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Innovation, Science and
Economic Development Canada
Canadian Intellectual Property Office

CA 3047760 A1 2020/12/25

(21) 3 047 760

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) **A1**

(22) **Date de dépôt/Filing Date:** 2019/06/25

(41) **Mise à la disp. pub./Open to Public Insp.:** 2020/12/25

(51) **Cl.Int./Int.Cl.** *F03B 13/20* (2006.01), *F03G 3/06* (2006.01), *F03G 7/08* (2006.01)

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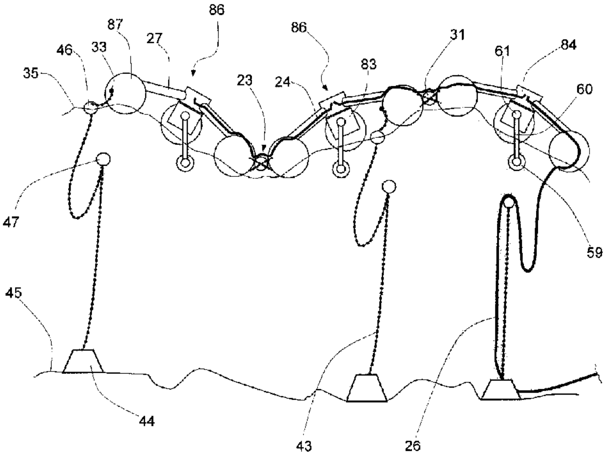
(54) **Titre :** SYSTEME DE COLLECTEURS UTILISANT L`ENERGIE HOULOMOTRICE ETROITEMENT INTERCONNECTES COMPRENANT DES PRISES DE FORCE AUTO-ORIENTEES

(54) **Title:** A SYSTEM OF CLOSELY INTERCONNECTED WAVE ENERGY COLLECTORS COMPRISING OF SELF-ORIENTING POWER TAKE-OFFS



(57) **Abrégé/Abstract:**

A wave energy harnessing system comprising of a plurality of wave energy devices coupled together, to form high capacity installation. The wave energy device includes a buoyant body which maintains a permanent orientation relative to the surface of the ocean, while the power take-off (PTO) would self-align in the direction of the incoming waves. The power take-off is completely enclosed, above the waterline and easily accessible. The buoyant body is coupled to the buoyant bodies of other similar wave energy devices by flexible or articulating coupling means. The wave energy devices are arranged in arrays or any other suitable layouts, to form large connected floating structures of desired sizes, and power systems of various capacities. interconnection cables linking the PTOs are secured on cable supports provided between the wave energy devices. Few underwater infrastructures are required. The moorings and the underwater transmission cable are shared by the whole installation.

Abstract

A wave energy harnessing system comprising of a plurality of wave energy devices coupled together, to form high capacity installation. The wave energy device includes a buoyant body which maintains a permanent orientation relative to the surface of the ocean, while the power take-off (PTO) would self-align in the direction of the incoming waves. The power take-off is completely enclosed, above the waterline and easily accessible. The buoyant body is coupled to the buoyant bodies of other similar wave energy devices by flexible or articulating coupling means. The wave energy devices are arranged in arrays or any other suitable layouts, to form large connected floating structures of desired sizes, and power systems of various capacities. Interconnection cables linking the PTOs are secured on cable supports provided between the wave energy devices. Few underwater infrastructures are required. The moorings and the underwater transmission cable are shared by the whole installation.

A SYSTEM OF CLOSELY INTERCONNECTED WAVE ENERGY COLLECTORS COMPRISING OF SELF-ORIENTING POWER TAKE-OFFS

FIELD OF THE INVENTION

The present invention generally relates to devices and methods for harnessing energy from ocean waves, particularly suitable for large scale energy production.

BACKGROUND OF THE INVENTIION

Waves from oceans have the potential to become a major source of sustainable and renewable energy. Wave energy is far more concentrated and reliable, when compared to solar or wind energy. Oceans cover about two-third of the planet, and wave energy can be harnessed practically anywhere on the ocean surface. It is estimated that the total wave energy resources available can exceed the entire global energy need. Large scale energy production from waves, together with other renewable energy sources could almost eliminate the need of fossil energy, and save our planet from pollution and global warming. Global warming is a very serious issue which need to be addressed urgently.

Wave energy has proven quite difficult to harness, even after decades of research and genuine interest. A reliable and cost effective method of harnessing wave energy remains to be found. To this day, while an impressive number of concepts have been proposed, there is still no commercial scale energy production from waves, except some few ongoing experiments. The constantly changing energy flux carried in the waves leads to a great diversity of devices, as designers continuously explore best possible methods to harness wave energy. The different environmental conditions offshore and near the shore, largely influence the designs of these wave devices, and how they operate. There are wave devices that float, those that sit on the ocean floor, and those installed on the shore. The large diversity of concepts may have actually slowed down the commercial development of wave energy, as winning concepts find it more difficult to immerge from the lots, and go through further refinements.

The harsh environment of the ocean greatly affects survivability and reliability of equipments. Violent storms are frequent, and the sea water is corrosive. Cost of installation in the open sea and construction of underwater infrastructure, are much higher compared to land based infrastructures. The ocean environment also makes access to installations particularly difficult for routine maintenance and repairs. Another difficulty lies in the fact that wave energy devices are mostly not scalable to be economically viable. The optimum size of a wave device depends on the size and frequency of the waves, and is usually much less than one megawatt. A wave energy installation of reasonable power capacity would generally comprise of a large number of wave devices, spread over a wide area of the ocean. This significantly add to installation cost, as more underwater cables are required to interconnect these dispersed wave devices, and the need of as many mooring systems to secure these devices. The cost of construction, installation, and exploitation of such wave energy installations is the main reason which has prevented the development of wave energy.

A basic approach to reduction of cost is the sharing of basic installations among as many wave energy devices, or power take-offs within an installation. Several power take-offs may be mounted on a single wave device, or several devices may be installed very close to each other. This allows sharing of infrastructures and equipments more effectively. Close proximity of wave energy devices allow significant reduction in the amount of interconnecting cables and various monitoring equipments. Group of connected wave devices have a higher capacity factor, as the combined power is smoother, which allow reduction in the installed capacity of power equipments being shared. Significant economy is also achieved during installation, commissioning and maintenance. In several prior arts, power take-offs are often mounted close together, in order to improve cost effectiveness.

The patent WO 00/17519 known as the Pelamis and the patent US 8,806,865, are examples of wave energy concepts where several power take-offs are mounted on single floating wave devices. However the modules comprising these wave devices are connectable only in single rows, and in limited in numbers. These wave devices are generally constructed as long as it is technically possible to operate. They are usually oriented in the direction of the waves, and they take up large amount of marine space to account for changes in wave direction. Some patents such as, US 2011/0057448 A1 and WO 2010/082033 A3 overcome this shortcoming by disclosing concept of devices where larger numbers of modules are connected in several arrays, and which does not need to be oriented in the direction of the waves. However, all these wave devices remain extremely vulnerable to the condition in the ocean. While the power take-off of these devices may be disconnected for self-preservation, the external articulating members and joints comprising these wave devices remain exposed to extreme mechanical forces resulting from the waves. The risk of water infiltration through defective seals at these articulating members is also a permanent concern. Patent WO 2014/026219 A1 is also another wave device comprising of several connected modules, but is most suitable for shallow water.

Wave energy devices with completely enclosed hulls, are the most suitable in order to harness the most intense offshore waves, and harmlessly endure the worst condition that prevail. The enclosed articulating or reciprocating elements of the power take-offs are less exposed to the direct force of the waves, and the risk of water infiltration is also greatly reduced. However, these wave devices can be operated as standalone units within energy farms at some distance from adjacent devices, making it difficult to share most infrastructures. While heaving type devices would operate in all direction of waves, they are subjected to interference by similar devices in the proximity. Pitching type wave devices, as in patent US 2011/0089690 A1 also need some operating distances, as they need to be oriented in the direction of the waves. In order to operate in waves from all direction, pitching-type wave devices, as in patent US 8,129,854 B2 have to rely on a plurality of power take-offs, aligned in several directions. The design is rendered complex, and the power take-offs are not fully utilised.

If wave energy is to become a reliable and popular energy source of the planet, it is most desirable that wave energy devices should be able to harness the higher concentration of energy contained in the offshore waves, and most cost effectively. Another desirable feature is that these wave devices may also be used in most diverse ocean environments. Hopefully, the abundant numbers of wave energy devices concepts may be narrowed down to a fewer most suitable concepts, which when mass produced on a larger scale would further lead to reduction in cost.

OBJECTS OF THE INVENTION

The main object of the invention is to provide a method and system of harnessing energy from ocean waves, while reducing cost of construction, installation and maintenance.

Another object of the invention is to provide for wave energy harnessing devices which can operate in diverse marine environments, with all critical components sheltered within waterproof enclosures, well above the waterline for easy access.

It is also another object of the invention to provide for wave harnessing devices which are particularly suitable for the use of conventional rotary electrical machines and electronic equipment similar to those used in wind energy conversion, which are largely available and with proven track record.

A further object of the invention is to provide for wave energy harnessing devices which can operate without causing harm to marine life, and is not disrupted by debris in the oceans.

Yet another object of the invention is to provide for versatile wave energy harnessing devices which can be operated offshore in the deep seas, in shallow lagoons, or even nearer to the shoreline.

SUMMARY OF THE INVENTION

In this present invention, several embodiments of wave energy systems and related components are disclosed. Herein, wave energy harnessing devices are generally referred as wave energy collectors. The most prominent features will be discussed briefly in this summary, without limiting the scope of the invention as expressed by the detail description, drawings and claims that follows.

In accordance with embodiments of the invention, a system of interconnected devices for harnessing energy from waves is disclosed, comprising of a plurality of wave energy devices which are electrically and mechanically coupled together, forming a single large floating structure with a high combined power capacity. The use of underwater cables to interconnect the multitude of devices is eliminated, while underwater infrastructures and moorings are considerably reduced. The modular concept of the invention makes possible the construction of wave devices and installation of diverse power capacity, with relative ease. A large numbers of these wave devices may be assembled in a port facility and then tug to installation site ready for use. The power capacity of these installations may even be significantly upgraded if required at a later stage, as more wave devices may be coupled to the existing installations without the need of additional underwater infrastructures. All these features contribute to the reduction of cost during construction, installation, and maintenance. In comparison, current method to harnesses large amount of power from a given installation is by the use of a plurality of interconnected wave devices within energy farms. Each device within such energy farm has to be maintained at a safe reasonable distance from each other by independent moorings, and then interconnected by underwater power cables. High numbers of wave devices are required. The power capacity of each wave device is usually limited by the characteristics of the waves, and scaling up of these devices is usually not possible.

In accordance with other embodiments of the invention, a wave energy device is disclosed, comprising preferably of a single power take-off which would rotate and self-align instantly in the direction of the incoming waves, while the external buoyant body of the device would maintain a permanent orientation. Energy from the waves is extracted as the buoyant body of the device would pitch and roll from side to side in any direction. The buoyant body of the wave device may be mechanically couple by some suitable means to a multitude of other similar wave devices in any numbers of rows and columns, forming a system of interconnected devices as referred earlier. As a matter of fact, it is of highest importance that these devices harness energy efficiently from any direction of waves, as it is technically not always practical to constantly having to orient a high numbers of interconnected devices with the changing direction of the waves. Existing pitching-type wave devices are mostly designed to operate only in a given direction of waves, and hence cannot be coupled together. A pitching-type wave energy device designed to harness incoming wave from all direction would generally, according to prior art, comprise of a plurality of power take-offs within the device, each aligned to handle waves in a particular direction most efficiently. The need of higher numbers of power take-offs only add to the complexity and cost of the installation. The use of less efficient and less reliable hydraulic systems is then mostly preferred due to cost consideration.

In accordance with yet another embodiment of the present invention, a large standalone wave energy device is disclosed, comprising of a plurality of self orienting power take-offs mounted on a single floating structure. While comparable in several aspects with the system of interconnected wave devices introduce earlier, such a single device of high capacity allow for further economy of scale.

The features, functions, and advantages in various embodiments of the present invention, can be achieved independently or may be combined in yet other embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is described with reference to the following drawings:

FIG. **1** is an isometric view of a group of wave energy collectors interconnected in an array configuration, floating in the ocean.

FIG. **2** is a top view of a group of wave energy collectors interconnected in a different configuration, floating in the ocean.

FIG. **3** is a side view of a coupling means used to couple two adjacent the wave energy collectors, as shown in FIG. **1** and FIG. **2**.

FIG. **4** is a side view of a group of interconnected wave energy collectors, pitching in the waves.

FIG. **5** is a side sectional view of a completely enclosed nacelle, showing the main components of the Power Take-off.

FIG. **6** is a top sectional view of the nacelle shown in FIG. **5**.

FIG. **7** is a side view of the nacelle in FIG. **5** in a pitched position during operation, shown with some internal details.

FIG. **8** is a side sectional view of another embodiment of a nacelle with some externally mounted components.

FIG. **9** is the top view of another embodiment of a wave energy collector, comprising of a nacelle shown in FIG. **8**.

FIG. **10** is a side view of the wave energy collector shown in FIG. **9**.

FIG. **11** is a top view of several wave energy collectors shown in FIG. **9** coupled together, comprising of completely enclosed nacelles.

FIG. **12** is a side view of interconnected wave energy collectors shown in FIG. **9**, pitching in the waves.

FIG. **13** is a top view of another embodiment of a wave energy collector, comprising of a plurality of enclosed nacelles as shown in FIG. **5**.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the invention are set forth in the detailed description that follows herein and the accompanying drawings. The drawings are not to scale and are for illustration only. The detailed description is subdivided into several sub-sections for clarity, discussing different aspects of the invention. Corresponding components and components having similar functions in the drawings are designated by the same numerals, except in cases where specific parts are referred. Embodiments of the invention may have different structures and shapes, without departing from the scope of the invention. Some used terms are also defined for the purpose of clarity.

The term “wave energy collector”, herein refers to wave energy harnessing devices. “WEC” or “WECs”, is used as an abbreviation of the word “wave energy collector”. The terms “wave energy device” or “wave device” also generally refer to embodiments of the wave energy harnessing devices. Wave energy harnessing devices are known by several other names in different literatures.

“Pontoon” herein refers to a floating body which may be completely closed or open at the top similar to the hull of a floating vessel, purposely designed to have pronounced pitching and rolling movements when interacting with the waves. The “pontoon” would be constructed in relation to the dimension of the wave, in order to pitch most efficiently.

