a controlled manner. Particularly, it is concerned with the manner in which movement of the float can be controlled in extreme conditions. In stormy weather, large waves can cause excessive oscillations of the float, putting at risk the structure upon which it is supported and of course, any operating personnel in the vicinity.

[0017] In each of FIGS. **2** to **5** the float **10** lower surface **34** extending via a chamfered edge or edges **36** to a generally cylindrical side wall or side walls **38**. Generally, the cross-section of the float will be circular, and the side wall **38** either cylindrical or slightly conical, for the reasons given above. In all four examples, the vertical length of the sidewall or walls **38** is less than the lateral diameter of the float. Preferably the float diameter is greater than the height of the wall or walls **38**, normally by a factor of at least 2. A typical float of the type shown in FIG. **2**, has a mass of 250 tonnes, and a cylindrical cross-section of diameter around 10 m with a wall height of around 4.0 m. The diameter of the stem **42** is around 2 m. As shown, it has a height of around 4 m, but this could be much greater, typically 7 or 8 m. The chamfered edge or edges **36** reduce turbulence and maximise the upwardly directed hydrodynamic forces on the float.

[0018] In the example of FIG. **2**, the upper surface **40** of the float takes the form of a frusto conical section extending from the edge **42** of the sidewall to the element or stem **44** which projects upwardly and centrally of the float. The cone angle of the section is approximately 120°, making the inclination of the upper surface **40** from the lower surface **34**, around 30°.

[0019] When used in wave energy apparatus of the kind illustrated in FIG. **1**, the float **10** of FIG. **2** will ideally be suspended partially submerged in a body of water, and the upper surface **40** above the waterline. As the float rises and falls in correspondence with wave motion in the body of water, water will wash over the upper surface **40** and as it does so, generate downward forces on the float acting against the upward forces on the lower surface. This results in a damping effect, which progressively increases with the amount of water washing over the upper surface **40**. This effect can be controlled by adjusting the depth at which the float is suspended in the body of water. In order to generate maximum energy from the wave motion, it is of course desirable to keep the damping effect to a minimum. Thus, in relatively calm weather with small to medium waves the float is suspended as near the surface as possible to maximise power output. However, with larger waves movement of the float can become excessive, and some control is required. To achieve this the float is lowered into the body of water, thereby increasing the amount of water sloshing over the upper surface and generating downward hydrodynamic forces counteracting the upward forces acting on the lower surface **34**. Normally the geometry of the float is such that the hydrodynamic downward forces never match or exceed the upward forces on the float, and this can be accomplished by establishing an arrangement in which the upper surface when resolved onto a plane parallel to that of the lower surface **34** is always smaller in area. In the embodiment described this is assured by the presence of the element or stem **42** that projects from the upper surface. This stem or element should normally be surface piercing when water is impinging on the upper surface **40**. However the stem is not essential if the top of the upper surface itself is surface piercing at least for part of a wave cycle.

[0020] While the edge or edges between the lower surface **34** and the side or sides **38** are chamfered to minimise turbulence around the periphery of the lower surface **34**, around the upper surface **40** the edge or edges **44** are made sharp. The intention here is to create turbulence as water impinges on the float, to generate downwardly directed hydrodynamic force on the peripheral portion of the upper surface **40**.

[0021] The depth at which the float **10** is suspended in the water can be most easily adjusted by altering its effective weight. In the apparatus as shown in FIG. **1**, the mass of the counterweight **20** may be altered thereby altering the effective weight of the float **10** in the body of water. Alternatively, ballast may be moved to and from the float, and such ballast is conveniently water from the body in which the float is suspended. A pump **46** may be housed in the float and with suitable valving (not shown) pump water to and from a chamber in the float to alter its weight.

[0022] We have found that the vertical movement of the float may be substantially stabilised in adverse wave conditions by lowering the depth at which the float is suspended in the water. The preferred depth is that at which in still water, the stem or upper surface of the float projects upwardly from the float body with its cross sectional area at the water surface being in the range 0.01 to 0.2 of the mean cross sectional area of the float body. Thus, the preferred depth in still water of the float illustrated in FIG. **2** is that at which only the stem, of diameter 2 m pierces the water surface with the entirety of the float body beneath the surface. The effect of this depth selection is illustrated in FIGS. **7**, **8** and **9**. Each shows the movement of a float of the kind shown in FIG. **2** in response to regular wave movements (FIG. **7**); irregular wave movements (FIG. **8**) and a sudden large wave (FIG. **9**). FIG. **7** shows two graphs with the movement of the float (line **52**) superimposed over the substantially regular wave motion (line **50**). As can be seen, the amplitude of the wave is reasonably constant and does not exceed 10 m. With the effective mass of the float such that the upper surface of the float body is above water level in still water (FIG. **7**A), the amplitude of the float movement (line **52**) is a little less, peaking at around 5 m. When the float is lowered in the water such that when in still water only the stem **42** pierces the water surface (FIG. **7**B), with the remainder of the float immersed, the amplitude of the float movement is significantly reduced to around one third of the wave amplitude; around 2 m. While this suggests a significantly reduced energy output, in practice there would be little if any loss as the reduced amplitude motion of the float will still be more than sufficient to drive a generator at a normal maximum capacity.

