



(51) International Patent Classification:
F03B 13/18 (2006.01)

(21) International Application Number:
PCT/US2010/055366

(22) International Filing Date:
4 November 2010 (04.11.2010)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
61/258,851 6 November 2009 (06.11.2009) US

(72) Inventor; and

(71) Applicant : HON, Raphael [MY/US]; 62 Claret, Irvine, California 92614 (US).

(74) Agent: MULROONEY, Jeffrey D.; James Ray & Associates, 2640 Pitcairn Road, Monroeville, Pennsylvania 15146 (US).

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PE, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: WAVE ENERGY CONVERSION DEVICE

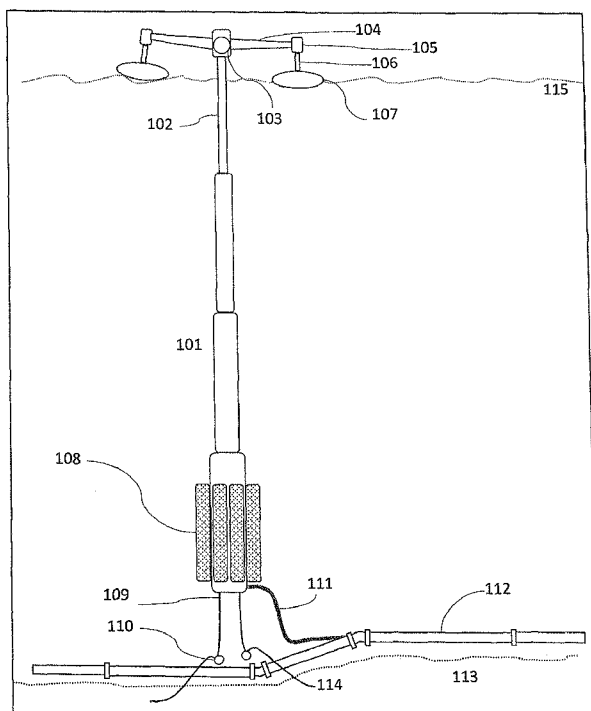


FIG. 1

(57) Abstract: Several embodiments of a device for economically harvesting wave energy are disclosed. A sealed vessel for air storage, the spar buoy, is mostly submerged under water is also used as an inertial body that surface floats move relative to. The spar buoy may take many geometrical forms, but all have a stem that is above the water surface. Piston pumps are placed at the top of the stem. The pump has a gearing reduction to optimize the rotational motion of the pump drive shaft. Small angular motion at the drive shaft results in multiple cycles of linear reciprocal motion of the piston. Various mechanisms could convert the relative motion between the floats and the spar buoy to a rotational motion of the shaft. The compressed air generated by the pump is stored in the spar buoy and regenerated as electrical energy by expanding the compressed air in a turbine.



Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *without international search report and to be republished
upon receipt of that report (Rule 48.2(g))*

WAVE ENERGY CONVERSION DEVICE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to and claims priority from
5 provisional patent application 61/258,851 filed November 6,
2009 and is herein incorporated by reference.

FIELD OF THE INVENTION

This application relates to a wave energy conversion
10 device through air compression.

BACKGROUND OF THE INVENTION

Renewable energy is currently a small portion of
society's energy generation compared to fossil fuels energy
15 sources. Although wave energy is a large source of renewable
energy, it is an underutilized source because current methods
and technologies are not economically competitive. This is due
to the high cost of the current technologies or the extensive
infrastructure required. In addition, the technology should
20 not pose a threat to marine life or cause other environmental
damage. Ideally, the harvested energy may also be stored for
use during peak energy demand.

Most wave energy extraction devices known as point
absorbers utilize wave motion to move a float relative to
25 another float or body. Two common types of relative motion are

employed. The first utilizes float motion relative to rigidly anchored bodies such as sea platforms while the other uses the relative motion of two floating bodies. The large infrastructure cost makes the former type expensive while
5 present known methods of relative motion between two floating bodies have high unit cost. This is because most of these systems need to be designed to withstand the severe marine environment.

Many inventions harvest wave energy by placing floats in
10 the sea and directly attach the linear (heaving) motion of the float to push or pull a piston in a hydraulic cylinder. U.S. Patent No. 582,282 and 888,721 illustrate such a mechanism. Floats are connected to a rod or a lever arm that is connected to double acting cylinder on the other end. In many designs,
15 one end is rigidly anchored to the sea bed while the other is connected to the floats. The motion of the float drives the double acting cylinder to generate energy. Many of these prior articles require a platform or infrastructure anchored to the sea floor. For large scale energy production, these structures
20 have to be designed to withstand high loads at sea which is very costly.

Devices that directly connect the linear motion of a float to the linear motion of a piston pump will only be cost effective for pumping an incompressible fluid such as water or
25 hydraulic fluid. Incompressible fluids are incapable of

storing energy unless they are pumped to a high elevation and stored in a dam. Compressible fluids such as air can store energy in the form of pressure. However, a piston pump will not generate sufficient pressure with compressible fluids
5 unless the piston travels a significant portion of its stroke. As ocean waves are unpredictable and irregular, the transmission of wave motion directly to a simple piston will only be efficient in a small range of wave heights. Shallow waves will not generate sufficient compression, and large
10 waves beyond the stroke length of the cylinder are not harvested.

A method described by Leavitt in U.S. Pat. No. 322,129 converts the linear motion of the float to a rotational motion and converted back into a linear motion of a fixed stroke
15 length using a rack and pinion gearing. Such a method would be preferable for compressing air with a piston pump. However, the Leavitt invention requires a structure that is rigidly anchored to the sea floor. In fact, numerous inventions including U.S. Pat. No. 738,996; U.S. Pat. No. 971,343; U.S.
20 Pat. No. 1,045,654; U.S. Pat. No. 4,009,395; and U.S. Pat. No. 6,269,636 require the use of a platform with permanent foundation for the mechanism to work. These structures, as described earlier, would be costly to build and maintain.

Many designs utilize the relative motion between a float
25 relative to another float or body to harvest wave energy. The

relative motion between floats eliminates the need for rigid structures anchored to the sea bed. U.S. Pat. No. 581,067 illustrates such an embodiment of harvesting wave energy. Patented in 1897 by Fletcher, the invention pumps sea water to the shore, where it is used to drive a Pelton wheel to generate energy. A large plate is attached to a submerged float to increase its inertia relative to the surface float. The heaving motion of the float drives the piston in a double acting cylinder combined with one way check valves to pump sea water. As discussed previously, the Fletcher invention only works well for pumping liquid, and pumping sea water have undesirable effects for both marine life and the pump.

Other prior art references use the relative motion of floats to compress a piston pump with hydraulic fluid. The hydraulic fluid is immediately used to drive a small turbine that is typically placed within the float or the point absorber unit at sea. Other prior art references convert the undulating motion of floats to a unidirectional rotary motion using mechanisms such as ratchets or clutches. Many of these inventions that generate electrical energy at sea are inefficient and have high costs. Very few inventions are in practice or generate energy on a large scale, and even fewer are capable of storing the generated energy.

SUMMARY OF THE INVENTION

Several embodiments of a device to economically harvest wave energy are disclosed. A sealed vessel for air storage, the spar buoy, is mostly submerged under water is also used as
5 an inertial body that surface floats move relative to. The spar buoy may take many geometrical forms, but all have a stem that is above the water surface. Piston pumps are placed at the top of the stem. The pump has a gearing reduction to optimize the rotational motion of the pump drive shaft. Small
10 angular motion at the drive shaft results in multiple cycles of linear reciprocal motion of the piston. Various mechanisms could convert the relative motion between the floats and the spar buoy to a rotational motion of the shaft. The compressed air generated by the pump is stored in the spar buoy and
15 regenerated as electrical energy by expanding the compressed air in a turbine.

In one embodiment, floats are connected to the piston pump drive shaft through lever arms. Float motion in response to waves causes the rotation of the lever arm. In another
20 embodiment, the float drives a rack in a rack and pinion gearing arrangement. The pinion gear motion is coupled to the drive shaft of the pump. In another embodiment, a cable and pulley mechanism is used. The linear motion of the float pulls the cable which rotates the pulleys. The pulley rotation is
25 connected to the pump drive shaft. In yet another embodiment,

the axis of a float is connected to the pump drive shaft. The float is designed to rotate easily due to wave motion, rotating the pump drive shaft. In another embodiment, the float is used to drive the pump placed at the end of a lever arm. The lever arm motion captures the energy from the gross motion of the float while the pump at the end of the lever arm generates energy from the rotation of the floats. In any of these embodiments, the spar buoy may be oriented horizontally or combined with the vertical spar buoys. Multiple stems, pumps and floats may be attached to a single spar buoy. A combination of vertical and horizontal spar buoy orientation may be used to optimize energy harness at a given site.

The spar buoy method eliminates the need to build expensive permanent structures at sea. The simple mechanisms in these embodiments keep the equipment costs low. Direct air compression with the piston pump eliminates the need for additional components such as ratchets, clutches, or active control systems to maintain a high compression ratio of the piston pump. Additional components and electronics are not a necessity to generate energy. The irregular wave energy harvested in the form of compressed air can be stored and consumed at a constant rate upon demand. Energy can be harvested from small waves, and the amount of energy harvested is proportional to the wave height. Energy is harvested independent of direction of rotation of the pump crankshaft,

i.e. on both the up or down motion of the float. Electrical energy generation may be performed at sea or on shore by transmitting the compressed air to shore through pipelines similarly used for natural gas transport. Alternatively each
5 spar buoy have an electrical generator for producing electricity from the compressed air. Also, a central station comprising at least one electrical generator could be used for producing electricity at sea or another location.

BRIEF DESCRIPTION OF THE DRAWINGS

10 FIG 1 shows an overall diagram of the main components of first embodiment.

FIG 1-A shows the components of the pump unit and the float in the first embodiment.

FIG 1-B shows the cross sectional view of the section A-A
15 of Fig 1-A.

FIG 2 shows the components of the pump and float in the second embodiment.

Fig 3 shows the components of the pump and float in the third embodiment.

20 Fig 4 shows of the main components of the fourth embodiment.

Fig 4-A shows the cross sectional view B-B of the fourth embodiment.

Fig 4-B shows the possible float shapes used in the fourth embodiment.

5 Fig 5 shows the overall diagram of the fifth embodiment.

Fig 6 shows the overall diagram of the sixth embodiment.