“Buoy” refers to a floating body of smaller dimension relative to the ocean waves, which enable them to heave most efficiently in the waves. The “buoys” may be of any shape, generally completely enclosed to prevent ingress of water.

“Power Take-Off” abbreviated as “PTO”, refers to a power extraction means installed within a WEC for transforming the energy from waves into a useful form of energy. The “PTO” is operated by movement of the WEC relative to a fix reference, or by the relative movement of articulating members connected to the “WEC”. The wave energy is transformed into useful energy, in the form of hydraulic, pneumatic, or electrical energy.

“Flexible coupling device” or “coupling device” in this detail description refers to a wide range of devices for the purpose of securing two separate bodies, while allowing the connected bodies a certain amount of movements relative to each other, with none or little mechanical resistance. This includes any mechanical coupling devices which can perform this function, such as universal joints, but also chains, ropes, or connecting members having elastomeric properties. “Flexible coupling devices” may comprise of a single or several devices assembled together.

“Power conduit” herein refers to connecting elements used for the transmission of energy in the formed of fluid or electricity. “Power conduits” would comprise of hollow pipes when energy is carried in fluids, such as air, water, or oil. The term “cable bus” is also a type of “power conduits” comprising of electrical cables for transmission of electrical energy.

"Cable support" refers to various devices and structures which may provide support for "cable bus" or "power conduit" laid across two adjacent WECs which are coupled together by "coupling device". This include support structures, cable channel, cable trays, cable ladders, articulating cable carriers, conduits, including aerial cable supports.

General concept

Embodiments of the invention generally comprise of a plurality of independent wave energy collectors (WECs) which are coupled together mechanically and electrically, so as to form large connected floating structures. In FIG. **1**, a group of WECs **20** is shown coupled together in an array configuration within an installation. In FIG. **2**, another group of WECs **20** is shown coupled together in a different configuration. The WECs **20** are usually of similar size and power capacity to facilitate interconnection. The WECs **20** may be coupled together forming installations of various shapes, to maximise the absorption of wave energy, better resist rough weather, or to fit certain installation site. For example, rows of interconnected WECs **20** may stretch along the shoreline over long distances, facing the incoming waves. By absorbing as much energy from the waves, the arrays of WECs **20** may also act as a wave breakers preventing coastal erosion. In offshore installation, the WECs **20** may be bundled in some tight configurations to better resist rough weather.

The WECs **20** may be designed to various scales, in order to operate either in large offshore waves or in relatively smaller waves near the shore. Embodiments of WECs **20** would generate between a few kilowatts to several hundreds of kilowatts (KW) of energy, depending on the dimension of the WECs **20** and the wave characteristics, such as intensity and wavelength. A WEC **20** may be operated as a single standalone unit, but in general a single installation would comprise of several numbers of interconnected WECs **20**, ranging from a few to several thousands in numbers, with the aim to produce several megawatt or even gigawatt of electrical energy. Installation of such high capacity can be easily deployed as no extensive underwater infrastructures is required, except the laying of underwater power transmission cable to the shore, and moorings to secure the installation in the ocean.

Large numbers of WECs **20** may be coupled together in port facilities, and then tugged in the open sea to the installation site ready for operation. Power capacity of a given installation may even be substantially increased by coupling additional WECs **20**, without the need of additional moorings or power transmission cable. Embodiments of the invention, because of the ease of deployment and installation, can be use as temporary power installations in coastal areas following disasters and major power network failures.

As shown in FIG.**1** and FIG. **2**, each of the WECs **20** includes a pontoon **21** and a nacelle **22** firmly secured at the center. The nacelle **22** is a waterproof enclosure which houses the Power Take-Off (PTO). In preferred embodiments of the invention, the PTOs generate electrical energy as the nacelles **22** pitch and roll about the horizontal plane together with the pontoons **21**. The pontoon **21** of a given WEC **20** is coupled to the pontoons **21** of adjacent WECs **20** within an installation by flexible coupling devices **23**. This allows each of the WECs **20** to move freely about the joints of the coupling devices **23**. A cable bus **24** of appropriate power capacity connects and combines all the power generated in the PTOs. Waterproof cable entries are provided in the nacelles **22** for interconnection of the PTOs. The cable bus **24** is properly secured to the side of the pontoons **21**, and to the cable supports **25** where the cable bus **24** is laid across the coupling devices **23**. The cable supports **25** allow free movements of the interconnected WECs **20**, while preventing the cable bus **24** from potential damages.

The combined power of the interconnected PTOs is usually transmitted by a single underwater transmission cable **26** to the power grid on shore. But certain large embodiments of the invention may comprise of several underwater transmission cables **26** for increased reliability. The underwater transmission cable **26** may also connect the installation to other groups of wave energy devices, located at some distance within an energy farm. In other use of the invention, the power may be consumed by manufacturing and processing plants installed within the WECs **20**, or on separate floating platforms. The energy harnessed may be used for undersea mining in the proximity of the installation, or the production of fresh water. A very practical use of wave energy is the production of hydrogen from the seawater, which can then be transported by ships or pipelines. Embodiments of the invention may also be mounted on watercrafts of appropriate designs, and the energy from the waves used for propulsion of the watercrafts.

Main structures

The WEC **20** is designed in shape and size so as to interact with the waves, and harnessed wave energy most effectively. The pontoon **21** may be constructed in the shape of a buoyant ring, as shown in FIG. **1** and FIG. **2**. The buoyant edge of the pontoon **21** further from the center of the nacelle **22** provides better leverage and torque required to operate the PTO. The nacelle **22** is secured at the center of the pontoon **21** by a number of spars **27**, or any alternative structural framework, or platform to ensure integrity of the construction. The spars **27** may be made steel frames members, such as hollow pipes or steel sections. Steel must be galvanised, painted, or coated by some other protective materiel to better resist corrosion. Other construction material, such as wood, fibreglass, or similar synthetic materials may be used for construction of the spar **27**, provided they are of adequate size to endure the work load. A number of spars **27** are used distributed evenly about the perimeter of the pontoons **21** to ensure integrity of the construction. In FIG. **1**, the nacelle **22** is shown secured to the pontoon **21** by four set of spars **27**. In FIG. **2**, the nacelle **22** is shown secured by eight set of spars **27**. As an alternative to pontoon **21**, a plurality of independents floating bodies may be disposed around the nacelle **22**, each secured directly to the nacelle **22**, or by the use of a plurality of spars **27**. In other embodiments of the invention, the nacelle **22** may be secure at the center of the ring-shaped pontoon **21** by a plurality of support cables or ropes under tension. The cables are used as an alternative to rigid spar **27** in a construction similar to wire wheel, where the central hub is secured to the rim by cables under tension. In some other embodiments of the invention, the pontoon **21** may be constructed as a circular hull like platform. The nacelle **22** may then be mounted above at the center, or inside the hollow body of the hull.

The circular shape of the pontoon **21** allows efficient spatial distribution of the WECs **20** when they are coupled together. The interconnected pontoons **21** can then move about the coupling devices **23** with minimum interaction with each other. The symmetrical circular shape of the pontoon **21** also allows energy to be harnessed from waves in all direction with same uniformity. The WEC **20** would generally have the center of gravity and the center of buoyancy vertically aligned, in order to ensure flotation stability and correct operation of the PTO. The WECs **20** which are used as standalone units may be designed with a lower center of gravity to enhance flotation stability in rough weather condition. Embodiments of the invention comprising of large numbers of interconnected WECs **20** are naturally stable in rough weather.

The pontoons **21** are robust construction so as to withstand extreme weather condition. The design of the pontoons **21** may vary widely in different embodiment of the invention. The pontoons **21** may be made of metal or other synthetic material such as fibreglass, and air-filled to ensure flotation. The pontoon **21** is built to required dimension, so as to enable the WEC **20** to float and also provide the forces required to operate the PTO in the nacelle **22**. The pontoon **21** may be entirely constructed of some solid lightweight material of density lower than water. Pontoons **21** with air filled cavities would generally comprise of several separate airtight compartments to ensure integrity in case of damage. The pontoons **21** may also be made of soft inflatable material, such as rubber or equivalent synthetic material, as a cost effective alternative. Pontoons **21** made of soft material also effectively cushion the contacts between each other during operation. Additional internal or external reinforcement structures may be required to ensure stiffness and strength of the pontoons **21**. Pontoons **21** may be constructed in other cost effective shapes, depending on the manufacturing means and material of construction. As such, the pontoons **21** may be constructed as regular polygons with a number of sides, instead of being circular. The pontoon **21** may also comprise of a plurality of independent modular segments assembled and secured together in required numbers, in order to accommodate WECs of different dimension. As the pontoons **21** within an installation of interconnected WECs **20** would be constantly rubbing and bumping with each other, the sides of the pontoons **21** may need to be protected from premature wear and damages. Marine fenders, bumpers, old tires, or pads may be mounted around the perimeter of the pontoons **21** for additional protection where required. The parts of the WEC **20** exposed to seawater may need some antifouling treatment, but in general fouling do not seriously affect performance of the WECs **20**, because of the absence of any external articulating members or joints. Furthermore, it should be noted that the proliferation of marine life in the underside of the WECs **20** may be rather beneficial to the marine ecosystem.

The coupling devices **23** are used only as a means to secure the pontoons **21** together, and take no part in the operation of the PTOs. The coupling devices **23** also allow each of the pontoons **21** to move freely with the waves, so that the PTOs mounted on each pontoon **21** can harness energy from the waves. So, the coupling devices **23** are designed to provide as little mechanical resistance as possible, to the movement of the pontoons **21**. The coupling devices **23** are also designed to resist extreme mechanical forces in all weather conditions. The sides of the pontoons **21** where the coupling devices **23** can be reliably mounted, are reinforced in order to endure the forces involve. The coupling devices **23** are positioned where required on the side of the pontoons **21**, according to the layout of the interconnected WECs **20** in a given installation. The coupling devices **23** can be constructed in a variety of ways. Coupling devices **23** may comprise of one, or a combination of several standard off-the-shelves mechanical devices, such as universal coupling, spring coupling, elastomeric coupling, bellow coupling, knuckle coupling and others. Coupling devices **23** may be custom-made. Coupling devices **23** may also comprise of other components such as spring, ropes, chains, fabrics, used tires, and any flexible material. When large numbers of WECs **20** are coupled together, their movement may become significantly damped as the pontoons **21** would pull and push mutually on each other, hence reducing the overall energy extraction efficiency. This problem is attenuated by the use of coupling devices **23** which are able to extent and contract in length substantially. These embodiments of coupling device **23** may then also comprise of telescopic joints, springs, material of elastomeric properties, or made of articulating members, so as to allow the coupling device **23** to stretch and contract by the amount required. Each of the WECs **20** within such large installation, is then able to surge and sway sideways more freely within the extra space provided, hence reducing the mechanical forces the WECs **20** may exert mutually on each other.

An example of a coupling device **23** is shown in FIG. **3**, comprising of standard marine equipment commonly use to secure floating structures and boats. The same type of coupling means is used in embodiment of the invention shown in FIG. **1** and

FIG. **2**, but any other alternative coupling means which meet the operation requirements could have been used. As shown in FIG. **3**, a marine fender **31** of cylindrical shape is secured between the pontoons **21** of two adjacent WECs **20** by mooring pendants **32**. The mooring pendants **32** are maintained slack, which allow the pontoons **21** to move relative to each other with negligible mechanical resistance. The mooring pendants **32** may comprise of chains, or synthetic ropes. The mooring pendants **32** may also have some elastic properties to better endure and absorb shocks. Mooring rings **33** are provided on the side of the pontoons **21** and the marine fender **31**. The mooring springs **34** of appropriate load capacity provide a graded restraining force, and manage the excess slack in the mooring pendants **32**. The mooring springs **34** are mounted on the sides of respective pontoons **21** and the marine fender **31**. Marine fenders **31** of suitable size and diameter are selected according to the size of the pontoons **21**, in a given installation. The marine fenders **31** may float between the sides of the pontoons **21**, or secured above the ocean surface or waterline **35** as shown in FIG. **3**. Marine fenders **31** are usually made of synthetic material, such as rubber which is adequately deformable, pliable, and with good cushioning properties. The marine fenders **31** may be filled with air or foam. Marine fenders **31** of other shape and design may be used to improvise other form of coupling device **23**. Alternative mounting arrangements may be used to secure the marine fender **31** to the pontoons **21**.

FIG. **3** also shows an example of a cable support **25** which carry the cable bus **24** between two adjacent pontoons **21**, in order to connect the PTOs in the respective nacelles **22**. Cable supports **25** are placed along the path of the cable bus **24** where require, and are firmly secured to the side of the pontoons **21**. The cable support **25** may comprise as shown, of an articulated cable carrier or tray. The members comprising the cable support **25** articulate about a plurality of hinges **36**, hence the cable support **25** opposes no resistance to the free movements of the pontoons **21**. The cable bus **24** is secured on the cable support **25** and the side of the pontoons **21** by cable clamps **28** or any other appropriate means. The cable bus **24** would have a reasonable amount of excess length in order to allow bending around the articulations of the cable support **25**. The articulations of the cable support **25** must accommodate the most extreme movements between the pontoons **21** and the marine fender **31**, without causing damage to the cable bus **24**.

The cable supports **25** may be constructed in a number of various other ways. The cable supports **25** may comprise of flexible synthetic material which can easily twist, stretch and bend. The segment of the cable bus **24** across the flexible coupling device **23** may comprise of spiral power cable, so as to easily stretch and contract. The cable bus **24** may be secured by some aerial means across the pontoons **21**. In some other embodiments of the installation, cable supports **25** may not be used. The cable bus **24** may be secured directly to coupling device **23** of appropriate designs. In other embodiments of the invention, the cable bus **24** may be allowed to hang loose and free between the connected pontoons **21**, or even trail in the sea water. In these cases, the cable bus **24** may be provided with additional protective sheath for protection against mechanical damage due to possible interaction with the WECs **20**, and protection against the seawater. In other embodiment of the invention, the coupling devices **23** may include internal cableways for the cable bus **24**. Internal cableways may be also provided within the pontoons **21**, so that the cable bus **24** between the interconnected WECs **20** is completely internal and not visible from the outside. It is understood that power conduits other than electrical cables may be used to carry the harnessed energy from the interconnected WECs **20**, in other embodiments of the invention. Such power conduits may comprise of network of pipes or hoses which carry fluids from the PTOs, and then transformed into electricity by a centralised generator. These power conduits may be installed in similar manner as described for the cable bus **24**.