[0023] In the same way as does FIG. **7**, FIG. **8** illustrates float movement superimposed over wave movement with the depth of the float being set in still water with the float at the surface (FIG. **8**A) and with the float body submerged such that only the stem **42** pierces the water surface (FIG. **8**B). As can be seen, by submerging the float body the amplitude of its vertical movement in response to the wave motion is moderated and stabilised. FIG. **9** similarly illustrates how lowering of the float can reduce the impact of a large and unexpected wave, again reducing the amplitude of the float movement to tolerable levels, broadly consistent with those provoked in response to a regular wave (FIG. **7**).

[0024] The benefits of reducing the amplitude of the float movements are considerable. While as noted above there is no significant loss in power generation, extreme movements of the float are avoided. This significantly reduces the strain on the support mechanisms for the float, the gantry and the generator couplings, and also the space within which the float can be suspended in the water. This is important as where multiple floats are used in an array, the manner in which the movement of one float can influence the movement of another must be accounted for. A typical array, of the kind disclosed in International Publication No: WO 2006/109024, referred to above, can have a total of twenty five floats of the kind illustrated in FIG. **2**, and their interaction can result in an increase in the amount of energy generated, relative to the amount generated by twenty five single floats operating quite independently.

[0025] In the example of FIG. **3**, the upper surface **40** of the float **10** is substantially flat. FIG. **4** shows an example in which the upper surface **40** has a concave-conical shape. This shape maximises the hydrodynamic forces acting downwardly on the float at its peripheral area, with the effect being reduced as the impinging water moves closer to the centre or the stein **42**.

[0026] The float shown in FIG. **5** incorporates an additional feature. A keel **48** depends from the float to a bulb **54**. The depth at which the keel is suspended below the float is relatively high to maximise its stabilizing effect, and the mass of the float insofar as is possible, is concentrated in the bulb **54**. With this additional stability, the float can be suspended in the body of water with its base **34** closer to the water surface, thereby maximising the conversion of wave energy into vertical movement of the float and thereby generation of power. The keel **48** can be formed with fins or ribs **56** to resist lateral movement, without impeding vertical movement. Fins or ribs can also or alternatively be fitted to the bulb **54**. The keel might be replaced by a flexible element such as a chain. The bulb **54** thus provides weight and a stabilising effect.

[0027] FIG. **6** shows a float in which the upper surface **40** extends to form the element or stem from which it is suspended. The upper surface also merges with and into the continuous sidewall **38**, thus removing the edge **44**. In all other respects the float is the same as that of FIG. **4**, and the upper surface **40** can include an intermediate frusto conical section.

[0028] It will be noted that whereas the float **10** in the known apparatus of FIG. **1** is shown as a solid cylinder whose axial length is greater than its diameter, in the examples of floats used in accordance with the present invention, the height is significantly less than a relevant lateral dimension. The reason for this is the exploitation of the upper surface of the float as a component in a damping mechanism effective when the float is suspended in stormy waters. Adjustment of the depth at which the float is suspended enables an apparatus to select when the damping effect is applied.

1-13. (canceled)

14. A method of controlling the vertical motion of a float suspended in a body of water, the float having a mean cross-sectional area between a lower surface and an upper surface that includes an upwardly projecting stem, the cross-sectional area of the stem being in the range 0.01 to 0.2 times the mean cross-sectional area of the float, in which method vertical movement of the float provoked by motion of the water drives a power generator, and the depth at which the float is suspended is adjusted relative to the amplitude of waves in the water to control the movement of water on the upper surface of the float, and wherein the effective mass of the float is such that when it is at rest in still water the stem projects above the water surface.

15-20. (canceled)

21. A method according to claim **14** wherein the float defines a chamber and its mass is adjusted by the movement of ballast to and from the chamber.

22. A method according to claim **14** wherein the float is suspended in the water by a mechanism including a counterweight for the float, and wherein the effective weight of the float is adjusted by altering the counterweight.

23. Wave energy apparatus comprising a float suspended in a body of water and in which vertical movement of the float provoked by motion of the water is linked to a power generator, the float having an upper and a lower surface with a stem projecting from the upper surface and oriented to pierce the water surface when the float body is immersed, the ratio of the cross-sectional area of the stem to the mean cross-sectional area of the float body being in the range 0.01 to 0.2, and wherein the depth at which the float is suspended in the water is adjustable while the float is in the water, the apparatus including means for effecting such adjustment.

24.-26. (canceled)

27. Apparatus according to claim **23** wherein said range is 0.04 to 0.09.

28. (canceled)

29. Apparatus according to claim **23** wherein the upper surface of the float converges upwardly towards the stem.

30. Apparatus according to claim **29** wherein the upper surface of the float is conical.

31. Apparatus according to claim **29** wherein the lower surface of the float is substantially flat and the upper surface is inclined to the lower surface of an angle of 10° to 45°.

32-36. (canceled)

37. Wave energy apparatus according to claim **23** wherein the float comprises a main body defining said mean cross-sectional area, and a keel suspended from the main body.

38. Apparatus according to claim **37** wherein the keel is suspended on an element having fins for minimising lateral movement of the float.

39. Apparatus according to claim **37** wherein the keel is suspended on a flexible elongate element.

40. (canceled)

41. Apparatus according to claim **23** wherein the float is suspended in the water by a mechanism including a counterweight for the float, and wherein the effective weight of the float is adjusted by altering the counterweight.

42. Apparatus according to claim **23** wherein the float upper surface around the stem is flat.

43. Apparatus according to claim **23** wherein the stem projects from a central location on the upper surface of the float body.

44. Apparatus according to claim **23** wherein the lower surface of the float has a flat central section bounded by a curved peripheral annular zone.

45. Apparatus according to claim **43** wherein the flat central section has an area of at least one fourth of the cross-section of the float at its base.

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