DRAWINGS-REFERENCE NUMERALS

Figure 1	127	Piston
101 Spar buoy	128	Check valve, inflow
102 Stem	129	Check valve, outflow
103 Pump unit	130	Air filter
104 Lever arm	131	Air duct
105 Secondary pump unit	132	High pressure air line
106 Vertical lever arm	133	Cooling fins
107 Float	134	Spar buoy flange
108 Spar buoy weights	135	Pipe (spar buoy)
109 Mooring chain		
110 Anchor buoy	Figure 2	
111 Pipeline hose	201	Spar buoy
112 Submarine pipeline		(decreasing diameter
113 Sea floor		embodiment)
114 Anchor point	202	Stem
115 Sea surface	203	Spar buoy pipe
	204	Pump unit
Figure 1-A	205	Piston Rod
121 Drive gear	206	Compression cylinder
122 Drive gear shaft	207	Piston
123 Pinion gear	208	Pinion gear
124 Crankshaft	209	Float column
125 Piston rod	210	Float
126 Compression cylinder	211	Check valve (outflow)

212	Check valve (inflow)	(parallel pipe
213	High pressure air line	embodiment)
214	Crankshaft	402 Stem
215	Roller	403 Spar buoy pipe
216	Pin Joint	404 Flange
		405 Weighted column
Figure 3		406 Horizontal beam
301	Spar buoy (tapering	407 Pump unit
	embodiment)	408 Unstable float
302	Stem	409 Spar buoy weight
303	Tapering spar buoy pipe	410 Float wall
304	Flange	
305	Submerged buoy	Figure 4-A
306	Pump unit	411 Float axis
307	Pin joint	
308	Float	Figure 4-B
309	Float column	421 Axis of rotation symbol
310	Cable Connector	422 Center of gravity
311	Cable	symbol
312	Pulley	423 Center of buoyancy
313	Crankshaft	symbol
314	Pump	424 Float weighting element
315	Roller	425 Triangular shaped float
		426 Rectangular shaped
Figure 4		float
401	Spar buoy	

427 Trapezoidal shaped
float
428 Pentagonal shaped float
429 Hexagonal shaped float
430 Triangular-weighted
hexagonal float
431 Parallelogram shaped
float

Figure 5

501 Spar buoy
(multiple section
embodiment)
502 Stem
503 Pump unit
504 Lever arm

505 Secondary pump unit
506 Unstable float
507 Pipe section
508 Flexible hose
509 Chain
510 Spar buoy weight

Figure 6

601 Horizontal spar buoy
602 Vertical spar buoy
603 Stem
604 Float and pump unit
605 Spar buoy weight

BRIEF DESCRIPTION OF A PRESENTLY
PREFERRED AND VARIOUS ALTERNATIVE
EMBODIMENTS OF THE INVENTION

The main components of a first embodiment are shown in
5 **Fig 1**. An elongated hollow vessel, the spar buoy **101**, is
submerged in the sea with only a smaller tubular beam, the
stem **102**, protruding through the sea surface. At the top of
the stem **102** is an air pump unit **103**. A lever arm **104**
connected to the drive shaft of the pump unit **103** is rigidly
10 attached to another similar pump unit **105**. Similar to lever
104, lever arm **106** extends from pump unit **105** is rigidly
attached a float **107**. The spar buoy **101** is secured with
optional weights **108**. The mooring chain **109** connected to the
body **101** at the deep end secures the entire device. A pipeline
15 hose **111** connects the spar buoy **101** to a submarine pipeline
112. The other end of the chain **109** is secured to the sea bed
113 at a suitable anchoring location **114**. Wave motion causes
the floats to drive the air pumps to generate compressed air.
The compressed air, or other fluid, is returned to the spar
20 buoy **101** for storage and transported to shore through the
pipeline **112**. Energy is generated from the compressed air on
shore using a turbine or other known methods.

In a first embodiment shown in **Fig 1**, the spar buoy **101**
is a long, hollow, tubular vessel that is designed to be
25 submerged in an approximate vertical orientation in the sea.

In this embodiment, the shape of the spar buoy **101** and stem **102** is similar to a hydrometer. The spar buoy **101** may be of any length, extending from the sea surface **115** to the sea floor or to the submarine pipeline **112** at any depth. Although
5 anchored, the spar buoy is allowed to have mobility to the extent allowed by the mooring chain **109**. The optional submerged anchor buoy **110** is to allow for the freedom of movement of the spar buoy **101** and chain **109**. Other known mooring methods may also be employed so that the spar buoy **101**
10 is anchored but operational at all water depths due to tidal changes. Due to the mobility of the spar buoy **101**, a flexible pipeline hose **111** allows for fluidic connection between the spar buoy **101** and the pipeline **112**.

The stem **102** is a slender beam tubular beam that extends
15 from the spar buoy **101** such that the top end of the stem **102** stays above the water level. The diameter of stem **102** is small in comparison to the diameters or widths of the spar buoy **101** and floats **107**. Since buoyancy is only dependent on the volume of water displaced by a spar buoy, the stem will have a
20 negligible contribution to the interacting forces between the spar buoy **101** and floats **107**. The length of stem **102** allows the spar buoy **101** to remain submerged for most wave conditions expected. The pump unit **103** is rigidly attached to the top of the stem **102**. The stem **102** may be hollow to allow for air lines

and other conduits to be connected between the pump unit **103** and the spar buoy **101**.

Fig 1-A illustrates the principles of operation of the pump unit **103** for one lever arm but applies to both levers shown in **Fig 1**. Within the casing of the pump unit **103**, a drive gear **121** is secured to a drive gear shaft **122** that extends out of the casing to connect to the lever **104**. The other end of lever **104** is rigidly attached to a secondary pump unit **105**, which is identical in function to the pump unit **103**. The lever arm **106** that extends from pump unit **103** is directed vertically to the float **107**. The overall rise and fall of the float **107** causes a rotational motion of the drive gear **121** within pump unit **103**, while the lateral motion of the float rotates the equivalent gear in pump unit **105**. Except for the specific placements of the pumps and the orientation of the respective lever arms, the description of pump unit **103** applies to pump unit **105**.

Pump unit **105** serves to harvest additional energy from the lateral motion of the floats. As waves tend to generate a sinusoidal surface, the float would tend to move such that it is normal to the free surface of the sea. The vector of the force on the float can be broken into two components, a sideward motion and a net vertical motion. Utilizing two pumps and lever arms, the surface wave energy is broken down into two orthogonal motions and captured by the respective pump

units **103** and **105**. Pump unit **105** may be omitted without the loss of function by connecting the lever arm **104** directly to float **107**. Float **107** may take any shape that optimizes the performance of the entire unit as well as have optional fins.

5 The floats **107** may be strengthened with internal spars or other methods known in the art.

A smaller pinion gear **123** is engaged to drive gear **121** such that the rotation of gear **121** rotates the smaller pinion gear **123**. The pinion gear **123** rotates with crankshaft **124**
10 which is connected to the piston rod **125**, compression cylinder **126**, and piston **127** assembly. The cylinder **126** is held rigidly in place with the pump casing. The rotation of the pinion gear causes the piston **127** to move up and down within the cylinder **126**. At suitable locations, check valve **128** allows the piston
15 to only draw ambient air during the intake stroke and check valve **129** allow only sufficiently pressurized air to exit the cylinder. The piston pump comprising of the piston, cylinder, and check valves is a known method for air compression. The direct coupling of arm **104** to drive gear **121** to pinion gear
20 **123** is more efficient than other inventions that use ratchets, clutches, or other intermediary mechanisms. **Fig 1-B** shows the section view AA of **Fig 1-A**, showing only the gears and pumps and omitting the other components for clarity. While **Fig 1-B** shows two pistons and cylinders, any quantity of pistons and
25 cylinders may be used with any combination of phase angles

between each piston. The size of piston pumps within the respective pump units **103** and **105** may be differently sized to maximize energy absorption.

Any appropriate type of gear, such as spur, helical, or
5 bevel, may be used for gears **121** and **123**. Pinion gear **123** is sized such that a small rotation of drive gear **121** is converted into one full rotation at the pinion gear. Although only one gear set is shown, multiple gear reduction sets may be used. For example, if a wave causes a float displacement
10 0.20m results in a full rotation of pinion gear **123**, then a 1m wave will result in 5 rotations of pinion gear **123**. Consequently, a single piston attached to crankshaft 124 will generate 5 compression strokes of piston **127**. If multiple pistons are used in this example, each piston placed at
15 different phase angles on the crankshaft 124, a full rotation for each piston is achieved at every 0.2m displacement of the float. Such an arrangement will result in a constant load at the gears. As a result of this gearing method, the amount of energy harvested is proportional to the wave heights. This
20 method compresses air whether the float moves up or down. It is only rotation of pinion gear **123** that is needed. The direction of rotation does not matter as each rotation of pinion gear **123** translates to one cycle of air compression. Incomplete rotations will result in partial strokes of the

piston **127**, and not generate sufficient pressure to open the check valve **129**.

While it may seem desirable to increase the gearing ratio of gears **121** and **123**, excessive gearing ratios will require
5 very large torque to be generated by the lever arm **104**. Larger torque will require a larger float and a longer lever arm **104**. As a result, larger wave swells will be required to move the float for the same amount of angular rotation of lever arm **104**. Since larger waves occur less frequently, practical
10 designs will require a compromise of the gearing ratio and the lever arm length.

Except for the air intake port, the pump unit may be sealed to allow for the gears and other components to be lubricated to increase mechanical efficiency. Referring to **Fig**
15 **1-A**, the interior of the pump unit **103** is sealed from sea water exposure through the drive gear shaft **122** by the use of O-rings or other known sealing mechanisms. The air intake conduit may be oriented vertically and flowing upward to minimize water intake to the air pump. Air is drawn in at the
20 intake port through filter **130** before travelling in sealed air duct **131** to the check valve **128**. The compressed air exiting the cylinder **126** and check valve **129** is routed to the high pressure air line **132**. Cooling fins **133** may be placed along line **132** or on cylinder **126** to cool the compressed air before
25 travelling to the spar buoy **101**. The high pressure air from

pump unit **105** is directed back to the stem through the lever arm. The air line between the moving parts of lever arm **104** and the pump units **103** and **105** are connected using flexible conduits, a rotating manifold, or other known methods. The
5 connection for the high pressure line **132** may terminate at the spar buoy flange **134**.