Operation of interconnected WECs

FIG. **4** shows some interconnected WECs **20** pitching in the waves. The pontoons **21** are able to pitch from side to side because the opposite sides of the pontoons **21** alternatively rest on the crest and the trough of the waves travelling across the lengths of the interconnected WECs **20**. The pontoon **21** is made rigid, in order not to bend under the forces of the waves, so that the turning moment of the forces is efficiently transferred to the PTO in the nacelle **22**. The diameter of the pontoon **21** is generally designed not to exceed half the wavelength of the waves, so that the pitching angle is a maximum, half a wavelength being the distance between an adjacent crest and trough. At wavelength less than the diameter of the pontoon **21**, the pitching angle is reduced, and less wave energy is extracted. The diameter of the pontoons **21** can measure in the range of a few meters, in order to operate both in waves of those magnitudes and in larger waves. In larger embodiments of the invention, the diameter of the pontoons **21** may measure in the range of 20-50 meters, in order to operate in offshore waves of those magnitudes. An installation of equivalent power capacity may comprise of a greater number of WECs **20** of smaller diameter, or a fewer number of WECs **20** of larger diameter. As the waves at a given installation site would normally vary between a maximum and minimum wavelength, the diameter of the pontoons **21** would be selected based on the most cost effective options, taking into consideration the construction and operation cost of the installation and the total energy that may be harnessed during the life time of that installation.

As shown in FIG. **1** and FIG. **2**, all the PTOs of the interconnected WECs **20** are linked by a common cable bus **24**. Together, they form a large power generating system of capacity equivalent to the total numbers of interconnected WECs **20** within a given installation. The cable bus **24** is preferably secured on the surface of the WECs **20** and the cable supports **25**, as the cable bus **24** may then be easily inspected during routine maintenance. The cable bus **24** should resist wear and tear, as they undergo a large numbers of bending cycles about the coupling devices **23**, during the lifetime of the installation. The pontoon **21** would generally carry only a single PTO, secured at the center within the nacelle **22**. However several PTOs of small capacity may be secured about the center of pontoon **21**, as a replacement for a single PTO of larger capacity. In other different embodiments of the invention where the wave energy is harnessed in a first stage by PTOs in the form of a compressed fluid, then a network of flexible conduits may collect the compressed fluid from all the PTOs, and then converted into electricity by a common generator. The generator may be installed within one of the WECs **20,** or alternatively on a separate floating structure, in an underwater station. In near shore installation, the compressed fluid may even be brought by under water pipes to drive generators located on the shore.

Because of the highly variable intensity of the waves, the PTOs would generate electrical energy of highly fluctuating amplitude and frequency, without the use of appropriate power interface within the nacelle **22**. The power interface system ensures that the electrical supply from the PTO conforms within certain constant electrical parameter before being connected to the cable bus **24**. Power is transferred from the PTOs to the cable bus **24** only at correct calibration of these AC or DC electrical parameters. The power interface system may comprise of diverse power electronic devices such as converters, inverters, rectifiers which are widely used in the wind power systems. The electrical power supply from the PTOs is generally designed to be connected in parallel by the cable bus **24** in a radial configuration, as shown in FIG. **1** and FIG. **2**. The cable bus **24** may also be laid according to some other configuration for higher reliability. The ways the PTOs are designed may also influence how they may be electrically connected, in parallel or in series, by the cable bus **24**.

The design of the power transmission systems from the interconnected WECs **20** to the main electrical grid on the land would mostly depend on the power capacity of the installation, and the distance from the shore. In small embodiments of the invention as shown in FIG. **1** and FIG. **2**, the use of a single underwater transmission cable **26** is most economical. However in larger embodiments of the invention, the power may be transmitted by several separate underwater transmission cables **26**, for increased reliability. The connections between the PTOs in the nacelles **22** are then also usually organised in separate clusters and subgroups by several segregated networks of cable bus **24**, for still higher reliability. The power for the transmission cable **26** may be tap-off directly at the cable bus **24** and transmitted to shore in the form of direct or alternating current supply (also referred as DC or AC supply). When the power from the cable bus **24** is transmitted over long distances, the DC or AC supply voltage is preferably stepped up by power transformers and appropriate equipment for higher voltage transmission, before connection to the transmission cable **26**. The high voltage transmission equipment may be installed within one of the nacelles **22**, on a separate floating platform, or in an underwater substation. The power transmission cable **26** may not always be under water. In embodiments of the invention operating very near the shoreline, the power transmission cable **26** may be installed by some aerial means, or some alternate method under specific installation layout conditions. Switchgears for isolation and disconnection of the installation are required for safe and reliable operation of the installation. The cable bus **24** and the transmission cable **26** must be protected from electrical overload. Faulty WECs **20** should be able to be selectively disconnected, in order to allow continued operation of the installation.

Deployment and mooring

Large embodiments of the WEC **20** are generally assembled in dry dock facilities, and then floated. Smaller embodiment of WECs **20** may be factory mounted. The plurality of WECs **20** is then coupled to each other by means of the coupling devices **23**, according to pre-layout designs in the calm water of a port, most likely. The cable supports **25** are then fitted where required. The cable bus **24** is later installed between the nacelles **22** and all the PTOs are interconnected. At this stage, the installation may be pre-commissioned and tested before being tugged in the open sea. Upon reaching the site of installation, selected WECs **20** are immediately secured to the mooring line **43** and the system connected to the underwater transmission cable **26**. Installations of the mooring systems on the seafloor **45** and the underwater transmission cable **26** have been completed prior to the arrival of the WECs **20**. The installation is then ready for final commissioning and exploitation. Embodiments of the invention comprising of very large numbers of WECs **20** may be partly assembled in several segments, and then tugged separately to the operation site, where the segments are then coupled together. An existing installation may be substantially upgraded at a later stage by coupling addition WECs **20**, without the need of additional underwater infrastructures, provided the existing mooring systems and the underwater transmission cable **26** have some spare capacity for such expansion. Similarly, installed capacity of an existing installation can be easily downgraded by removal of a number of WECs **20**. Embodiments of the invention are generally provided with means for personals to move safely and swiftly between the coupled WECs **20**, which is of extreme importance during installation and maintenance work. Protection means for personals would include, provision of anchors, footholds, safety nets, protection rails, where required on the WECs **20**.

Accommodations for visiting or permanent technical personnel may be provided within larger embodiments of the WECs **20**.

Embodiments of the invention are maintained on the ocean surface **35** by a slack mooring system. The slack mooring allows the WECs **20** to heave and pitch without restrain, and also prevent the installation from drifting due to wind and sea currents. The mooring system is designed to resist severe weather condition. As shown in FIG. **1**, only a few selected pontoons **21** are secured by mooring lines **43** to concrete blocks **44** on the seafloor **45**. The mooring lines **43** may be directly anchored to the seafloor **45**. The mooring lines **43** would comprise of chains, or synthetic ropes. Mooring buoys **46** are attached at the end of the mooring lines **43** in order to facilitate the mooring operation. The moorings lines **43** are spaced relative to each other, so as to prevent the installation from making a complete spin, hence avoiding potential damage to the underwater transmission cable **26** by twisting. The length of mooring lines **43** and the transmission cable **26** should account for seasonal tides variations and height of the waves. The slack in the mooring lines **43** and the transmission cable **26** are prevented from resting on the seafloor **45** by the use of underwater buoys **47**. Dragging of the mooring lines **43** and the transmission cable **26** on the seafloor **45**, may cause gradual damage to the fauna and the reefs. The use of underwater buoys **47** also reduces possible interference in the operation of the WECs **20**, by the weight of the mooring lines **43** and the transmission cable **26**. Embodiments of the invention may also be secured to other structures, such as the masts of offshore wind farms and oil rigs. Installation very close to the shoreline may be secured to land based structures. A properly designed mooring system must be carried out by the recommendation and skills of those familiar in the art.

The power take-off (PTO)

The PTO is another important aspect of the embodiments of this invention for efficiently harnessing the wave energy. The pontoons **21**, as they interact with the waves are subjected to various kinds of motions about the flexible coupling device **23**. In different embodiments of the invention, PTOs mounted in the nacelles **22** may exploit any of these motions, such as the heaving, the lateral surge motions, or the pitching and rolling motions of the pontoons **21**. Energy is harnessed as the pontoon

21 moves in relation to a fix reference connected to the PTO, where the fix reference provides the resistive force to operate the mechanism inside the PTO. In some embodiments of the invention, the fix reference may be provided by a tether lines secure to the seabed and to related components in the PTO. In other embodiments of the invention, the fix reference may be provided by the inertial of a reaction mass, where the reaction mass resists the motion of the pontoons **21**. In yet other embodiments of the invention, the fix reference may be provided by a member with a high drag coefficient in water, which resists the motion of the pontoons **21**. In preferred embodiments of the invention, the pontoons **21** being coupled by the flexible coupling devices **23** on several sided, would pitch and roll most efficiently, than any other motions induced by the waves. As such, in preferred embodiments of the invention, the PTOs are designed so as to utilize most particularly the pitching and rolling motion of the pontoons **21** about the horizontal plane.

A preferred embodiment of the PTO is shown in FIG. **5** to FIG. **7**. The PTO harnesses wave energy as the pontoon **21** pivots about the joints of the coupling devices **23**, pitching and rolling about the horizontal plane. This arrangement allows the PTOs to harness energy from waves reaching the connected network of pontoons **21**, from any direction. As shown in FIG. **5**, the components comprising the PTO are completely enclosed and protected within the body **49** of the nacelle **22**. The PTO comprises of a support frame **50** which is firmly secured to the lower section of a support shaft **51**. The support shaft **51** is mounted vertically at the symmetrical center of the nacelle **22** on roller bearings **53** and **54**, which together with the support frame **50** form a rotatable base. A pair of opposing tapered roller bearings **53** and **54** mounted within a bearing housing **55**, allow the rotatable base to endure a large amount of radial and axial forces, during operation of the PTO. The bearing housing **55** may be designed differently with different numbers of bearings and in different arrangements, to fulfill the same purpose. The rotatable base allows components of the PTO to rotate freely about the vertical axis of the support shaft **51**, and to align in any direction within the nacelle **22**. As shown in FIG. **6**, the bearing housing **55** is firmly secured at the symmetrical center of the nacelle **22** by a support structure, which may comprise of several truss members **56**. The side of the nacelle **22** may need to be reinforced about the circumference by appropriate frame structures, such as a number of ring members **57** and lateral struts **58**. The spars **27** (not shown in FIG. **5** to FIG. **7**) which secure the pontoon **21** to the external side of the nacelle **22**, are preferably secured to the ring members **57** so as to reduce mechanical stress to the body **49**. In other embodiments of the nacelle **22**, the spars **27** may be directly to the sides of the bearing housing **55**, rather than to the sides of the nacelle **22**. It is understood that the support frame **50** with the ability to rotate about a vertical axis of the nacelle **22**, may be constructed in a number of different ways, and which may not always require the need of a centrally mounted support shaft **51** as shown in FIG. **5** to FIG. **7**. In these alternative embodiments, the support frame **50** may be mounted on wheels which roll on a peripheral circular rail secured to the ring member **57** of the nacelle **22**.

The fix reference, or reference mass for operation of the PTO is provided by a heavy weight **59** inside the nacelle **22**. The weight **59** is made from some low cost and dense material, such as concrete. Preferably, a pair of suspension rods **60** is used to secure the weight **59** to either side of the pivot shaft **61**, both mounted on the support frame **50**. The suspension rods **60** also significantly off-set the center of gravity of the weight **59** acting on the pivot shaft **61**. The pivot shaft **61** is mounted on roller bearings **62** and **63,** which allow the weight **59** to hang vertically by the force of gravity, even as the nacelle **22** is pitched sideway as shown in FIG. **7**. The roller bearings **62** and **63** are preferably tapered so as to bear significant amount of radial and axial forces during operation. Clearance is provided between the weight **59** and the internal wall of the nacelle **22**, to the extent of the maximum pitching angle of the nacelle **22**. The need for clearance applies to the internal wall of the nacelle **22** all around the support shaft **51**, given that the pivot shaft **61** may be positioned in any direction within the nacelle **22** during operation. The body **49** of the nacelle **22** is shaped so as allow operation of the PTO in normal conditions and at pitching angle most commonly experienced by the pontoon **21**. Cushioning bumpers **64** are provided on both sides of the weight **59**, in order to prevent any hard contacts with the truss member **56** or the ceiling of the nacelle **22**, which may occur in most extreme conditions. The pivot shaft **61** is also symmetrically aligned with the axis of the support shaft **51**, with a balanced lateral weigh distribution, to ensure correct operation of the PTO. In other embodiments of the PTO, the weight **59** together with the suspension rod **60** may be mounted within the support frame **50**, in order to allow even more extreme pitching angle of the pontoon **21**. The gearbox **65** and the generator **66** are then mounted on the external sides of the support frame **50**. In this arrangement, the weigh **59** may be provided with sufficient headroom within the support frame **50**, so as to rotate completely about the pivot shaft **61**, during most extreme pitching of the nacelle **22**. Embodiments of WEC **20** with PTO designed accordingly, may be most useful as standalone units in very rough sea conditions, where during operation the WECs **20** may capsize without disrupting operation.

Energy is harness in the PTO when the longitudinal axis of the pivot shaft **61** is positioned perpendicularly to the travel direction of the ocean waves. Reciprocal movements take place between the suspension rod **60** and the support frame **50**, as the nacelle **22** is pitched alternately from side to side. The lateral forces acting on the bearing **53** and **54** are then symmetrically balanced, and the pivot shaft **61** remains perpendicular to the direction of the waves. When the direction of the waves changes and is no longer perpendicular to the axis of the pivot shaft **61**, the pitching movement of the nacelle **22** with the waves causes unbalanced lateral reaction forces in the bearing **53** and **54**. The support frame **50** would then rotate about the axis of the support shaft **51**, until the pivot shaft **61** is repositioned perpendicularly to the direction of the waves. The lateral reaction forces acting on the bearings **53** and **54** are balanced and symmetrical again. The ability for components of the PTO to rotate and align with the wave, while the nacelle **22** maintains a permanent orientation, is an important aspect of the invention. This feature makes it possible for WECs **20** to be couple together, as shown in FIG. **1** and FIG. **2** in large numbers. As the support frame **50** responds almost immediately to the change in wave direction, energy can be harnessed even in choppy irregular waves.