The spar buoy **101** can have a variety of geometries. It may consist of a single or several sections of pipes **135**. The cross sections of the pipes **135** may be round or rectangular or
10 other common shapes. The spar buoy **101** may be less buoyant than water or have approximately the same buoyancy. The main functions of the spar buoy **101** are to be a sealed storage vessel for compressed air and an inertial spar buoy that enable relative motion to floats **107**. Spar buoys may be of any
15 length, and long spar buoys also function as a conduit for transporting air to the depth of the submarine pipeline. Although shown as increasing with sea depth in **Fig. 1**, the diameters may be constant or decreasing with sea depth as well. The pipes **135** may have constant a constant taper or
20 incremental diameter change, similar to a telescope shape shown in **Fig. 1**. To minimize costs, the spar buoy **101** may be constructed from standard industrial pipes connected together with flanges **134**. Multiple pipes of the same diameter may also be placed in parallel orientation with an appropriate flange
25 to maintain fluidic connection. The flanges **134** may be

specially designed to allow for some motion between the pipes
135 to minimize stresses while maintaining fluidic connection.

A plurality of pipe sections may also be connected with flexible elements such as chains or cables and flexible hoses
5 to form the spar buoy **101**. Each pipe section may be neutrally buoyant individually and weighted to maintain a vertical orientation. Successive pipe sections are connected from the sea surface to the mooring chain or the main weight element nearest to the sea floor. Spars and ribs may be secured to the
10 inside of pipes **135** for additional structural strength. Other known strengthening elements such as beams and trusses may be secured to the exterior of the spar buoy **101** so that it can withstand turbulent sea conditions or ocean currents. At any part of flanges **134** and pipes **135**, check valves may be placed
15 in multiple locations such that one damaged or leaking pipe **135** do not render the entire spar buoy **101** inoperable.

The increasing diameters of the pipes **135** or the parallel arrangement of pipes have the two purposes: increasing the volume for air storage and slow the response of spar buoy **101**
20 to the wave. The increased diameter of pipes **135** increase the surface area resulting in increased drag force. A larger diameter of pipe **135** also increases the mass of the spar buoy **101**. The large drag force and inertia of the spar buoy **101** in comparison to the float **107** allows for relative motion between
25 them. The increased diameters of pipe **135** act similarly to a

heaving plate of other inventions while serving the additional function of air storage. The weights **108** may be attached to the deep submerged end of the spar buoy **101** to achieve neutral buoyancy, maintain the vertical orientation, and provide
5 stability to the spar buoy **101**. The weights **108** may be of any shape and size to enhance the function of the spar buoy **101**, or integrated to the shape, thickness and material composition of pipe **135**. The weights **108** may also be heavy columns attached in a parallel orientation around the spar buoy **101**.
10 The parallel arrangement of weights to the spar buoy **101** also increases the cross sectional and total surface area, acting in a similar manner of a heaving plate as well. The spar buoy length under water also acts as inertia to the torque generated by the float and the lever arm through the gears.

15 Another added advantage of an elongated spar buoy **101** is that if it experiences induced motion due to sea currents or other causes, the relative motion with the floats will generate energy as well. Any oscillatory motion of the spar buoy **101** floating in the sea would allow for energy harvest
20 even when there is insufficient wave energy. The spar buoy **101** may be also be designed to the need pump float **107** for its neutral buoyancy. Overall neutral buoyancy of the spar buoy **101** may be achieved merely by the volume of the spar buoy **101** or by using additional submerged buoys or auxiliary floats.
25 Auxiliary floats may be used to maintain the vertical

orientation and neutral buoyancy of the spar buoy **101**. Besides floats, the spar buoy **101** may be fitted with fins or flaps that maintain the orientation of the structures. Similar to a wing shape that provides net lift for airplanes, these fins or
5 flaps may be used to generate a net downward force on the spar buoy **101** as the float moves upwards due to an oncoming wave.

Although **Fig 1-A** only shows one extension arm and float, it is understood that multiple combinations of floats and lever arms may be connected to a single pump. The lever arms
10 and floats on each side of the spar buoy **101** illustrated in **Fig 1** drive separate gears and cylinders within a single air pump unit **103** to allow for independent motion of the two floats. Using the same principles described for the air pump unit **103**, additional pumps may be set up on the stem to
15 harness energy from the other axis of motion. For example, an additional pump may be placed on stem **102** to capture the rotational motion of pump **103** and arms **104** around the axis of the stem **102**.

The lever arm and float may also be designed to be
20 retracted off the water during severe storms. The lever arm may be designed with pin joints or other hinge connections to allow for folding the lever arm. Mechanisms that allow sliding motion of the lever arms may also be incorporated on the lever arm to allow for length change. The air compression may be
25 staged, where compressed air exiting a cylinder may be fed to

another cylinder for additional compression, and continued as needed. Alternately, high pressure air from one spar buoy **101** may be fed to the air pump of other spar buoys as compression stages. This is done to more efficiently generate higher
5 pressure compressed air than can be achieved with a single compression stage alone. Further, the piston and cylinder compression may be performed by a double acting cylinder. The linear motion generated by the piston can be converted using known linkages to drive the linear motion of the double acting
10 cylinder from the crankshaft. Other known mechanisms to convert the rotary motion at the crankshaft to linear motion may be employed to act on the double acting cylinder.

The multiple spar buoy **101** geometries described in this embodiment are illustrated in the drawings of the following
15 embodiments. In the following embodiments, unless specified, the same mooring method and submarine pipeline are employed. Generation of electrical energy may be performed at sea to eliminate the need for pipelines. Compressed air may be combined from multiple buoys to one turbine. Turbines and
20 generators may be placed in each spar buoy or housed in a special spar buoy, on a platform, an island, or a modified sea vessel. Placement of the electrical energy generation in modified sea vessels may allow for these more expensive components to be transported to safety during severe weather.

Electrical energy may be returned to shore using submarine cables.

In a second embodiment, the features and the function of the spar buoy **201** and stem **202** are the same as the first embodiment and may take any one of said geometries. **Fig 2** illustrates an alternate diameter arrangement of the spar buoy **201** where the diameters of the spar buoy pipe **203** incrementally decrease with depth. The weights, mooring, and connection to submarine pipeline are the same as described in the first embodiment. The stem **202** extends out of the water surface, where the pump unit **204** is attached near the top. In this embodiment, the motion of the floats is connected to the pump through a rack and pinion gearing. The pump unit **204** in the second embodiment has many similar components to the first embodiment. The piston rod **205**, compression cylinder **206**, and piston **207** for air compression are driven by the motion of the pinion gear **208**. The rack gearing is attached or part of the float column **209** which is connected to the float **210**. The check valves **211** and **212** are represented symbolically, illustrating the function that air flow direction during the compression cycle, as described in the first embodiment. For diagram clarity the air filter or cooling fins are not shown in **Fig 2**. As in the first embodiment, the high pressure air line **213** travels back to the stem for storage in spar buoy **201**.

The primary difference of the second embodiment with the first is that large drive gear in the first embodiment is replaced by the float column **209** with rack gearing that engage the pinion gear **208**. The motion of the float drives the rack to rotate the pinion gears **208** and crankshaft **214** to drive the piston pump. The rack motion is held with rollers **215** to maintain engagement of the pinion and rack gearing. Two piston pumps per pump unit **204** are shown in **Fig 2**, but any number and arrangement of piston pumps may be used. For example, racks may have gear tooth opposite sides, and cylinders may be placed on each side of the rack, and multiple pinion gears may be placed on a single rack. The entire rack and float is allowed to travel the range of the rack gearing. Springs may be attached near the ends of the float column **209** to prevent collision of the float to the pump unit **204**.

Wave energy harvest is enhanced by the use of a pin joint at **216**. This allows the pump unit **204** and float **210** to rotate as a unit relative to the stem **202** in response to wave motion. As the net force of the surface wave is constantly changing direction, allowing the float and pump to turn to the direction of the maximum force transmitted maximizes the energy harvested. Pin joint **216** also allows for the lateral motion of float to generate energy. The amount of rotation allowed may be limited to protect the float from colliding with the stem or any excessive movements. As in the first

embodiment, the float may be of any shape and size. The float may feature underwater fins to capture energy from currents which result in lateral motion of the floats. Flexible hoses, conduits or rotating manifolds may be used to connect high
5 pressure air generated in the pump to the stem.

In a third embodiment, the features and the function of the spar buoy **301** and stem **302** are the same as the first embodiment and may take any one of said geometries. **Fig 3** illustrates a tapering spar buoy **301** such that the diameter of
10 spar buoy pipe **303** decreases with water depth. Such a design may slow the spar buoy **301** movement in the upward direction and ease the downward motion. The reverse effect may be achieved by decreasing the diameter with depth. Near the sea surface, **Fig 3** shows the stem **302** is secured with submerged
15 buoys **305**, an optional feature of the spar buoy **301** as described in the first embodiment to maintain neutral buoyancy and vertical orientation. Pump units **306** are connected to the top of the stem through a pin joint connection **307**. The motion of the float **308** acts to push a float column **309** that drives
20 the air pump unit **306**, similar to the second embodiment. Where the second embodiment uses a rack and pinion gearing to convert the linear float motion to a rotary motion, the third embodiment uses a cable and pulley system.

The float column **309** has a cable connector **310** to attach
25 a cable **311**. Cable **311** loops around two pulleys **312** at the top

and bottom of the pump unit **306**, as shown in **Fig 3**. The pulley is secured and rotates with crankshaft **313**, which in turn is connected to the piston pump assembly **314**, consisting of the rod, piston, cylinder and check valves. The function of pump

5 **314** is as described in the first embodiment, generating compressed air due to the rotation of crankshaft **313**. The cable connection is in sufficient tension such that the movement of the float column **309** due to the float causes the cable to move in unison, and rotating the pulleys. The

10 rotation of the pulleys results in air compression at the piston pumps. As in the first embodiment, the direction of the pulley rotation is irrelevant, and with appropriate sizing of the pulley **312**, small linear vertical motions of the float is converted to full rotations of the pulley. The rotation of

15 pulley **312** may also be geared so that one rotation of the pulley results in multiple rotations of the crankshaft **313** driving the pump **314**.

Cable **311** and pulley **312** may be replaced with a chain and sprocket to achieve the similar effect. Another alternative to

20 the cable and pulley may be flexible belts with gearing teeth on the inner side of the belt that engage the pulley, similar to timing belts. The float column **309** in this embodiment may be configured to be shorter than the second embodiment while protecting the gearing elements from the exterior weather

25 elements. Similar to the second embodiment, rollers **315** are

used in the pump unit **306** to allow for smooth travel of the float column **309**.

In a fourth embodiment, the function of spar buoy **401** and stem **402** is as described in the first embodiment, and may take
5 any of the possible said geometries. **Fig 4** illustrates an overview of the design utilizing an alternate arrangement as described in the first embodiment where multiple spar buoy pipes **403** are placed in a parallel arrangement in between flanges **404**. Near the sea floor, weighted columns **405** may be
10 used in place of the pipes. In addition to being weights for stability and vertical orientation as described in the first embodiment, these weighted columns **405** may provide structural strength to the entire spar buoy **401**.

Fig 4-A shows the side view of section **B-B** of **Fig 4**. In
15 the embodiment shown, a beam extending vertically from the spar buoy **401** is attached to the middle of a horizontal beam **406**. Two vertical stems **402** extend from the ends of the horizontal beam. Pump units **407** are attached at the top of each stem **402**. The pump unit **407** utilizes the same components
20 and operates in the same principle as in the first embodiment, which is to generate compressed air through the rotation of the drive gear. The placement and orientation of the drive and pinion gears and the air compression cylinder are modified from the first embodiment to suit this application. The shaft
25 from the drive gear extends out from the pump unit **407** is

rigidly connected to the axis of float **408**. Weights **409** are secured at the corners of the float **408**. The float wall **410** is made to have sufficient strength and rigidity to support the weights **409** and allow for rotational motion of the whole float
5 **408**, as shown in **Fig 4**.

Although **Fig 4-A** shows two pump units **407**, one attached to each end of the float axis **411**, only one pump **407** for each axis **411** may be employed. Wave motion causes the float **408** to rotate on axis **411** relative to the stem **402**. This rotation
10 generates the rotation at the pinion gear and the piston shaft resulting in compressed air generation at the pump **407**. Similar to the first embodiment, due to the gearing ratio between the drive gear and the pinion gear, small motion of the float will result in multiple rotations of the air
15 compression cylinder. The float motion may be a small swaying motion like a pendulum or larger rotations which generates even more rotation of the pinion gear and therefore more compression cycles. As in the first embodiment, the direction of rotation is irrelevant to the generation of compressed air.

20 Floats may have several embodiments and stability features. Water vessels such as boats and ships are designed to stay afloat and remain stable. Stability ensures that if a boat is suddenly rolled or tilted in one direction, the boat will naturally generate a restoring force to return to its
25 original orientation, as opposed to continue tilting over

until it capsizes. This is done with a combination of the hull shape and weight distribution of vessel, such that the center of gravity of the boat is below the center of lift due to buoyancy. When the center of gravity is above the center of lift, such a vessel is considered unstable. In vessels with higher center of gravities than center of buoyancy, a sudden tilt in one direction will generate additional moment or tilting force in the direction of tilt and cause the vessel to continue to tilt even further.

While this instability is undesirable for water vessels, it may be desirable for the float in this application to have a high center of gravity than a center of buoyancy so that the float rotates easily. The rotation of the float turns the drive shaft and generates compressed air. It may be possible to design the floats to be easily rotated at wave heights that are most common at the site where the point absorber is placed. **Fig 4** shows the cross section of float is shown to be triangular in shape with straight walls and weight elements **409** attached in the corners. However, the float wall **410** may be round, elliptical, or have a multiple combination of curves, similar to the shape of the hull of a ship. Any combination of shape and weight distribution may be used such that the float is easily rotated. Wave motion causes the float rotation around the axis, and the instability may amplify the rotation.

Many float shapes are possible. Other applicable float shapes with weight combinations are shown in **Fig 4-B**. Symbols **421**, **422**, and **423** represent the axis of rotation of the float, the center of gravity, and center of buoyancy respectively for each float shape illustrated. Weight elements **424**, of any shape and size are placed at specific locations on the respective float shapes to create the instability condition. Similar to the triangular float in **Fig 4**, a three cornered float **425** with curved walls is shown in **Fig 4-B** as a guide for the other float shapes illustrated. **Fig 4-B** shows the rectangular **426**, trapezoidal **427**, pentagonal **428**, or hexagonal **429** shaped floats. A triangular-weighted hexagonal float **430** is similar to float **425** from a weight distribution, but has a different float shape. It can be seen from floats **425** and **430** that many other float shapes, for example pentagonal or circular shapes may be used with this triangular weight distribution. The center of gravity may be above, below, or coincide with the axis of rotation. The axis of rotation may or may not be located on the geometrical center of the float shape. The center of buoyancy is dependent on the shape and orientation of the float. It may also be possible to have non symmetrical float shapes such as the parallelogram shaped float **431**.

The stability of a given float design may favor just one orientation. In the float embodiments **426** and **427**, placements

of more weights or heavier elements at the bottom of the float, will cause the float to normally stay in that orientation. If the size of the perturbing wave is sufficiently large, the float may rotate 180 degrees to be
5 inverted topside down, but a smaller wave would easily push the float back to the preferred orientation. The nature of the float motion may also interact with the spar buoy **401** such that the float motion induces the spar buoy motion. For example, the float may tilt over, generating additional
10 buoyancy such that there is a net lifting of the spar buoy **401**. As the spar buoy **401** rises, the tilted float may revert back to its preferred orientation. As long as the motion induces rotation of the float, energy is captured.

The weight elements may be placed inside or outside the
15 float. The weight may be rigidly connected to the float at a distance away. For ease of transport and installation, weight elements on the float could be containers that are filled with water and sealed during deployment. For strength considerations, the float can be strengthened with internal
20 ribs or spars and other known structural strengthening methods, which may also act as weighting elements.

In a fifth embodiment, shown in **Fig 5**, the lever arm in the first embodiment and the rotating float in the fourth embodiment are combined. The spar buoy **501** and stem **502** may
25 take any form described in the first embodiment. Pump unit **503**

is placed on the top of stem **502** and lever arm **504** is connected to the drive gear of pump **503**. Pump unit **505** is rigidly connected to the other end of arm **504**, as described in the first embodiment, but in the fifth embodiment, the rotating float of the fourth embodiment is employed to drive pump **505**. The axis of rotating float **506** is secured to the drive shaft of pump **505**. The principle of operation of pumps **503** and **505** are as described in the first embodiment. A pump **505** for each side of the float axis may be used as shown in **Fig 4-A**, or only one pump may be needed for the axis.

Fig 5 illustrates the spar buoy **501** geometry comprising of multiple individual pipe sections **507** connected together. A flexible hose **508** or conduit maintains the fluidic connection of the compressed air between each pipe **507** but a shorter chain **509** is used to connect and maintain the maximum distance between two sections **507**. The chains provide tensile strength when two sections **507** are being pulled apart by the waves or ocean current. Each section **507** may have weights **510** attached to facilitate a vertical orientation in the water, as shown in **Fig 5**. Alternatively, only the section nearest to the sea floor may be secured with weights to maintain a vertical orientation for the whole chain of pipe sections. For the section nearest the sea floor, the anchoring methods remain the same as the first embodiment.

Wave displacements cause both the movement of the arm **504** as well as rotation of the float **506**. Small waves may only have negligible motion of arm **504** but cause float **506** to sway like a pendulum and generating compressed air from pump **505**.

5 In response to a larger wave, float **506** acts to lift arm **504** for compressed air generation at pump unit **503** as well as the rotation at float **506** to drive pump unit **505**. Pumps **503** and **505** as well as the floats **506** may be different have different sizes to optimize the wave energy harvest. In the example

10 mentioned above, pump **503** may be a bigger capacity pump since it responds to larger waves.

Any of the many embodiments described in the first and fourth embodiment may be combined. In the first embodiment shown in **Fig 1-A**, weights may be placed at the top of lever

15 arm **106**, or at the end of an extended lever arm **106** beyond the pump unit **105** such that the weight look like an inverted pendulum. Similar to the first embodiment, additional pumps may be used to capture the motions in the other axis of motion. For example, a pump may be placed on stem **502** to

20 capture the rotational motion of pump **503** and arms **504** around the axis of the stem **502**.

In a sixth embodiment, the vertical orientation of the spar buoy may be horizontal or angled relative to the surface of the sea, and may be combined with the vertical orientation.

25 **Fig 6** shows a horizontal spar buoy **601** which is connected to

multiple vertical spar buoys **602** and stems **603**. The function of the spar buoy **601** remains the same, providing a large inertial mass as well as storage for the compressed air. The vertical spar buoys **602** of **Fig 6** need not be included, so that
5 the horizontal spar buoy **601** is directly connected to stems **603**. Multiple stems **603** may be connected to a single spar buoy **601** in a horizontal orientation, and multiple horizontal spar buoys may be combined to form a network of stems **603** and bodies **601**.

10 The float and pump unit **604** combination may be any of the embodiments described above. As in the first embodiment, weights **605** may be attached to the bottom of the spar buoy **601** to maintain the buoyant stability. Auxiliary floats may be used to support the orientation of the horizontal spar buoy
15 **601** such that stems **603** extend vertically from the spar buoy to protrude the water surface. Long flexible conduits may be used to connect the bodies **601** to a submarine pipeline **112** if used or have one long vertical spar buoy that extends to the sea depth of the submarine pipeline. A similar mooring
20 mechanism to the first embodiment is also used.

The embodiments presented here allow for the low cost of the point absorbers placed in the sea compared to other wave energy generation methods. The spar buoy method facilitates the wave harvest mechanisms at lower cost compared to those
25 with permanent structures. The generated energy in the form of

compressed air allows for the energy to be stored. Since wave energy is inconsistent and unpredictable, the embodiments can harvest wave energy from a wide range of conditions and allow consumption at a constant rate. In these embodiments, the amount of wave energy harvested is proportional to the wave amplitude. The compressed air is used to power turbines or other known methods to generate electrical energy or to perform other useful work the turbines or other components used can be commercially available units that are more efficient and cost effective and may be placed at sea, on land, or on a sea vessel. The storage and transport of compressed air also do not pose environmental hazards if a spar buoy or pipeline is damaged or leaking. Additionally when the power grid has excess supply, on shore pumps may generate compressed air to be stored in the spar buoy, acting as an energy storage model for the power grid.

In the description above, at least one embodiment of the wave energy conversion device will provide a reliable, economical, and environmentally friendly method of harnessing wave energy. While the above description contains much specificity, these should not be construed as limitations on the scope, but rather as exemplifications of several preferred embodiment thereof. Many other variations are possible. For example, multiple pump unit embodiments and mechanisms may be combined with any of the spar buoy geometry embodiments

described. While air is described here as the compressed media, alternate compressible fluids may be used. In those cases, a closed loop may be needed to return the expanded, low pressure, fluid from shore with another pipeline. Furthermore,
5 even though the mechanism is described here for used at sea, the invention works in all bodies of water with waves.