A diverse range of mechanical or hydraulic equipments may be used to convert the slow movements of the articulating joints at the pivot shaft **61**, into high rotational mechanical movement suitable to drive the generator **66**. In some embodiments of the nacelle **22**, linear generators may be mounted on the support frame **50** and directly coupled to the articulating joint about the pivot shaft **61** by mean of suitable linkage mechanisms. In the embodiment as shown in FIG. **5**, the mechanical transmission system comprising of a gearbox **65** is coupled to a rotary generator **66** by a drive shaft **67**. Both the gearbox **65** and the generator **66** are firmly secured to the support frame **50**. In this embodiment of the PTO, the pivot shaft **61** is also used to drive the input shaft of the gearbox **65** and is hence lock to the suspension rods **60**, in order to allow transmission of torque. The gearbox **65** may comprise of several stages of gear trains, including chain drive or belt drive. The pivot shaft **61** or the drive shaft **67** generally includes a clutch mechanism, so that power transmission to the gearbox **65** or the generator **66** may be disconnected during severe weather conditions. In these conditions the nacelle **22** would pitch freely in the waves about the pivot shaft **61**, without causing damage to the mechanical transmission, or overload the generator **66**. There is a great flexibility in the design of the mechanical transmission and the way it is connected to the driveshaft **67** of the generator **66**. In some other design, the generator **66** may even be secured on the weight **59**, with appropriate gears mechanism mounted on both the drive shaft **67** and the support frame **50**. An electrical cable **68** connects the generator **66** to the power interface **69** in the equipment room **70**, located above the platform or internal deck **71**. The support shaft **51** is made hollow or provided with grooves. This allows the passage of the cable **68**, and any other cables for control and monitoring purposes, between the support frame **50** and the equipment room **70**. A slip ring **72** mounted on the support shaft **51** is required for connection of the cable **68** to the terminals of the power interface **69**. The slip ring **72** and the support frame **50** mounted together on the support shaft **51**, rotate to a new position every time there is a change in the direction of the waves. Brushless rotary transformers may be used as an alternative to conventional slip rings **72**. However conventional slip rings **72** which have a higher current capacity remain a practical choice, as the device is not subjected to intensive use. Additional low power slip rings may be required to connect the cables of any control and monitoring equipment located on the support frame **50**.

The equipment room **70** and space above the support frame **50** may accommodate various monitoring and control equipments. Energy storing devices such as batteries, capacitors, flywheels etc, may be installed within the equipment room **70**, or any other location of the nacelles **22**. Waterproof access traps or doors are provided to allow access inside the nacelle **22** for the purpose of installing equipment and maintenance. In larger embodiments of the invention, the nacelle **22** or other part of the WEC **20** may include storage areas and living space for maintenance crew. Weigh of equipments on the deck **71** also need to be evenly distributed and laterally balanced to ensure flotation stability, and correct operation of the self-alignment mechanism of the PTO. Waterproof cable passages are provided in the equipment room **70** for all electrical cables, such as the cable bus **24**, the transmission cable **26**, and cables required or any other devices.

The power supply by the generator **66** is highly variable in intensity and frequency. The power interface **69** transforms the supply from the generator **66** into AC or DC power supply with constant parameters which are compatible for electrical connection to the cable bus **24**. Only then, the power supply from the power interface **69** can be transmitted into the power network formed by the cable bus **24**. Switchgear is provided to disconnect and isolate the power interface **69** automatically during faults or for maintenance purposes. The underwater transmission cable **26** may be connected to the cable bus **24** at the output terminals of the power interfaces **69**. For higher voltage transmission to shore, the supply from the cable bus **24** is stepped up before connection to the transmission cable **26**. The equipment room **70** may accommodate the power transformer and convertor necessary for stepping up the voltage of the cable bus **24**. The power interface **69** can be designed in a number of ways, and would generally comprise of various power electronic equipment such as frequency convertors, frequency invertors, rectifiers, and boosters. The power interface **69** may also be constructed almost entirely of various interconnected electro-machines. The design of the power interface **69** largely depends on the type of generator **66**. The generator **66** can be of the permanent magnet type, or the most affordable and reliable induction type. The power interfaces **69** usually rectify the fluctuating supply from the generator **66**, before converting it into AC or DC supply, compatible for connection to the cable bus **24**. Electrical current is generated (as wave energy is harnessed in the PTO) when the stator and the rotor of the generator **66** rotates relative to each other, under the action of an external forces or torque. As the nacelle **22** is pitched from side to side by the action of the waves, the stator of the generator **66** rotates, forward and backward repeatedly, about the rotor. The induced current in the stator also produces a torque on the rotor, which prevent the relative rotation between the stator and rotor of the generator **66** from taking place. A rotor which is not restrained mechanically by an opposite restraining torque would rotate together with the stator, and no power would be generated by the stator windings of the generator **66**.

The restraining torque acting on the rotor of the generator **66**, is the result of the sideway displacement **73** of the weight **59** at the end of the suspension rods **60**, about the pivot shaft **61**, as shown in FIG. **7**. The sideway displacement **73** from the vertical axis **74** occurs in the direction of movement **75**, as the nacelle **22** is pitched from side to side. The restraining torque is proportional to the amount of the displacement **73** and the mass of the weight **59**. The length of the suspension rods **60** and the weight **59** are selected so that the sideway displacement **73** is a minimum for efficient extraction of energy by the PTO. A means to modulate the amount of the restraining torque would allow the WEC **20** to operate in very intense waves without having to shut down completely. The restraining torque can be modulated by the use of a suspension rod **60** of adjustable length, where the length is reduced during intense waves. Similarly the weight **59** may comprise of container fill with seawater, where the amount of liquid can vary, in order to modulate the amount of the restraining torque. The restraining torque may also be modulated electrically by the power interface **69**.

The dimension of the nacelle **22** as shown in FIG. **5** to FIG. **7** is mainly determined by the size of the weight **59** and the length of the suspension rod **60**. An alternative embodiment of a nacelle **82** is shown in FIG. **8**, which allow for greater flexibility in the design of the PTO. The support frame **50** together with the gearbox **65** and the generator **66** are enclosed within a separate lower enclosure **83**. The lower enclosure **83** together with the support frame **50** is secured to the support shaft **51**. The pivot shaft **61** extends through openings outside the enclosure **83** to secure the pair of externally mounted suspension rods **60** and the weight **59**. While the upper enclosure **84** is secured to the pontoon **21** by a number of spars **27**, the lower enclosure **83** is free to rotate and align in the direction of the waves. The nacelle **82** allows a great deal of flexibility in the construction of WECs **20** of different power capacity. The nacelle **82** has the ability to accommodate a wide range of weights **59**, together with suspension rods **60** of different length, in relation to the power rating of the generator **66**. Similarly, the enclosures **83** and **84** may be constructed of standard sizes to accommodate components of PTO for a wide range of power capacity. The weight **59** may be completely submerged below the water surface **35**, if constructed of material significantly denser than water. Watertight seals **85** are provided on the support shaft **51** and the pivot shaft **61** to prevent water infiltration inside the different compartments of the nacelle **82**. Other alternative means, such as rubber bellows, and barriers may be used to prevent water infiltration.

The preferred embodiments of the nacelles **22** and **82** as disclosed, harness wave energy by means of a PTO comprising of single reciprocating mechanism which rotate a generator **66**, wherein the reciprocating mechanism is maintained align in the direction of the incoming waves by an orientation mechanism. In other embodiments of the PTO, the reciprocating mechanism may comprise of a different orientation mechanism, such as a motor or actuator operated by a control system which detect the direction of the waves, and consequently rotate the reciprocating mechanism in the direction of the waves. In embodiments of the invention where the direction of the waves is mostly constant, the PTO may be aligned permanently in a given direction, without the need of an orientation mechanism. In yet other embodiments of the invention, orientation mechanism is not required when the PTO comprises of a plurality of reciprocating mechanisms aligned permanently in different directions, and thus is able to harness incoming waves from all direction. In such alternative designs, the suspension rod **60** with the weight **59** at its lower end may be suspended to an articulating joint, secured at the symmetrical center directly to the truss members **56** within the nacelle **22**. As the nacelle **22** would pitch in any direction about the articulating joint, a plurality of compression cylinders disposed and secured around the perimeter of the nacelle **22** may be operated through linkage members connecting the suspension rod **60** to the pistons of the compression cylinders. The compressed fluid from the cylinders may then be transformed at some stage into electrical power. The articulating joint may comprise of universal joints mounted on rotary supports, knuckle joints, or any equivalent means.

WEC comprising of heaving buoys

An embodiment of the invention is shown in FIG. **9** and FIG. **10,** comprising of only three set of independent buoys **87**. The WEC **86** shown in FIG. **9** and FIG. **10** comprises of nacelle **82**. Other embodiment of the WEC **86** may comprise a nacelle **22**. The buoys **87** are symmetrically disposed and firmly secured around the nacelle **82 or 22**, by independent set of spars **27**. Alternative to spars **27**, such as a structural platform may also be used to secure the buoys **87** to the nacelle **22** or **82**. The pitching movement required to operate the PTO, is the result of the heaving movements of the buoys **87** interconnected by the spars **27**. The spars **27** are designed to withstand the load during normal working condition and extreme weather. Additional support frames may be use to reinforce the spars **27**. The use of buoys **87**, which is more compact, is also more cost effective than fabrication of large floating body of elaborate shape. The use of three set of buoys **87** allows the WEC **86** to harness incoming waves from all direction with a fair degree of symmetry, compared to a perfectly circular floating body in the like of pontoon **21**.

The buoys **87** are watertight hollow structures and may be constructed in a number of ways. The buoys **87** may be made of metal or some synthetic material such as fibreglass. Internal or external reinforcement structures may need to be provided for the buoys **87** to withstand the water pressure and to provide support for the coupling devices **23**. The buoys **87** may also be constructed of soft inflatable material, such as rubber or some other similar synthetic material. The buoys **87** are generally constructed as spheres which are better able to resist water pressure, or in any other shape most suitable for fabrication. The buoy **87** may comprise of several modular elements assembled together, so that the size may be easily adapted to different power rating of WEC **86**, or to facilitate repair. Mooring rings **33** or alternative suitable mooring points are provided on the buoys **87**, so that the WEC **86** can be couple to other similar WECs **86** or anchored to the seafloor **45**. Mooring point may also be provided at the base of the spars **27** when the buoys **87** are made of material not suitable for such installation.

WECs **86** are coupled together in numbers, in order to form large power generating systems. FIG. **11** shows a few interconnected WECs **86** floating on the ocean surface **35**, connected by an underwater transmission cable **26** to the electrical grid on land. The WEC **86** may comprise of nacelle **22** or **82**. The WEC **86** are coupled in a similar manner described earlier to couple WECs **20**, which allow each of the WECs **86** to heave and pitch independently. The coupling device **23** shown in FIG. **11** comprises of marine fenders **31**, but may be constructed in alternative ways, comprising of various coupling devices and other means. Appropriate cable supports **25** are provided where required for crossing of the cable bus **24** between the WECs **86**. Higher numbers of WECs **86** may be secured together in a similar configuration as shown in FIG. **11**, or in some other configurations. The cable bus **24** is shown secured on the surface of the spars **27**, but may be installed within internal cable ducts provided within the WECs **86**. Appropriate numbers of mooring lines **43** and mooring buoys **46** are used to secure the installation to the seafloor **45**. The PTOs within larger installations may be connected in separate clusters by several networks of cable bus **24**, and with several underwater transmission cables **26** for increased reliability.

A side view of interconnected WECs **86** fitted with nacelle **82** pitching in the waves is shown in FIG. **12**. The maximum pitching angle of the WECs **86** occurs when the distance between the buoys **87** is about half the wavelength of the waves. The WEC **86** may be easily optimised for the wave characteristics at a given location by selecting the most suitable length of the spars **27**, or the size of the buoys **87**. With many buoys **87** heaving in close proximity and also acting as generators of waves, the interference pattern of these waves are difficult to predict in real time. During operation of large numbers of interconnected WECs **86**, some of the buoys **87** may experience little or no heaving motion, being in areas of destructive interferences. However the operation of the WECs **86** is not permanently affected, as all the buoys **87** of a particular WEC **86** do not remain together for extended period in an area of destructive interferences, or in a state of synchronised heaving motion. Actually, the dip in power output of a few WECs **86** would be compensated by other WECs **86** within the installation experiencing more intense pitching movements. The constant changing direction of the waves due to the interference has no significant consequences on the power harnessing ability of the WECs **86**, as each of the PTOs independently and almost instantly reacts to the changing direction of the waves.

Embodiment of a WEC comprising of a plurality of PTOs

Another embodiment of the invention shown in FIG. **13** is a single WEC **90** comprising of a plurality of PTOs mounted within nacelles **22**. Other embodiments of

WEC **90** may comprise of nacelles **82**, with respective PTOs. The WEC **90** shown in FIG. **13** is equivalent to the layout of interconnected WECs **86** shown in FIG. **11**. Both have the same general layout configuration, and the same numbers of PTO within nacelles **22**. Other embodiments of WEC **90** may be constructed to different scale, according to different layout configurations, or with different numbers and type of PTOs. In general, embodiments of WEC **90** comprises of a plurality of spars **27** connecting a plurality of flotation buoys (buoys **87**, **91**, and **92**), and a plurality of PTOs, all permanently assembled together as a single unit, in a manner so that the PTOs can experience independent pitching movements. In any embodiments of the WEC **90**, the PTOs need to be firmly secured to at least two separate spars **27**, each spar **27** resting on two different buoys so that the heaving motion of the buoys can cause the PTO to pitch from side to side. In order to harness waves from all direction most effectively, the PTOs are supported by three set of spars **27** symmetrically disposed, with each spar **27** resting on a separate buoy, as shown in FIG. **13**. A given buoy within the embodiment in FIG. **13** would then accommodate a single, or up to three spars **27**, each spar **27** secured to a different PTO.