While a presently preferred and various alternative embodiments of the present invention have been described in sufficient detail above to enable a person skilled in the
10 relevant art to make and use the same it should be obvious that various other adaptations and modifications can be envisioned by those persons skilled in such art without departing from either the spirit of the invention or the scope of the appended claims.

15

CLAIMS

What is claimed is:

1. An apparatus for harvesting wave energy by
5 compressing a fluid comprising:

a plurality of sealed hollow vessels coupled to a spar
buoy for storing a compressed fluid,

at least one piston pump,

at least one unidirectional valve,
10 a plurality of floats for harnessing wave energy,

a means for converting the relative motion of said
plurality of floats and said spar buoy to a reciprocal
linear motion of said piston pump by means of at least one
gear.

15 2. The apparatus of claim 1, wherein said at least one
piston pump comprises at least two pistons.

3. The apparatus of claim 1, wherein said spar buoy is
weighted to achieve a preferred orientation in the water.

4. The apparatus of claim 1, wherein said spar buoy is
20 weighted to achieve a neutral buoyancy.

5. The apparatus of claim 1, wherein said means for converting the relative motion of said plurality of floats and said spar buoy comprises a lever arm connected to said plurality of floats such that the motion of said lever arm
5 causes a rotational motion of a shaft, wherein said shaft is mechanically coupled to said at least one gear,

wherein said at least one gear is mechanically coupled to said at least one piston pump, resulting in reciprocal linear motion of at least one piston of said at least one piston pump
10 for compressing fluid.

6. The apparatus of claim 1, wherein said means for converting the relative motion of said plurality of floats and said spar buoy comprises,
15 a rack and pinion gearing.

7. The apparatus of claim 1, wherein said means for converting the relative motion of said plurality of floats and said spar buoy comprises,

a pulley and cable arrangement, wherein linear motion of
20 said plurality of floats moves a cable causing a rotation of a pulley, and the rotation of said pulley is coupled to said piston pump resulting in the compression of said fluid.

8. The apparatus of claim 1, wherein said fluid comprises nitrogen.

9. The apparatus of claim 1, wherein said fluid is air.

10. The apparatus of claim 1, wherein said fluid comprises
5 a gas.

11. The apparatus of claim 1, wherein said means for converting the relative motion of said plurality of floats and said spar buoy to a reciprocal linear motion of said piston pump by means of at least one gear, comprises an elongated
10 member connected to said plurality of floats.

12. The apparatus of claim 1, wherein the multiple pistons are arranged at different phase angles along crankshaft.

13. An apparatus for harvesting wave energy by compressing a gas comprising:

15 a plurality of sealed hollow vessels coupled to a spar buoy for storing a compressed gas,

at least one piston pump,

at least one unidirectional valve,

a plurality of floats for harnessing wave energy,

a means for converting the relative motion of said plurality of floats and said spar buoy to a reciprocal linear motion of said piston pump by means of at least one gear.

14. The apparatus of claim 13, wherein said means for
5 converting the relative motion of said plurality of floats and said spar buoy comprises a lever arm connected to said plurality of floats such that the motion of said lever arm causes a rotational motion of a shaft, wherein said shaft is mechanically coupled to said at least one gear,

10 wherein said at least one gear is mechanically coupled to said at least one piston pump, resulting in reciprocal linear motion of at least one piston of said at least one piston pump for compressing fluid.

15 15. The apparatus of claim 14, further comprising a means for transferring a compressed gas from said plurality of sealed hollow vessels to an electricity generating turbine,

wherein said electricity generating turbine uses said compressed gas to produce electricity.

16. The apparatus of claim 13, wherein said spar buoy is
20 tampered along a vertical axis.

17. The apparatus of claim 13, wherein said spar buoy comprises a plurality of spar buoy pipes oriented substantially parallel to each other.