The size of the buoys within embodiments of WEC **90** varies, depending on the forces acting on them, and which depend on the numbers of spars **27** mounted on them. The size of buoy **87** is designed to support only a single spar **27**. The buoy **91** is larger in order to support two set of spars **27**, and provides twice as much upthrust compared to buoy **87**. The buoy **92** is made even larger as it support three set of spars **27** and provide thrice as much upthrust, compared to buoys **87**. The embodiment shown in FIG. **13** comprises of a single larger buoy **92**, but other larger embodiments of WEC **90**, with different layout of buoys, may comprise of a plurality of buoys **92**. It should be noted that the buoy **87** is used only for illustration purposes to appreciate the comparison between embodiments of the invention as shown in FIG. **11** and FIG. **13**.

When two or more spars **27** are mounted on a single buoy, a flexible base coupling **93** is used to secure each of the spars **27** to the buoys. The base couplings **93** allow each of the connected spars **27** to move independently from each other, as each of the spars **27** is connected through respective nacelles **22** or **82** to other buoys, which are heaving at different phase and pace relative to each other. This arrangement enable the PTOs mounted in their respective nacelles **22** or **82**, to pitch independently from each other. The base couplings **93** may be constructed of various standard couplings devices such as universal couplings, elastomeric couplings, spring couplings, bellow joints, and other similar devices. The base couplings **93** may comprise of custom made mechanical devices or constructed of some soft and flexible material, such as textiles, rubbers, etc.

In large embodiments of the device **90** comprising of a high numbers of buoys (buoys **87**, **91**, and **92**), the spar **27** may include telescopic joint or suitable linkage mechanisms, to allow the length of the spars **27** to stretch or contract freely by some amount. This reduces the damping forces on the heaving movements of the buoys, caused by the buoys themselves pushing upon each other through the connecting spars **27**. Cable bus **24** running across the flexible base **93** are installed in appropriate supports to prevent damage and premature wear. The WEC **90** may be coupled to other similar WECs, according to method discussed earlier by the use of coupling devices **23**, to form even larger installations.

* * *

The invention has been described with reference to certain preferred embodiments thereof. The invention is not limited to these preferred embodiments, and many other variations are possible Embodiments of the invention are also not intended to be limited by the drawings herein, but may be carried with other choice of designs, and methods of construction. The invention may have embodiments within a form which does not provide all the features and benefits set forth, as some of the features may be used or practice separately from others. It should be understood various omission, substitution, and changes in design may be made without departing from the spirit of the invention. The invention is also not limited by construction material. Embodiments of the invention may be constructed with material most suitable to the particular size of the embodiments and the condition of operation. The scope of the invention is indicated by the appended claims rather by the foregoing descriptions.

CLAIMS

The embodiments of the inventions in which an exclusive property or privilege is claimed are as follows:

1. A wave energy harnessing system, comprising:
at least two buoyant bodies;
connecting elements to secure said buoyant bodies adjacent to each other, wherein said buoyant bodies can feely articulate about said connecting element;
said buoyant bodies, each comprising at least one power extraction means, wherein said power extraction means is operated by the relative movement of said buoyant body to a reaction mass mounted thereof ; and
a power connection means which connect and combine the energy extracted by said power extraction means mounted on said buoyant bodies.

2. A wave energy harnessing system according to claim **1**, wherein said reaction mass is pivotably mounted to a horizontal pivot shaft secured on said power extraction means.

3. A wave energy harnessing system according to claim **2** wherein said horizontal pivot shaft is rotatably mounted to said buoyant body, such that said horizontal pivot shaft can be positioned perpendicular to the direction of the incoming waves.

4. A wave energy harnessing system according to claim **3**, comprising a self-orientation mechanism which automatically position said horizontal pivot shaft perpendicular to the direction of the incoming waves.

5. A wave energy harnessing system according to claim **1**, further comprising of support means secured said power connection means between said buoyant bodies.

6. A wave energy harnessing system according to claim **1**, wherein said connecting element comprises of articulating mechanical coupling.

7. A wave energy harnessing system according to claim 1, wherein said connecting element comprises of marine fenders secured between said buoyant bodies.

8. A wave energy harnessing system according to claim **1**, wherein said connecting element comprises of mooring chains.

9. A wave energy harnessing system according to claim **1**, wherein said connecting element comprises of synthetic ropes.

10. A wave energy harnessing system according to claim **1**, wherein said power extraction means is mounted within said buoyant body.

11. A wave energy harnessing system according to claim **1**, wherein said power extraction means is mounted externally to said buoyant body.

12. A wave energy harnessing system according to claim **1**, wherein said buoyant body is substantially in the form of a circular platform.

13. A wave energy harnessing system according to claim **1**, wherein said buoyant body is in the shape of a ring.

14. A wave energy harnessing system according to claim **13**, wherein said power extraction means is secured to said buoyant body by support members.

15. A wave energy harnessing system according to claim **1**, wherein said buoyant body comprises of a plurality of buoyant elements firmly secured around said power extraction means.

16. A wave energy harnessing system according to claim **15**, wherein said support member is used to secure each of said buoyant elements to said power extraction means.

17. A wave energy harnessing system according to claim **1**, wherein said power extraction means converts the energy collected from the wave into electrical energy.

18. A wave energy harnessing system according to claim **17**, wherein said power connection means comprises of electrical cable which interconnect said power extraction means.

19. A wave energy harnessing system according to claim **1**, wherein the combined l energy collected by said power extraction means is transmitted by at least one power transmission means.

20. A wave energy harnessing system according to claim **17**, wherein the combined electrical energy from said power extraction means is transmitted by at least one power transmission cable.

21. A pitching-type wave energy harnessing device for the purpose of extracting energy from incoming waves in any direction, comprising:

a substantially symmetrical buoyant body in the horizontal plane about a central vertical axis;

a support frame rotatably mounted to said buoyant body, wherein said support frame is free to rotate about the vertical axis of said buoyant body; and

a power extraction means mounted on said support frame, wherein said power extraction means would aligned in the direction of the waves for maximum power extraction, while said buoyant body maintains substantially a permanent orientation relative to the ocean surface.

22. A pitching-type wave energy harnessing device according to claim **21**, comprising of a horizontal pivot shaft rotatably mounted on said support frame, wherein the axis of said horizontal pivot shaft and the vertical axis of said buoyant body substantially intersect.

23. A pitching-type wave energy harnessing device according to claim **22**, wherein said power extraction means comprises of a reaction mass with a low center of gravity mounted to said horizontal shaft, such that the energy is extracted by resisting the relative movement between said reaction mass and said support frame.

24. A pitching-type wave energy harnessing device according to claim **23**, wherein the unbalanced lateral and radial forces acting on the bearings supporting said support frame enable rotation of said support frame, such that said horizontal pivot shaft would always align perpendicular to the direction of the waves.

25. A pitching-type wave energy harnessing device according to claim **24**, wherein said power extraction means comprises of at least one hydraulic ram operated by the relative movements between said reaction mass and said support frame.

26. A pitching-type wave energy harnessing device according to claim **24**, wherein said power extraction means comprises of at least one electrical generator operated by the relative movement between said reaction mass and said support frame.

27. A pitching-type wave energy harnessing device according to claim **24**, wherein said horizontal pivot shaft is firmly lock to said reaction mass, thereby causing rotation of said horizontal pivot shaft, when there are relative movements between said reaction mass and said support frame.

28. A pitching-type wave energy harnessing device according to claim **27**, wherein a power transmission means is couple to said horizontal pivot shaft to drive a rotating generator.

29. A pitching-type wave energy harnessing device according to claim **26**, wherein electrical energy from said electrical generator is transmitted to a power transformation means located on said buoyant body, through rotary electrical connectors.

30. A pitching-type wave energy harnessing device according to claim **29**, wherein said power transformation means transforms the power supply from said electrical generator into a usable form of electrical power supply.

31. A pitching-type wave energy harnessing device according to claim **25**, wherein energy from said hydraulic ram is transmitted through a rotary hydraulic connecting means to a hydraulic power system located on said buoyant body.

32. A wave energy harnessing device, comprising:

a plurality of buoyant elements disposed at regular interval over an area of the ocean surface in a lattice layout;

a plurality of rigid connecting members, each pivotably coupled to at least two of said buoyant elements, wherein said buoyant elements can heave independently in the waves;

a plurality of power extraction means, each firmly secured to at least one connecting member, wherein the movement of said connecting members enable said power extraction means to harness energy from waves; and

a power connection means interconnecting and combining the power of said power extraction means, wherein said power connection means is installed on said connecting members and said buoyant elements.

33. A wave energy harnessing device according to claim **32**, wherein each of said connecting members is secured to at least three of said buoyant elements symmetrically disposed, thereby said connecting member can pitch with relative uniformity in all direction of waves.

34. A wave energy harnessing device according to claim **32**, wherein each of said power extraction means comprises an orientation mechanism which align thereof, in relation to the direction of the waves.

35. A wave energy harnessing device according to claim **32**, wherein said power extraction means converts useful energy collected from the wave into electrical energy.

36. A wave energy harnessing device according to claim **35**, wherein said power connection means comprises of electrical cables which combine the electrical power of said power extraction means.

37. A wave energy harnessing device according to claim **35**, wherein the combined electrical energy from said power extraction means is transmitted by at least one power transmission means.

38. A method of deploying a wave energy system comprising a plurality of buoyant bodies, the method comprising:

securing power extraction means on respective buoyant bodies in a port facility;

securing plurality of said buoyant bodies together, according to desired layout of said wave energy system, by the use of connecting elements;

installing support means between said buoyant bodies where required;

installing power connection means to link said power extraction means;

securing said power connection means on said buoyant bodies and said support means;

tugging said wave energy extraction system to site of operation;

mooring said wave energy system at site of operation; and

connecting said wave energy system to a power transmission system.

39. A method for expanding the power capacity of an existing wave energy system comprising a plurality of buoyant bodies, the method comprising:

securing power extraction means on respective buoyant bodies in port facility;

tugging said buoyant bodies to installation site;

securing said buoyant bodies to existing installation with connecting elements;

installing support means to said buoyant bodies;

installing power connection means to link said power extraction means to said existing wave energy system;

adding mooring system to modified wave energy system, if required; and

increasing the capacity of the power transmission, if required.