18. The apparatus of claim 6, further comprising a pin joint.

19. The apparatus of claim 7, further comprising a pin joint.

1/10

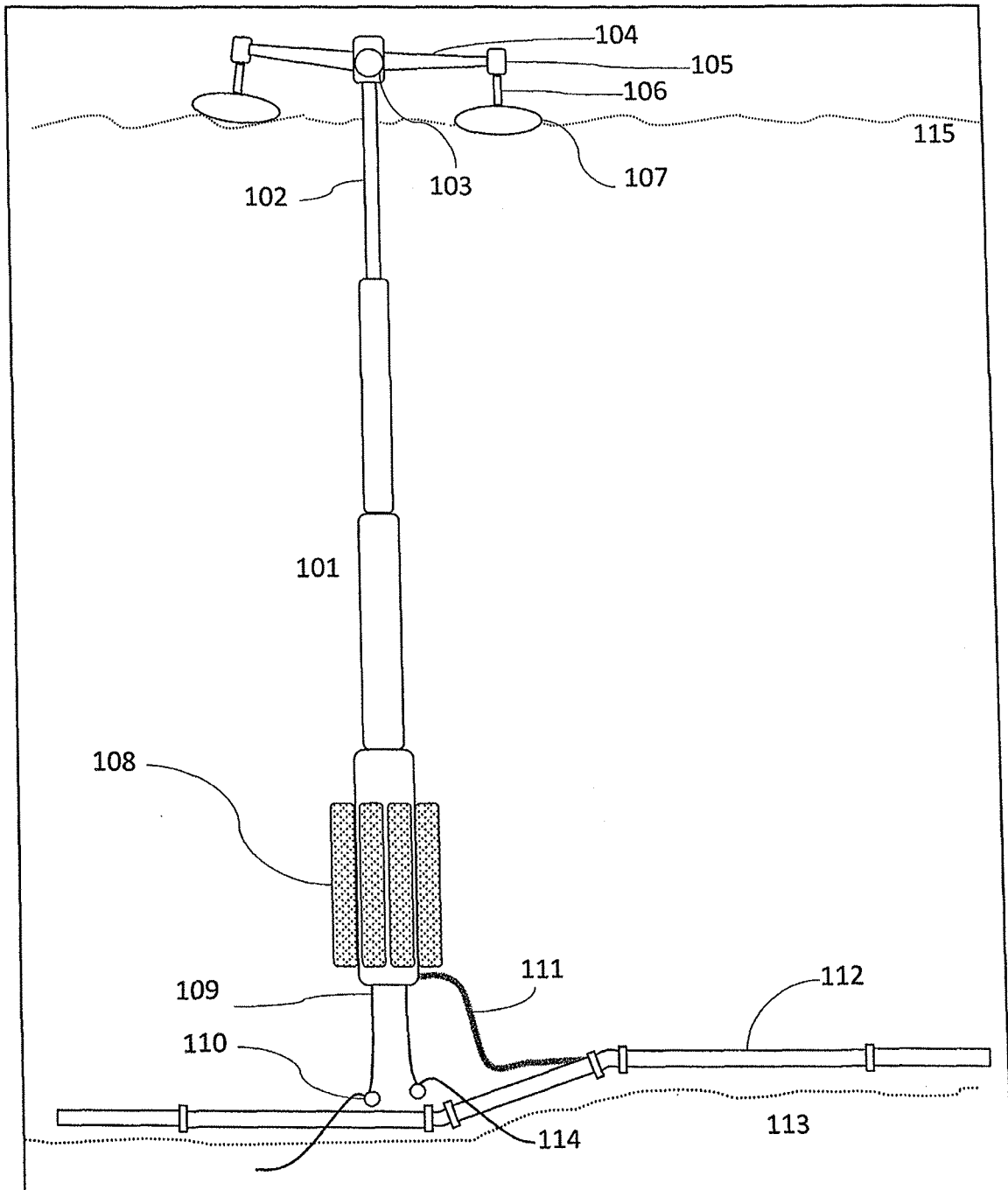


FIG. 1

2/10

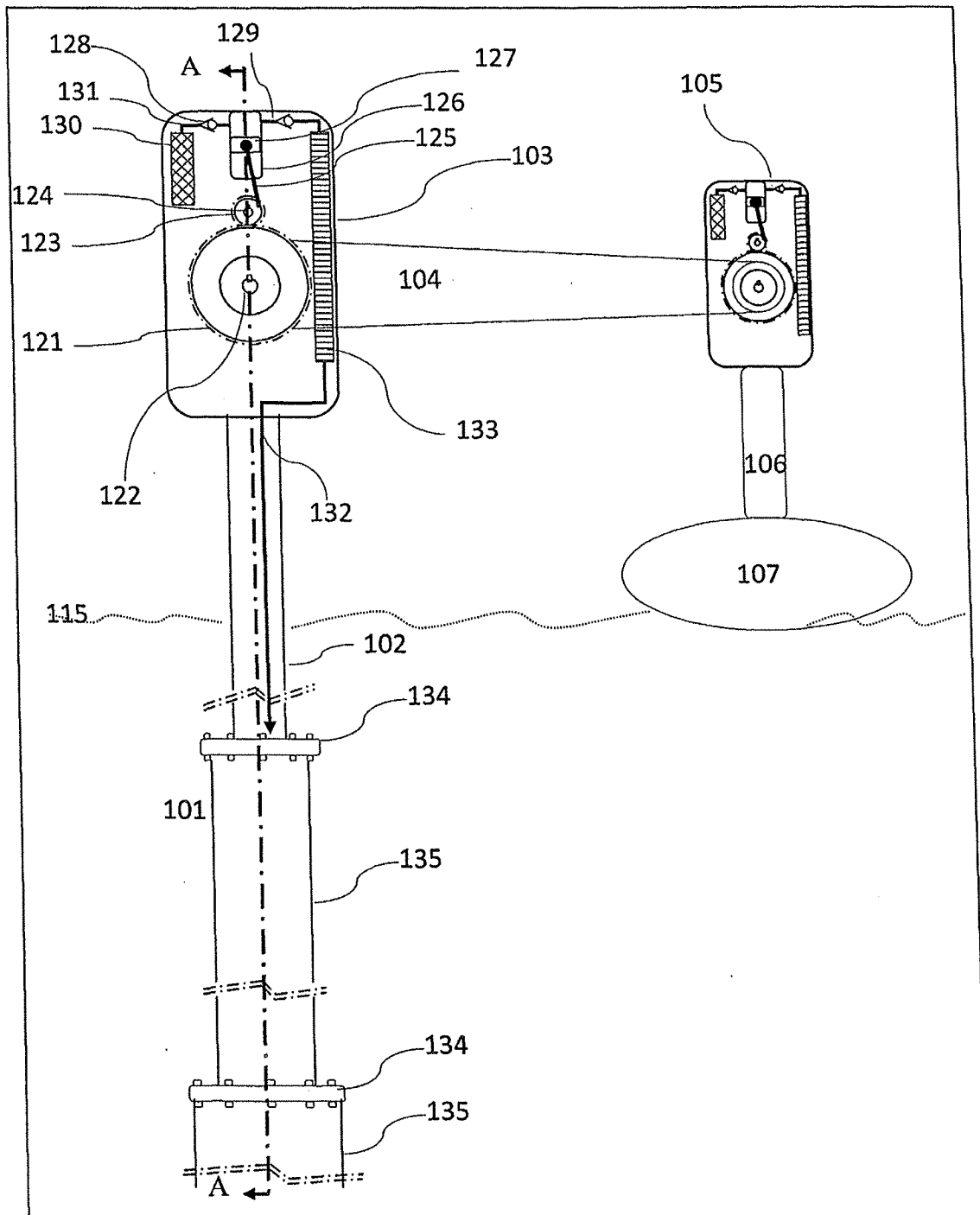