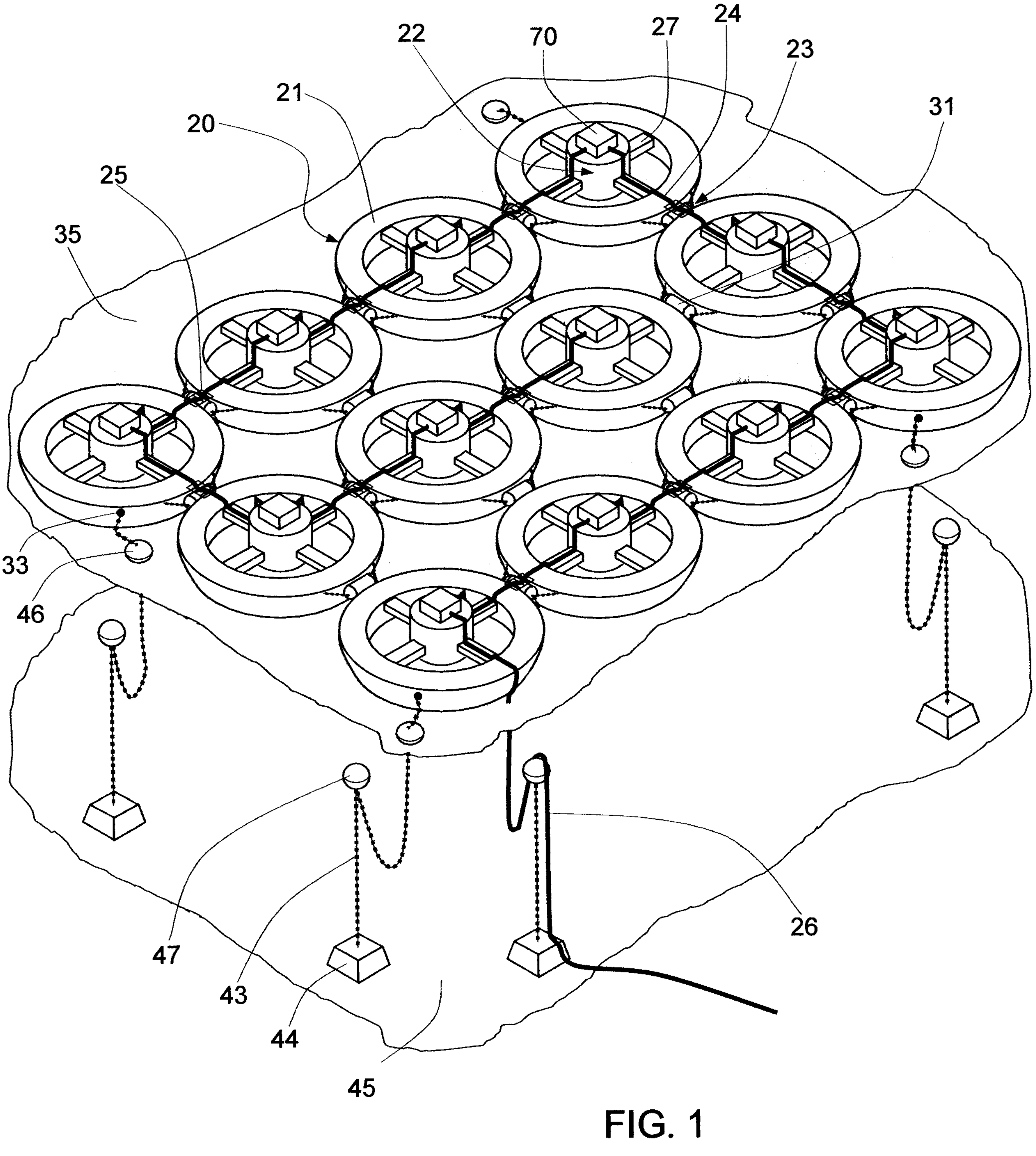


FIG. 1

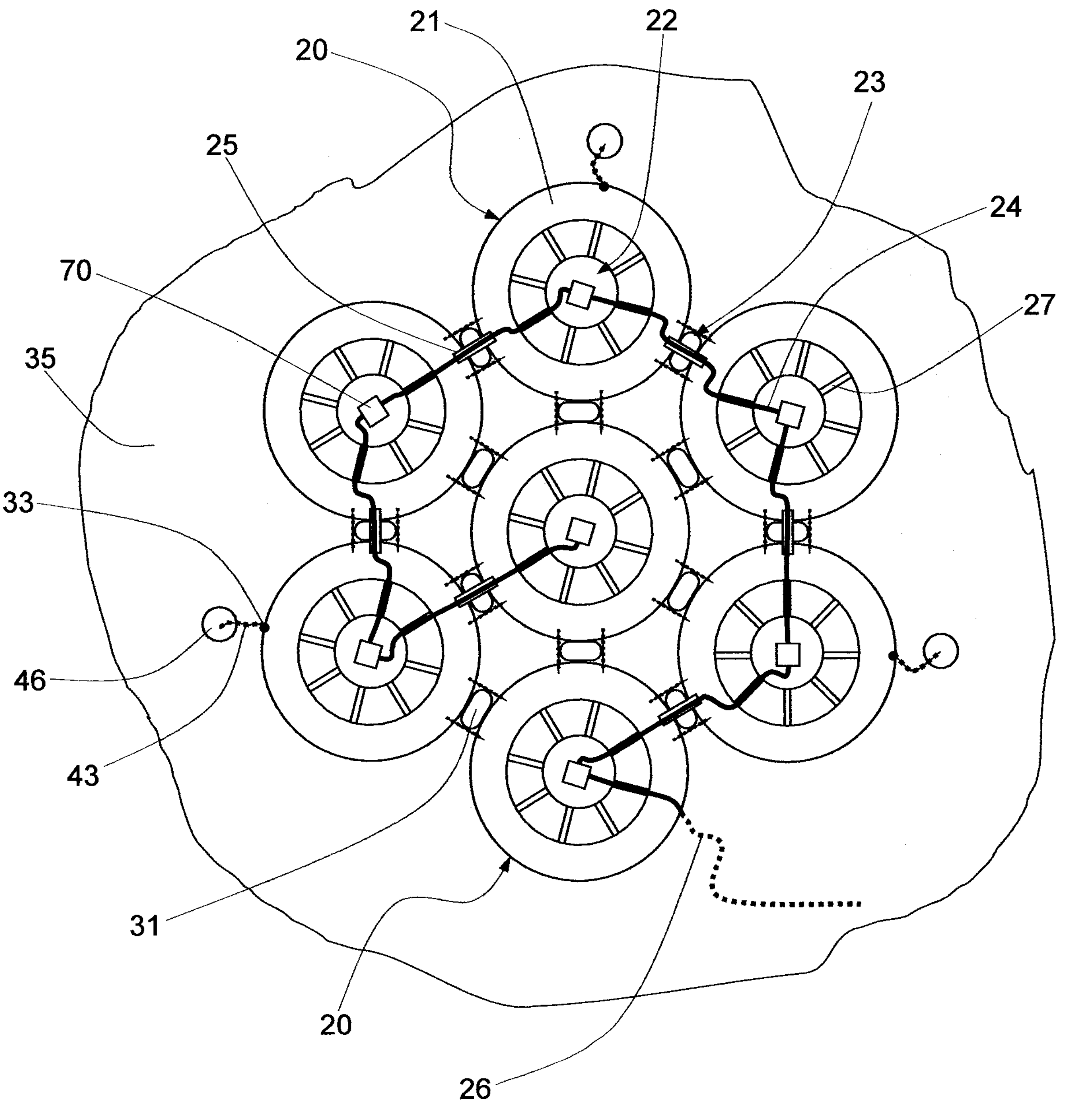


FIG. 2

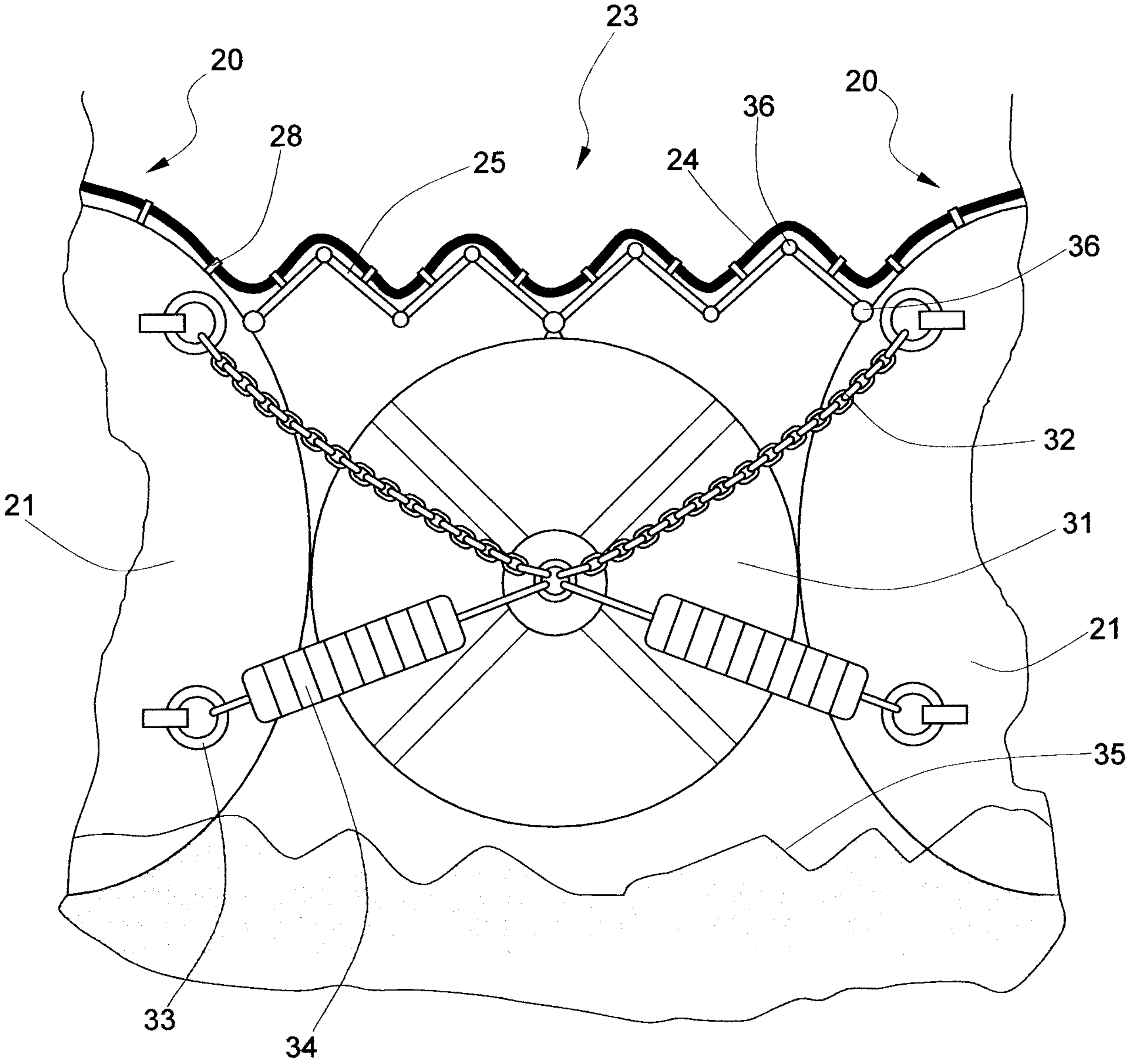


FIG. 3

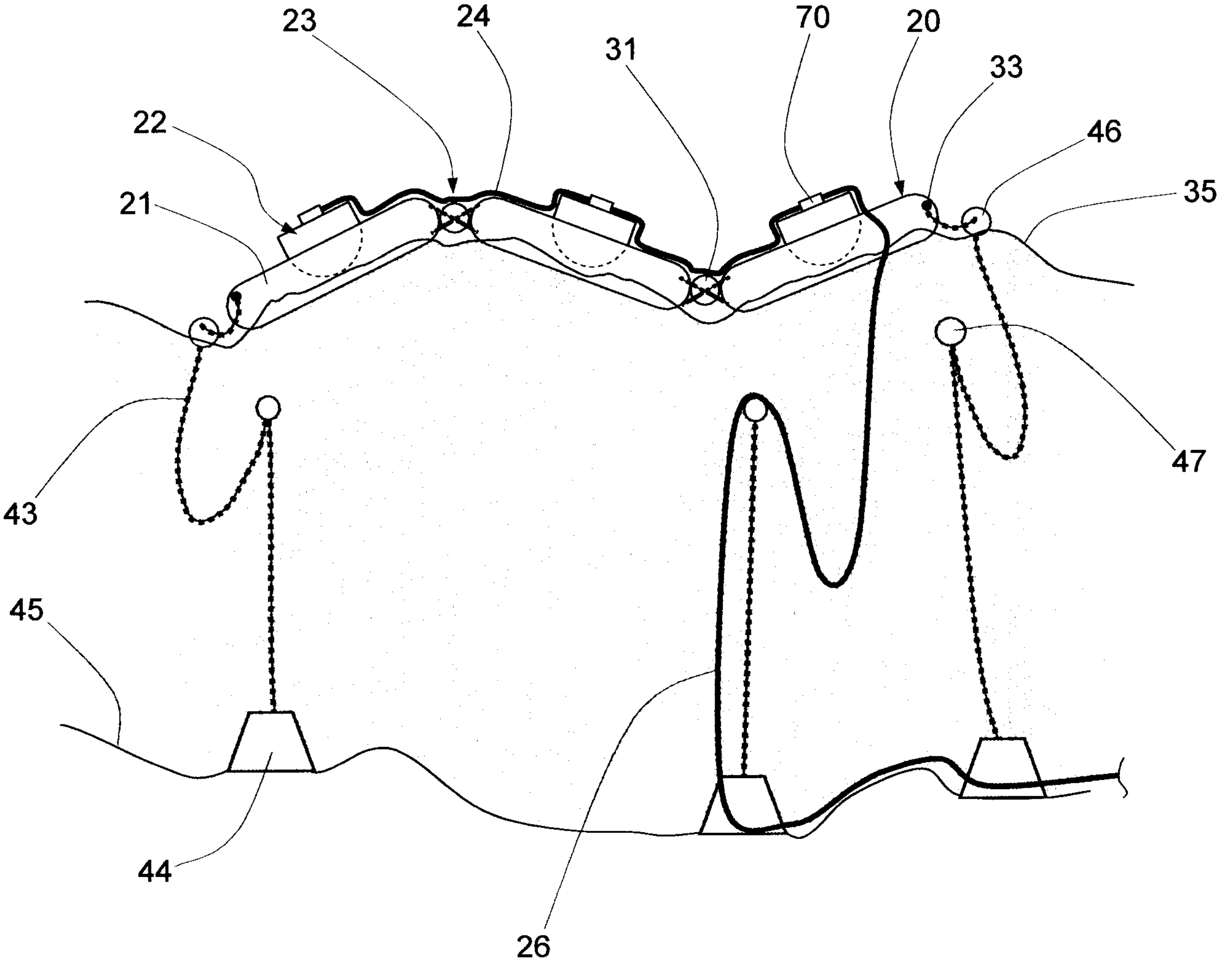


FIG. 4

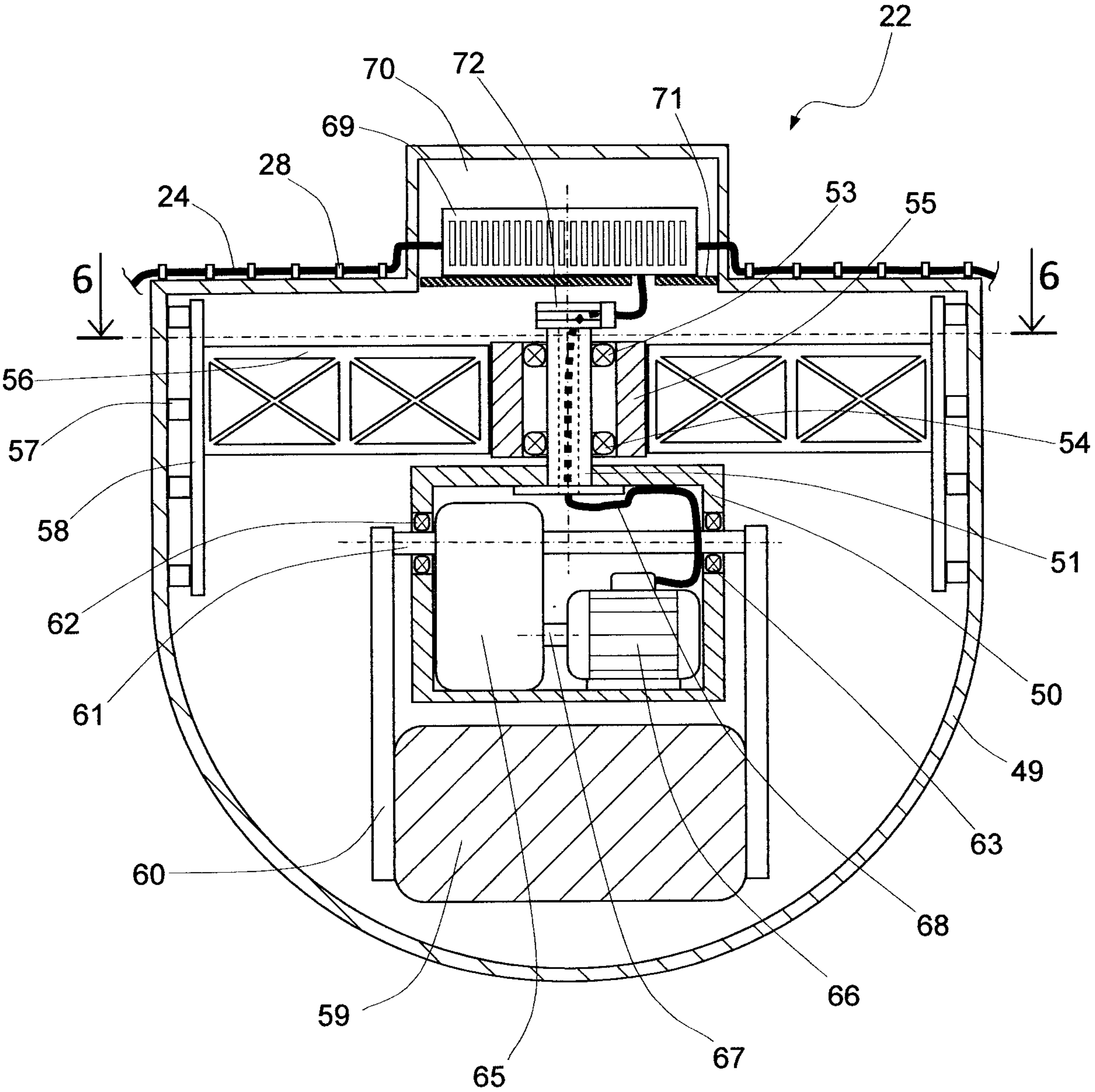

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FIG. 5

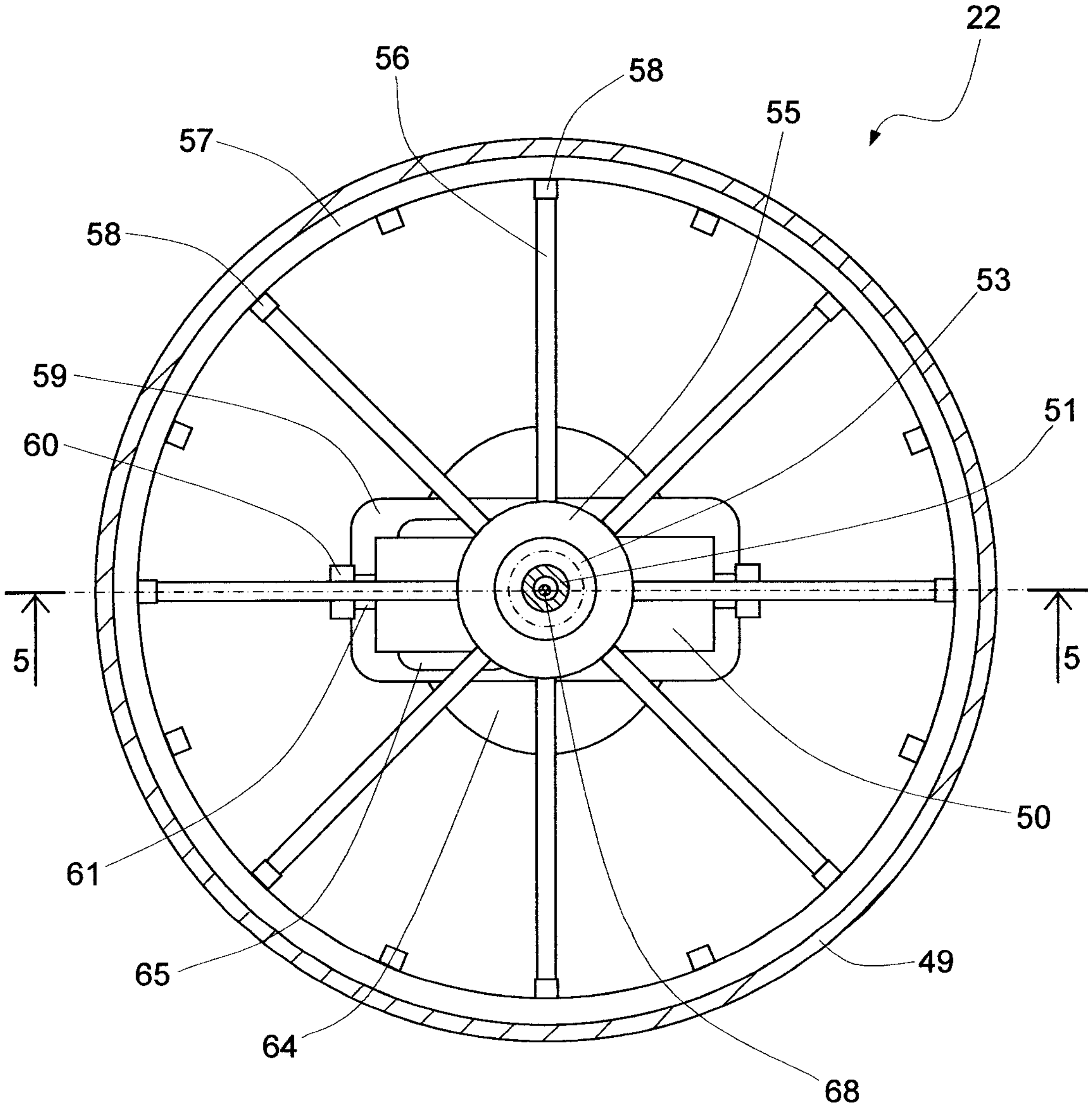

FIG. 6

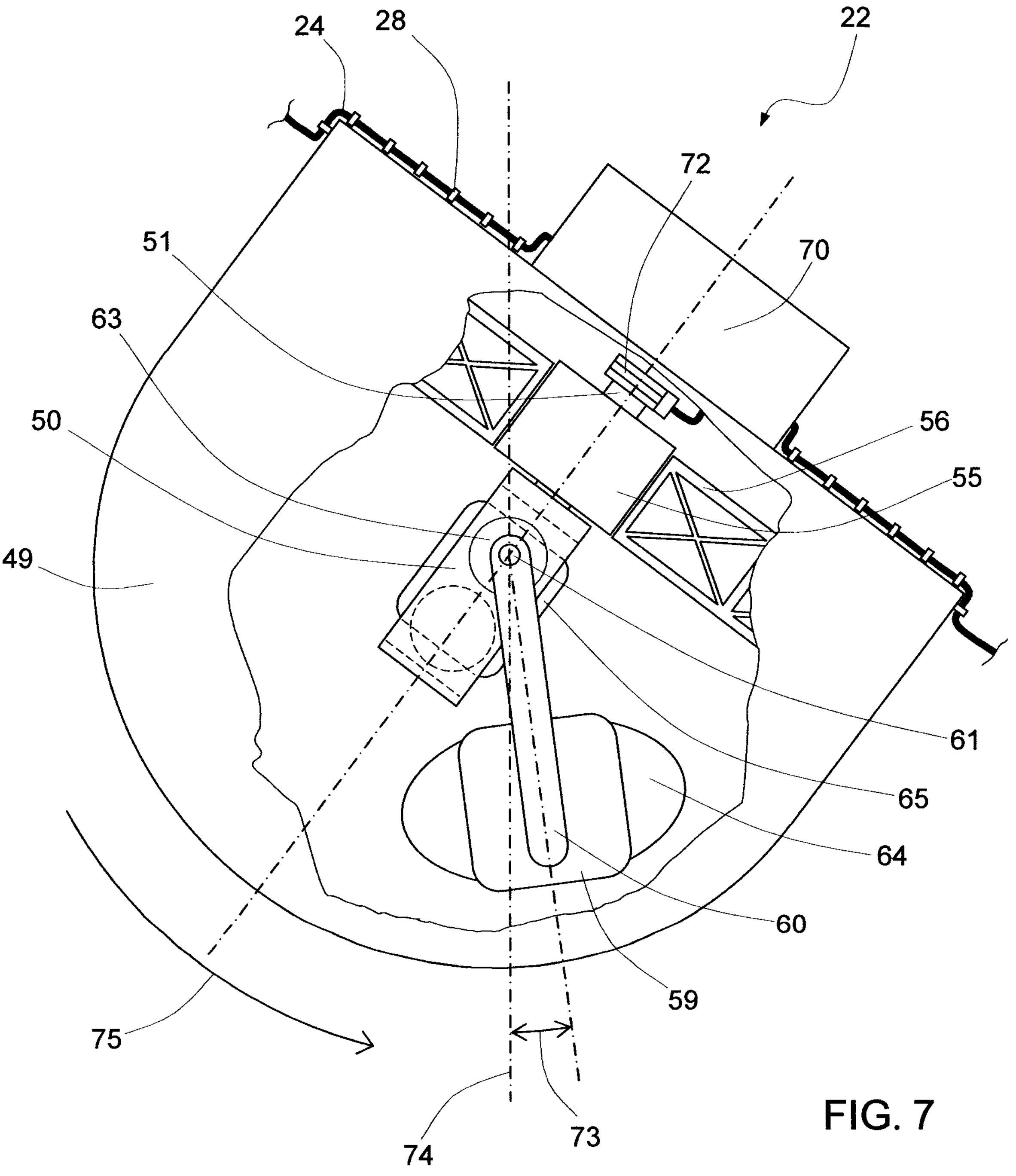

FIG. 7

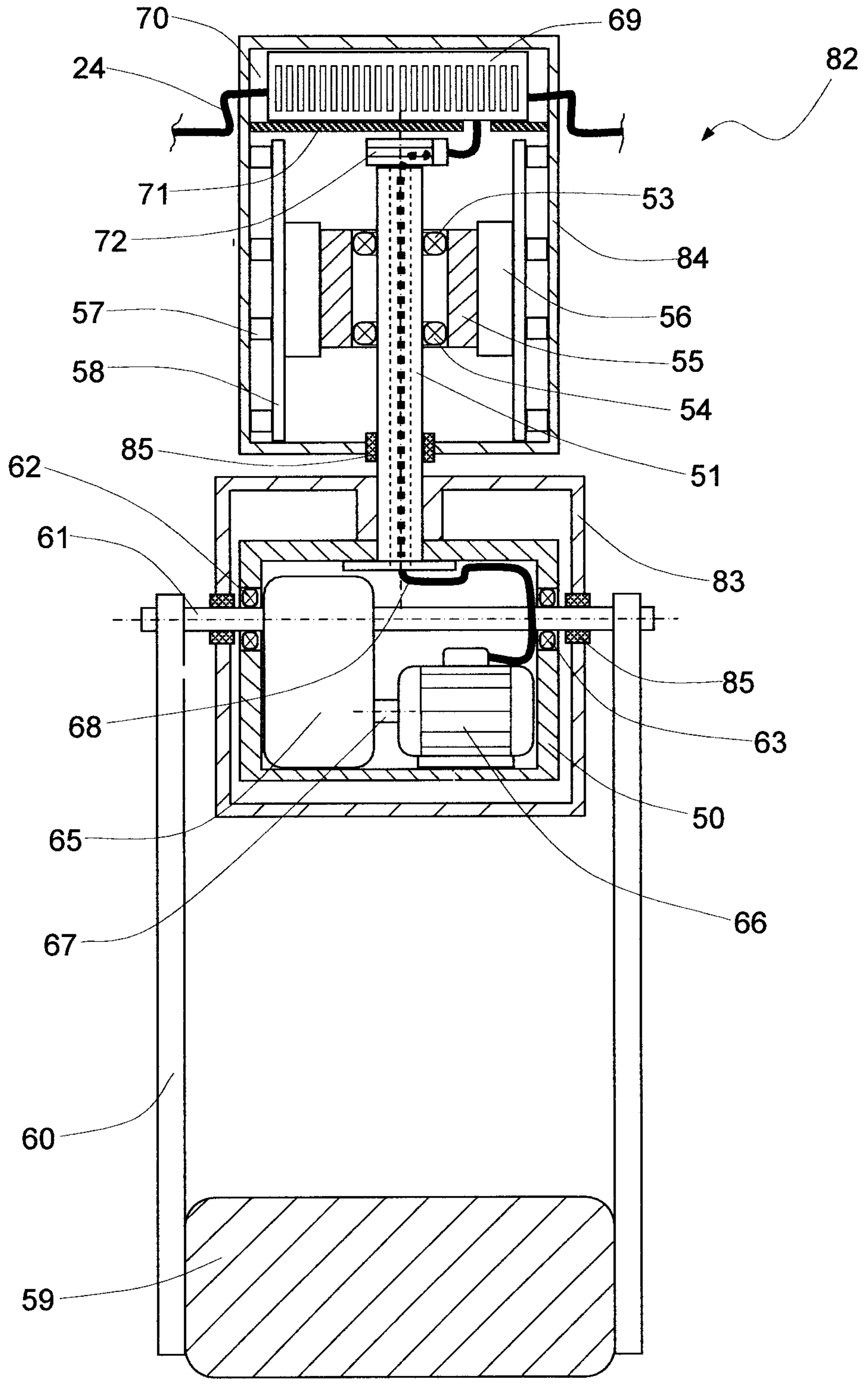
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FIG. 8