FIG. 1-A

3/10

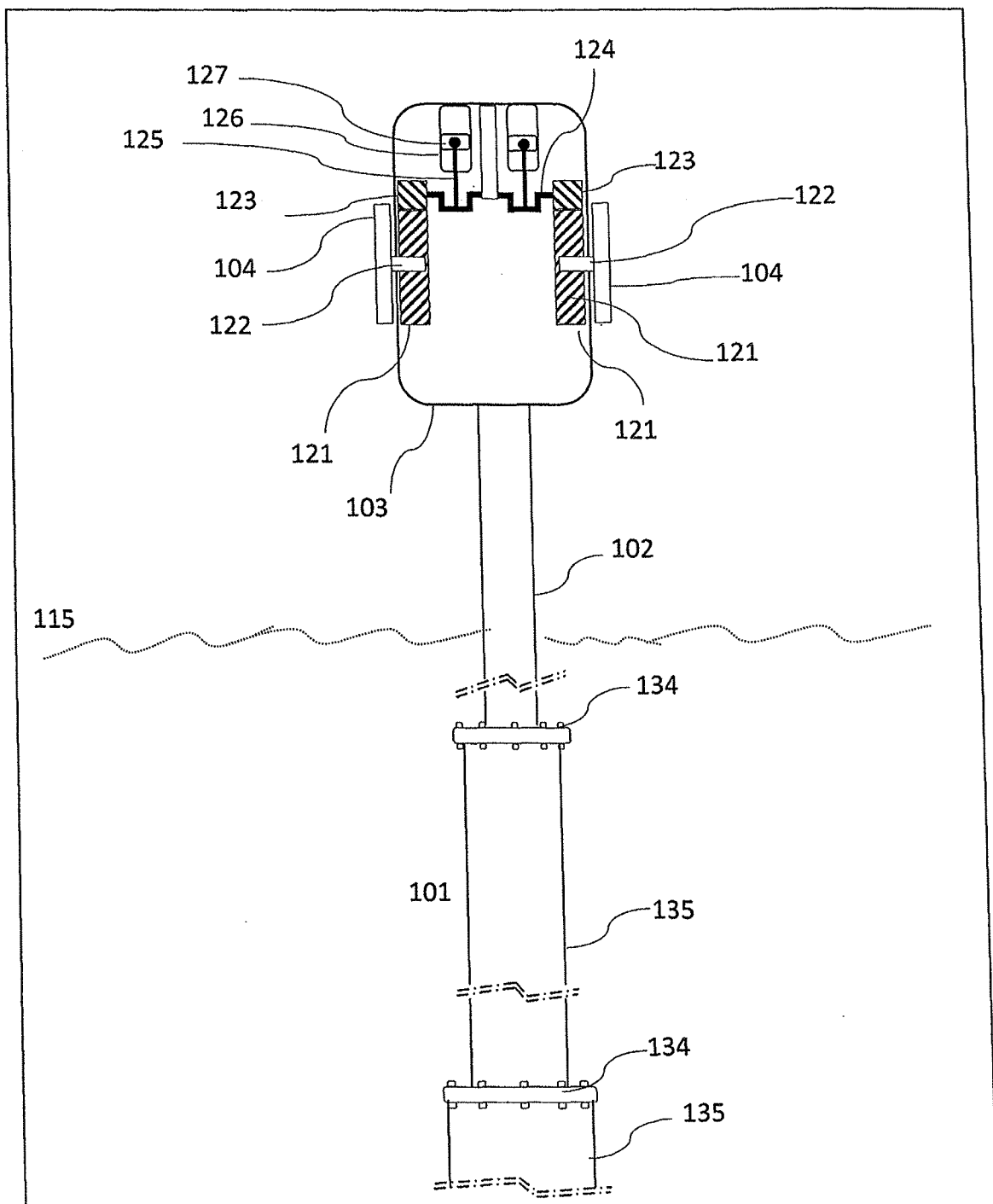


FIG. 1-B

4/10

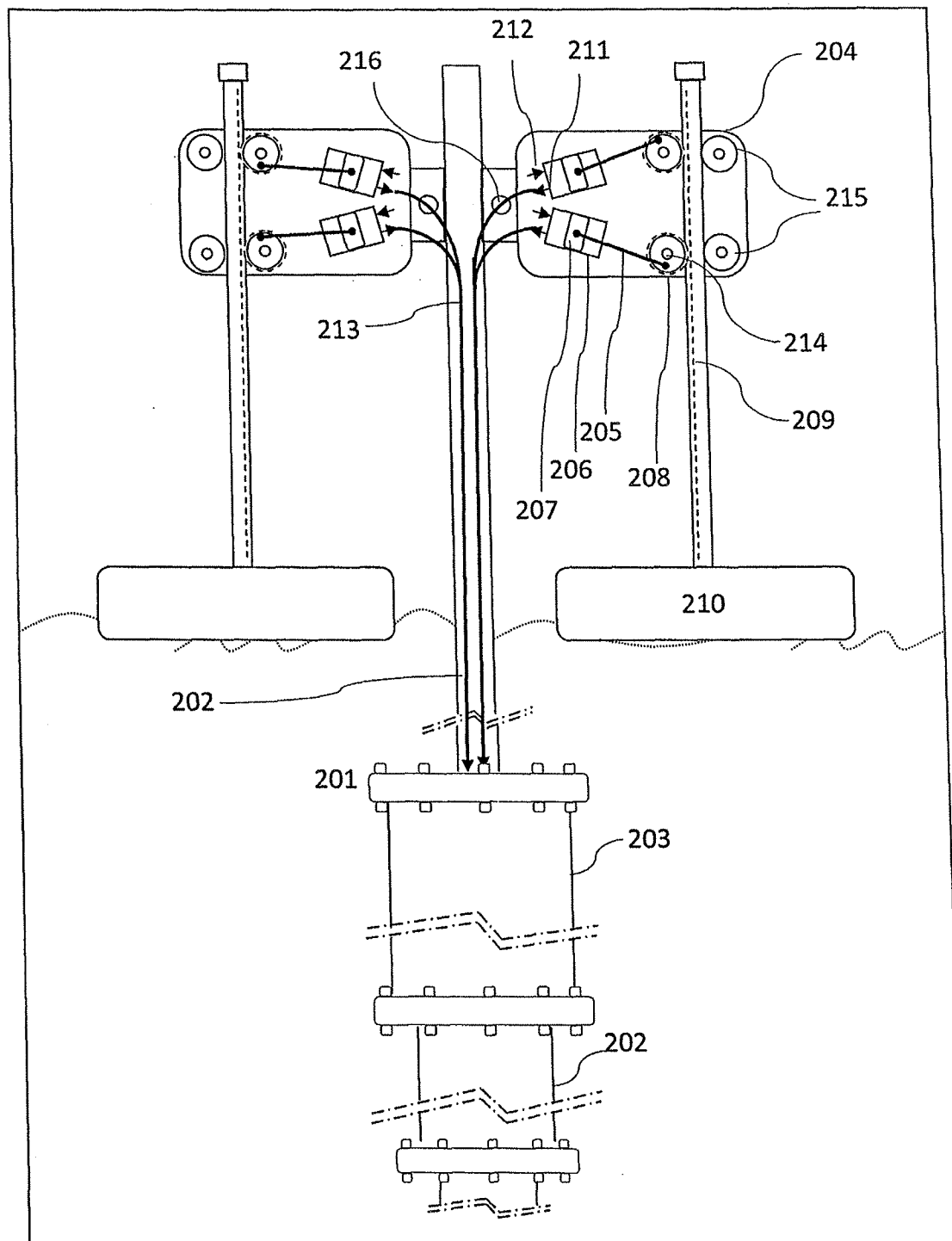


FIG. 2

5/10

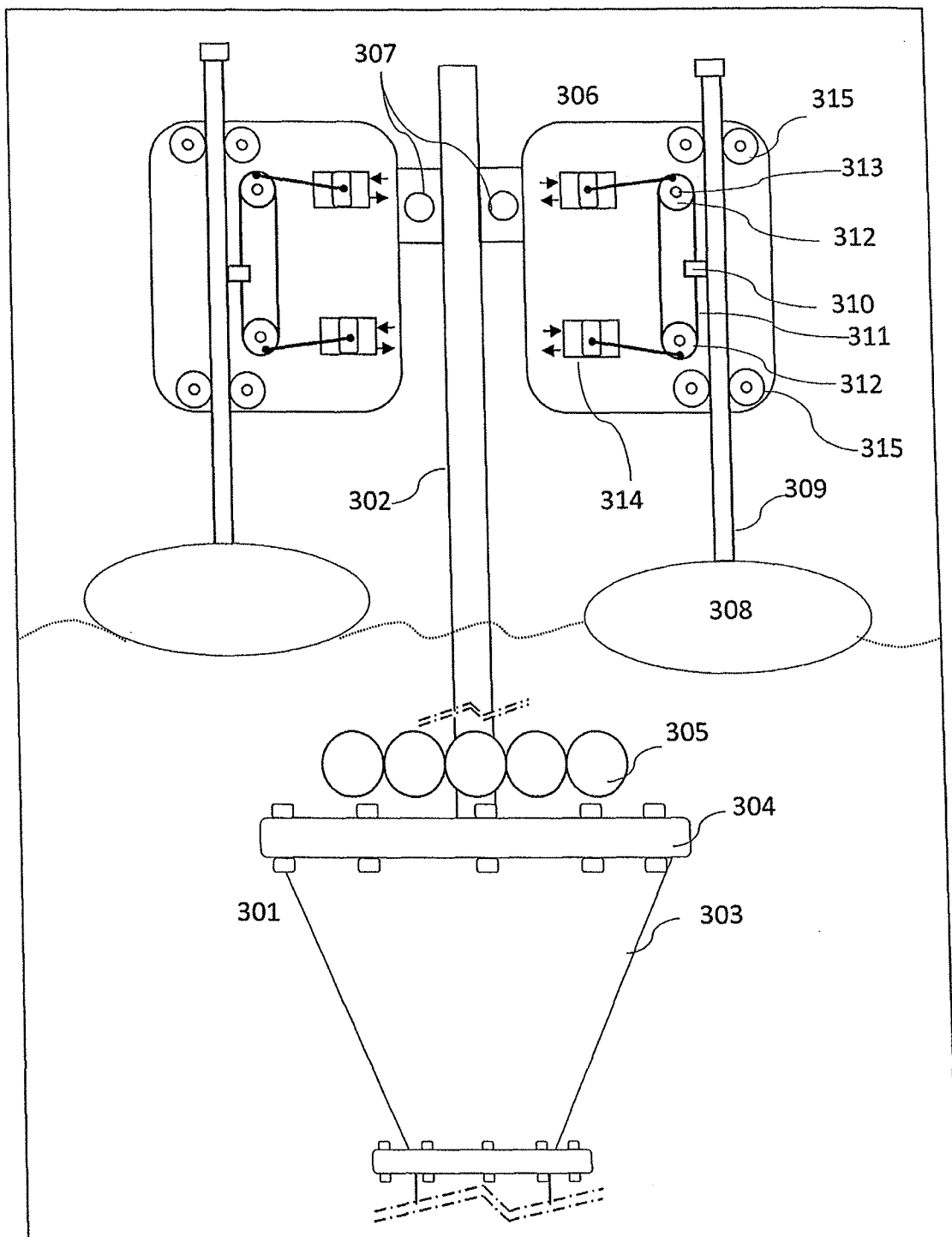


FIG. 3

6/10

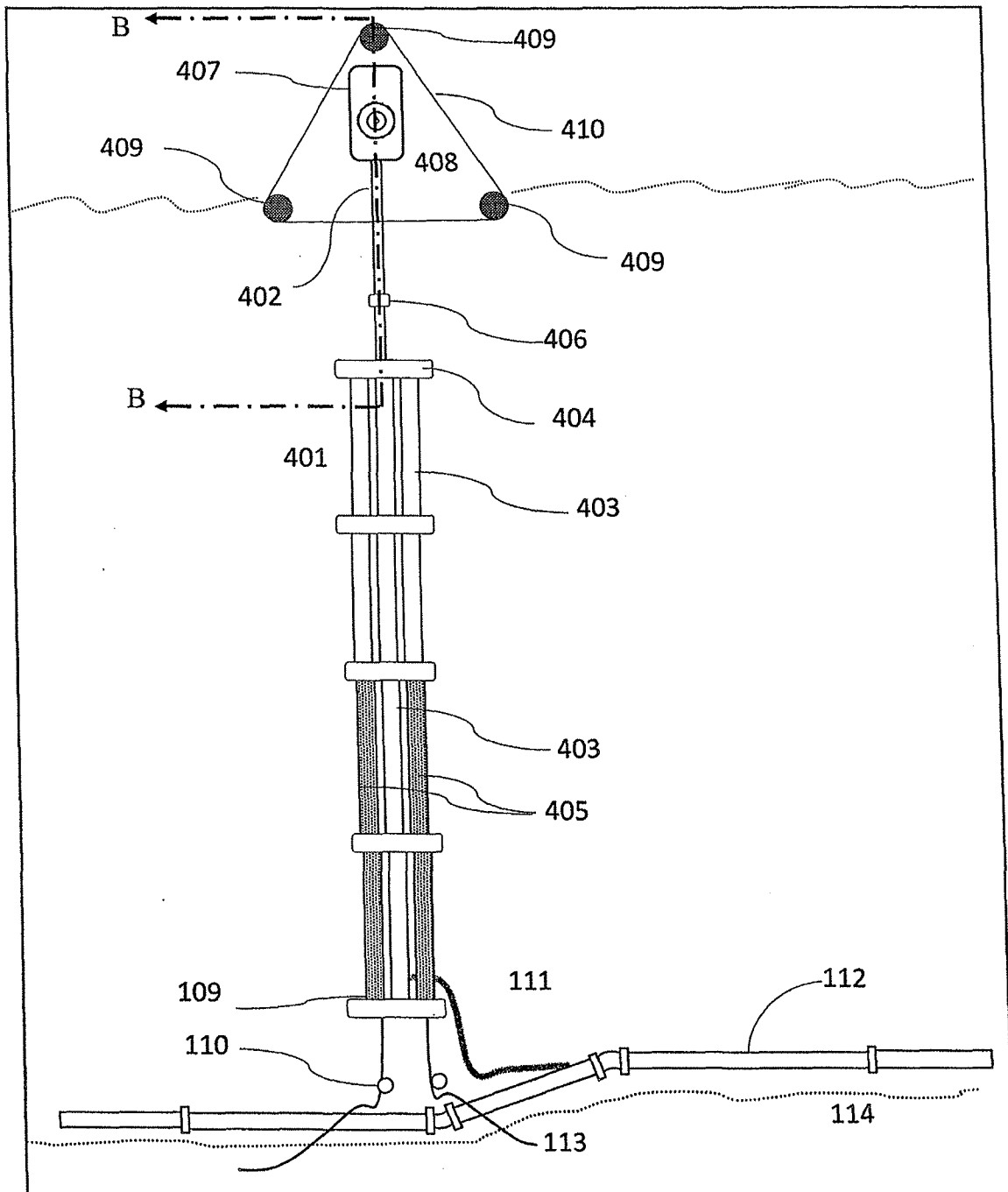


FIG. 4

7/10

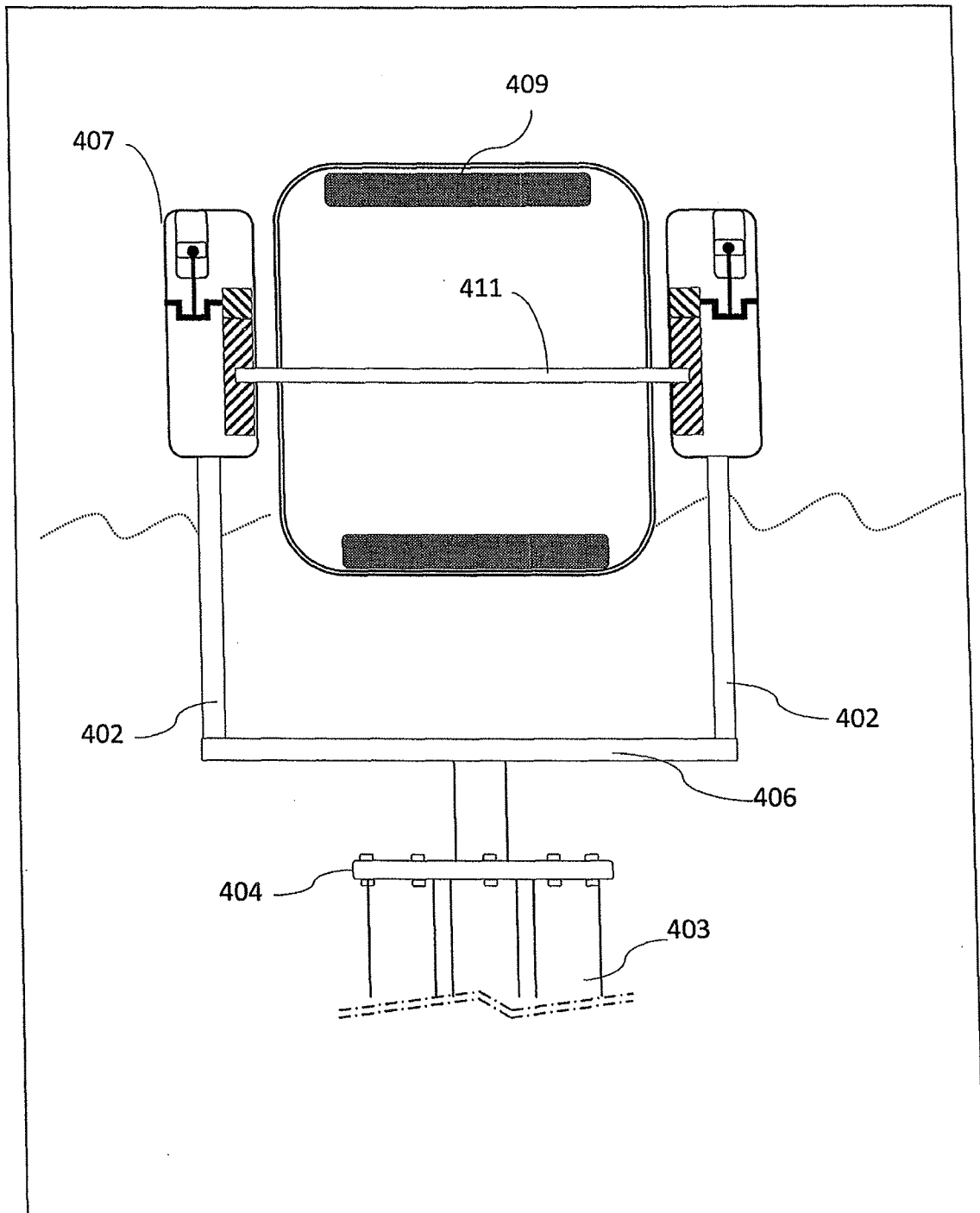


FIG. 4-A

8/10

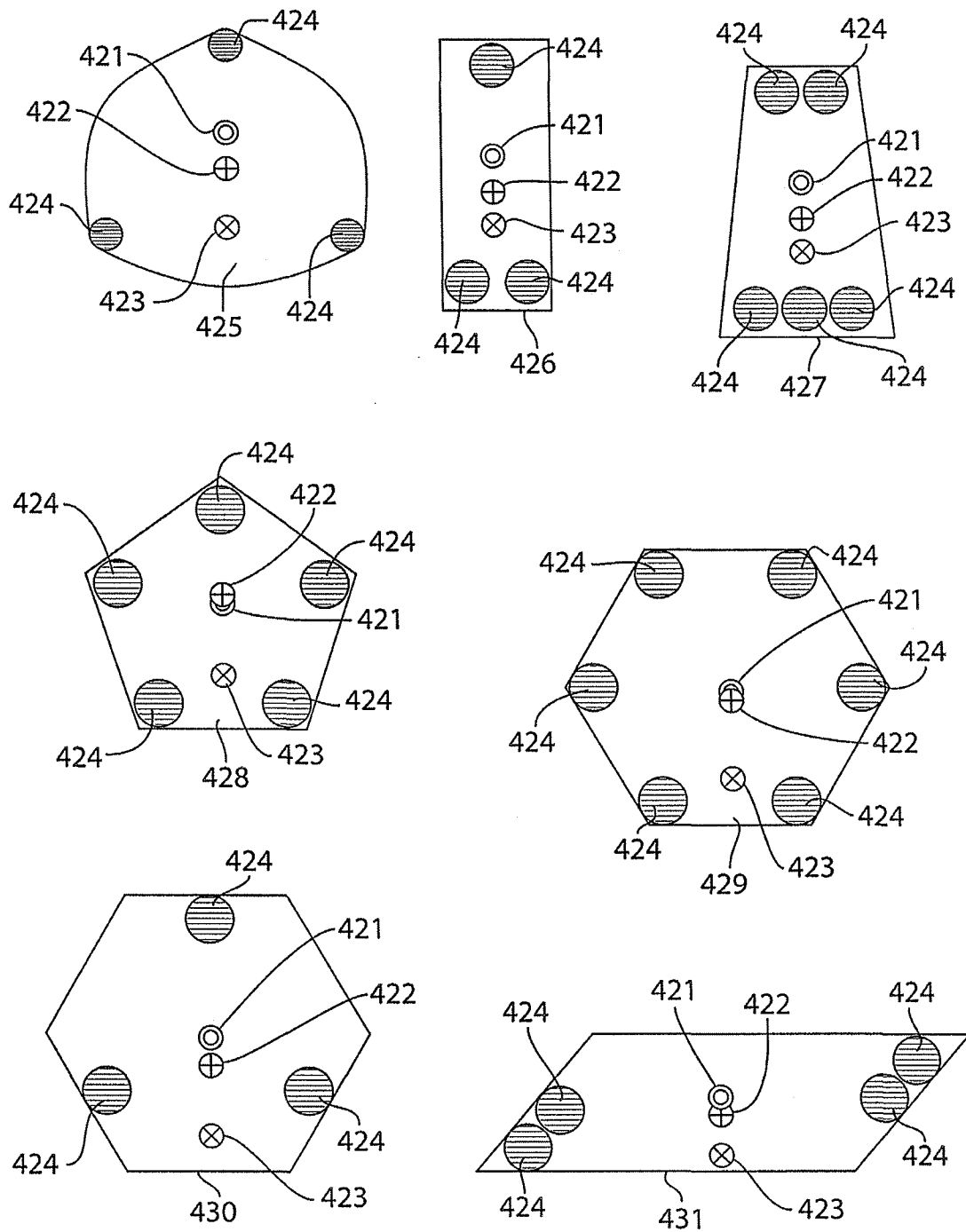


FIG. 4B

9/10

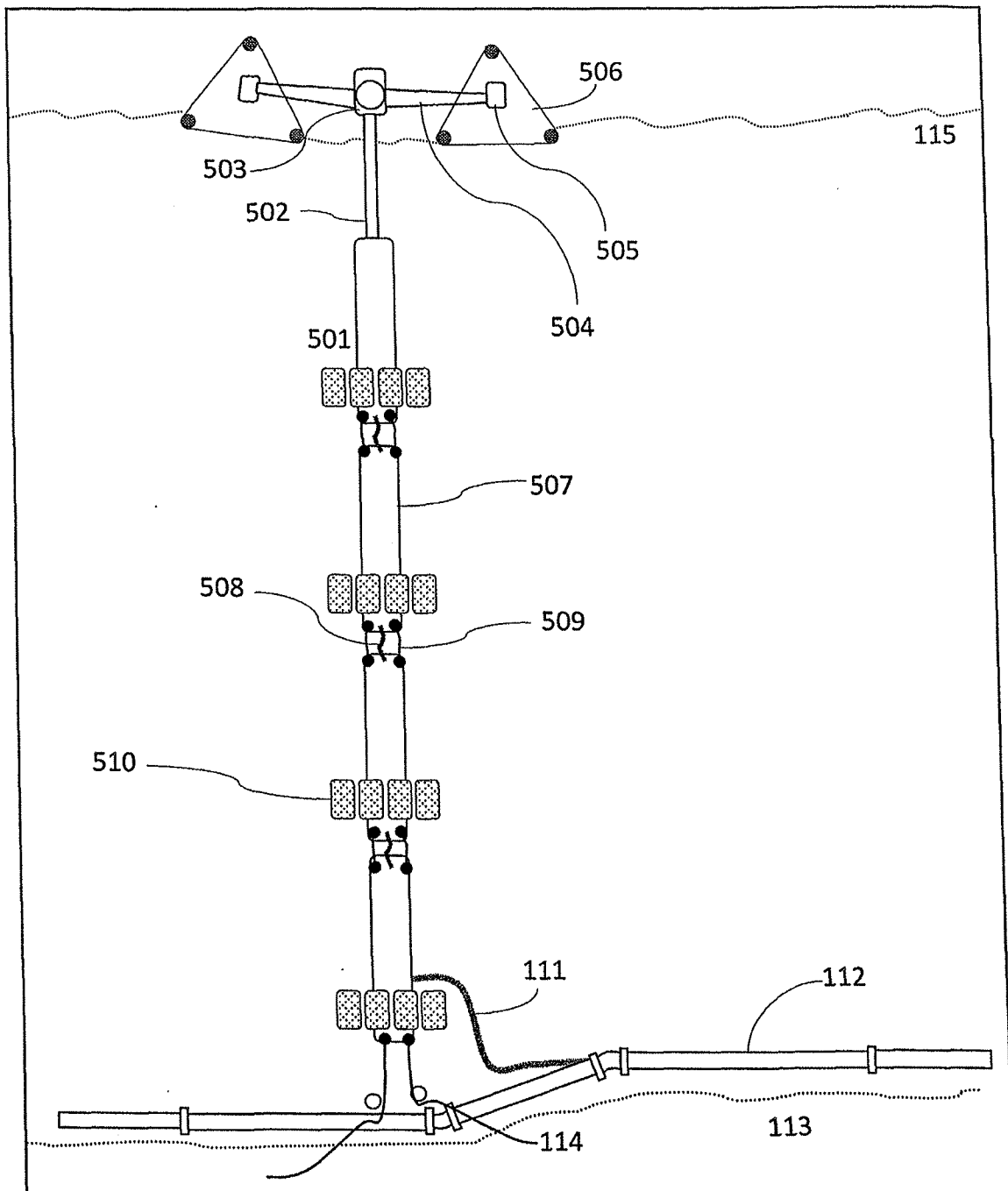


FIG. 5

10/10

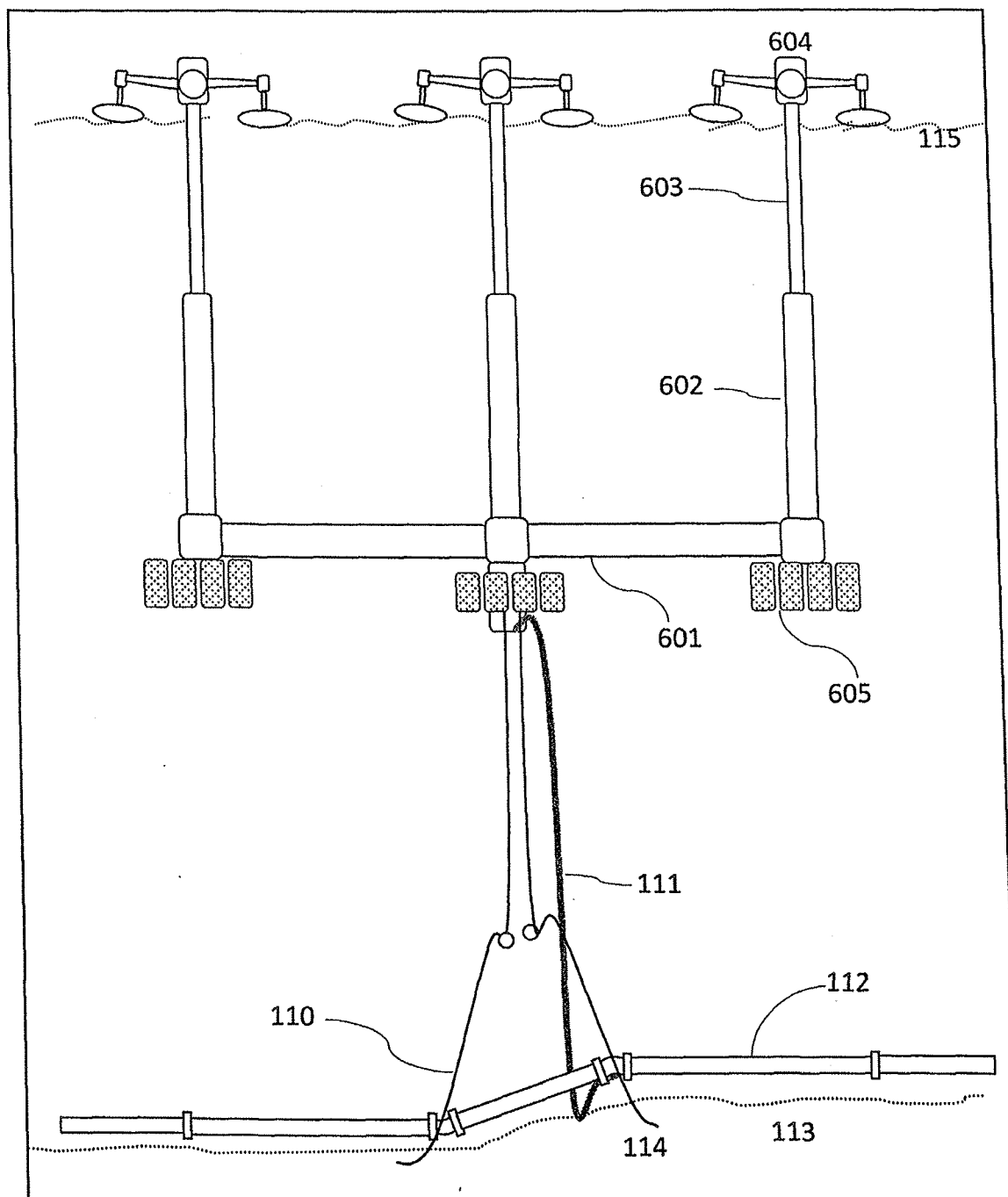


FIG. 6