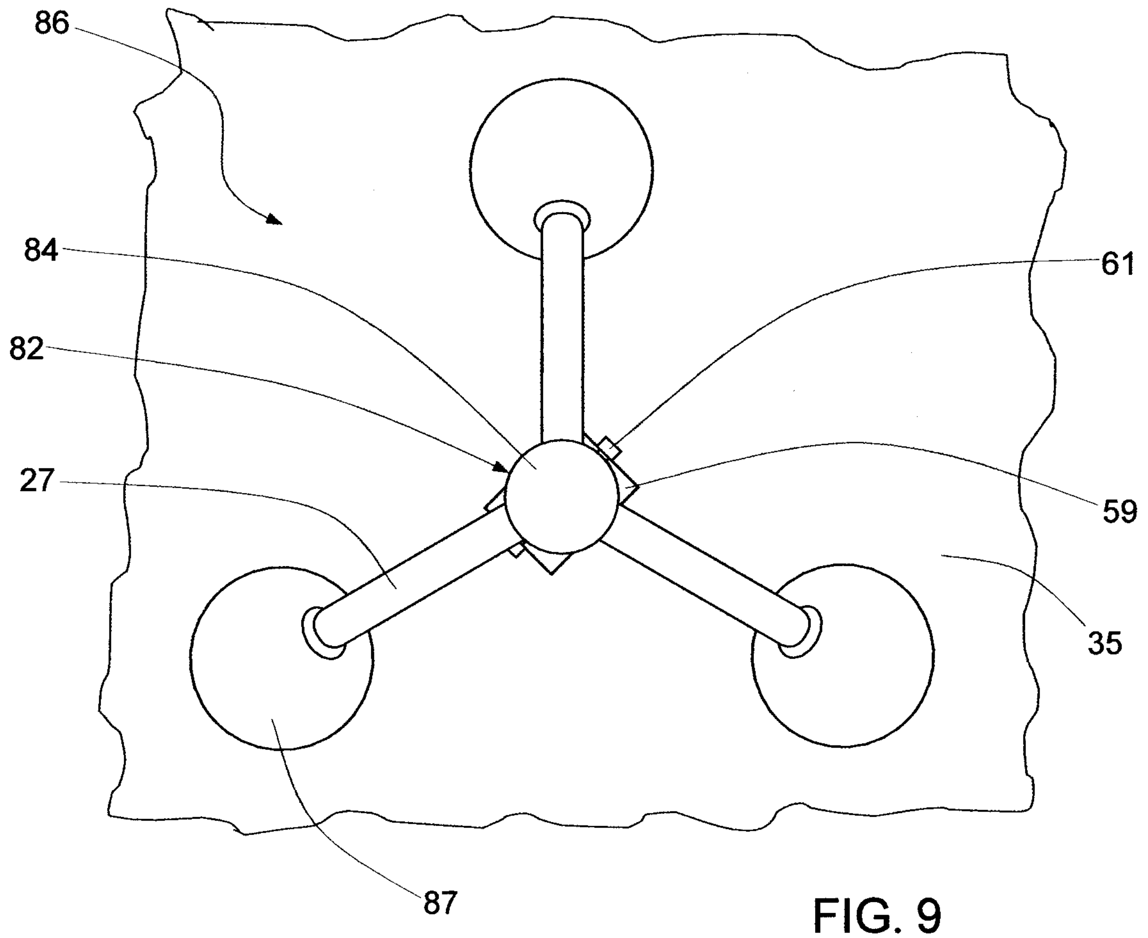


FIG. 9

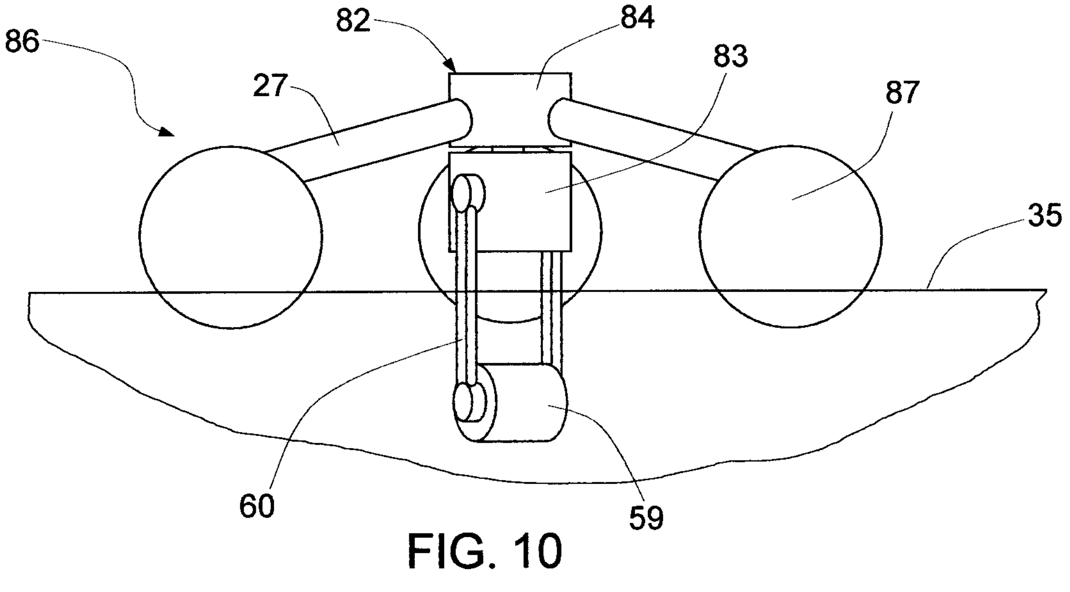


FIG. 10

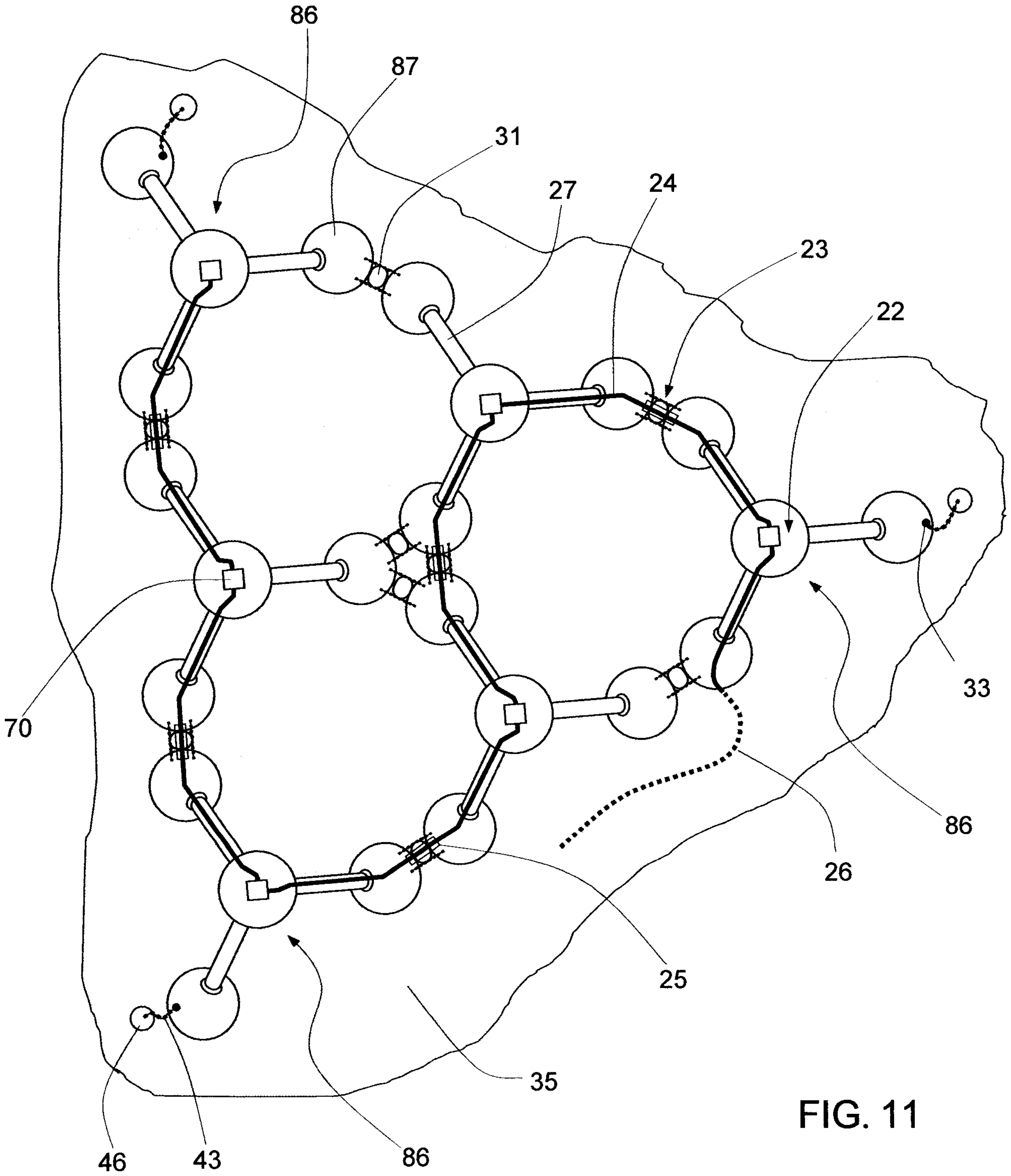


FIG. 11

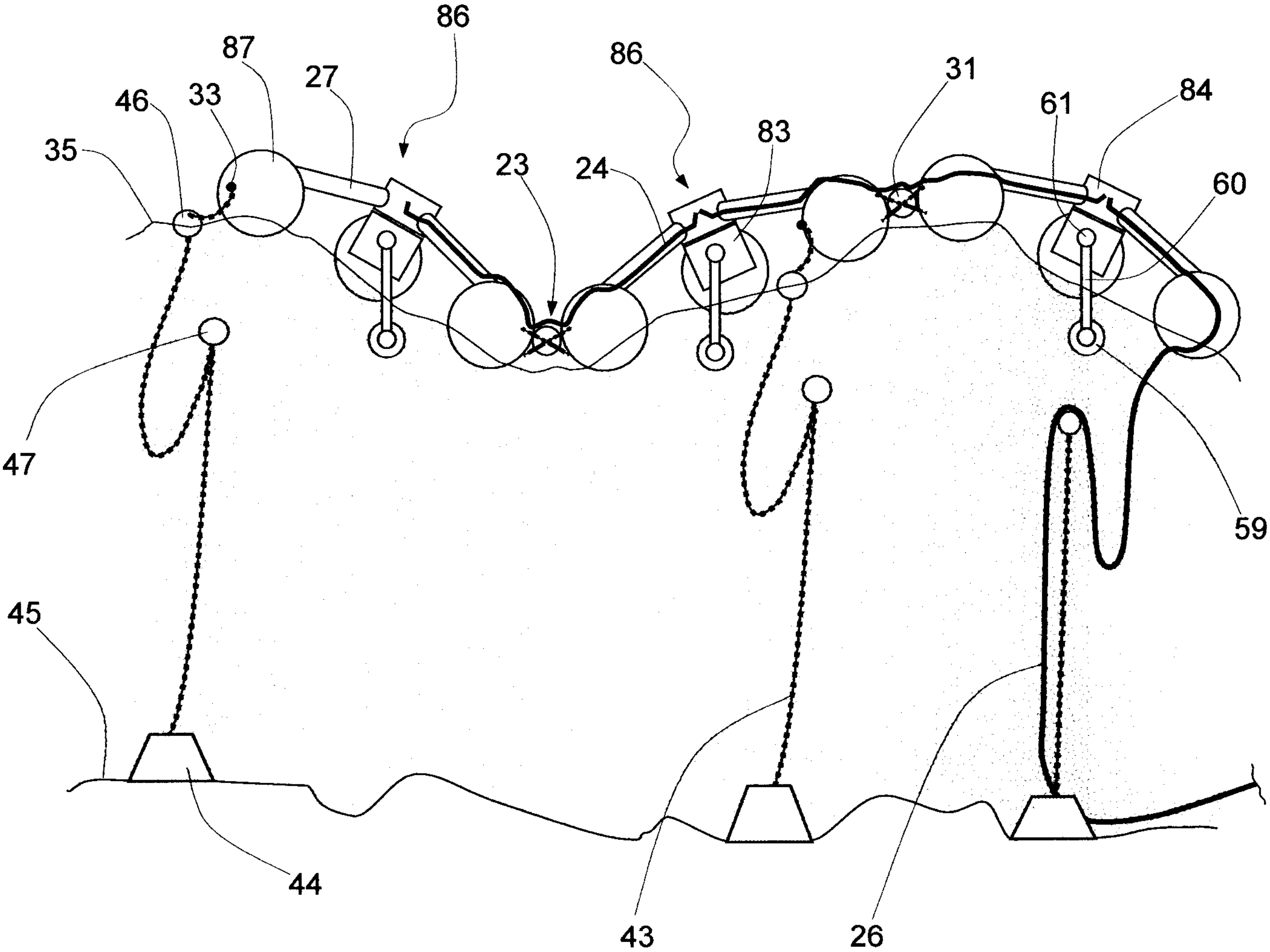


FIG.12

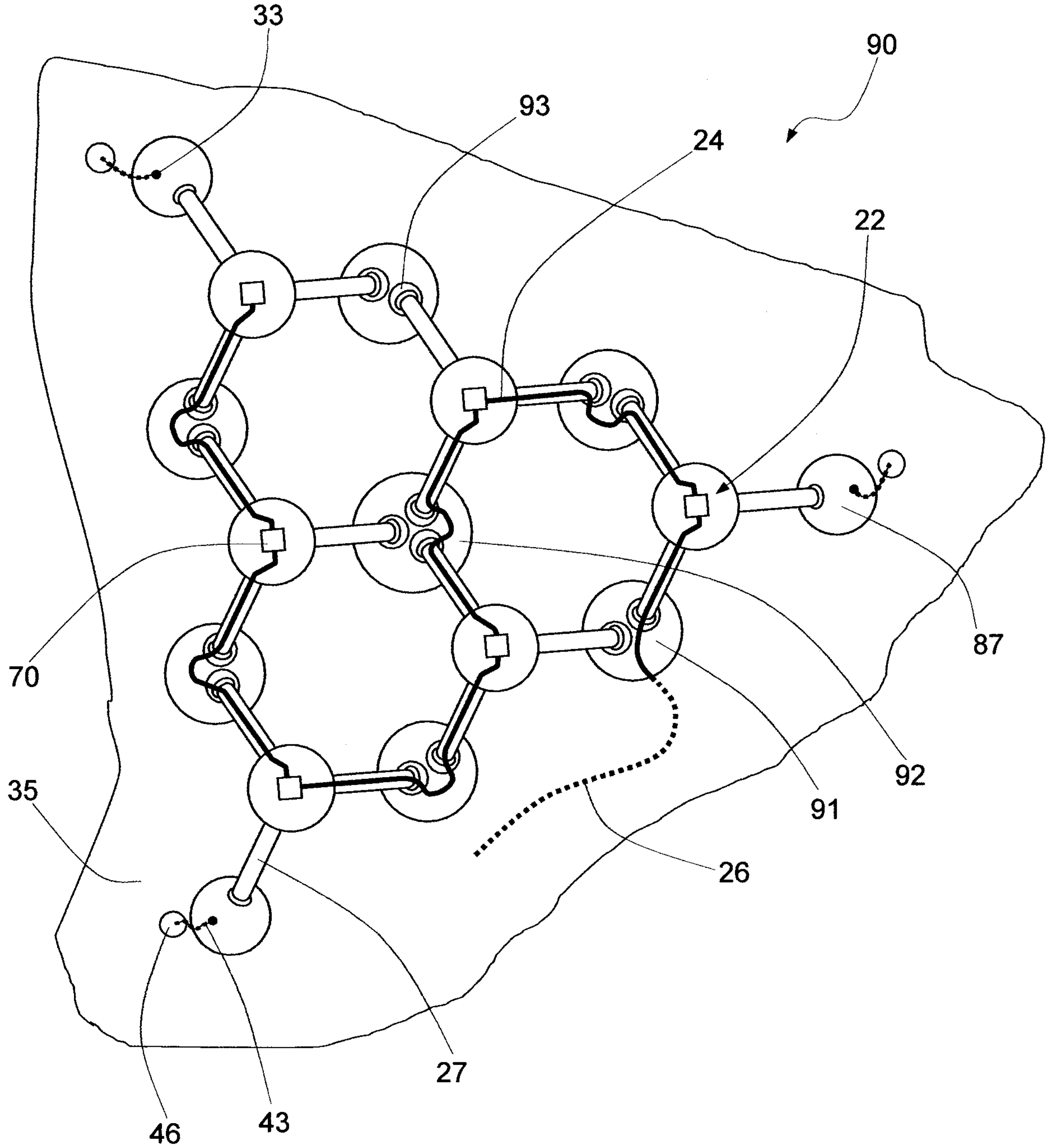
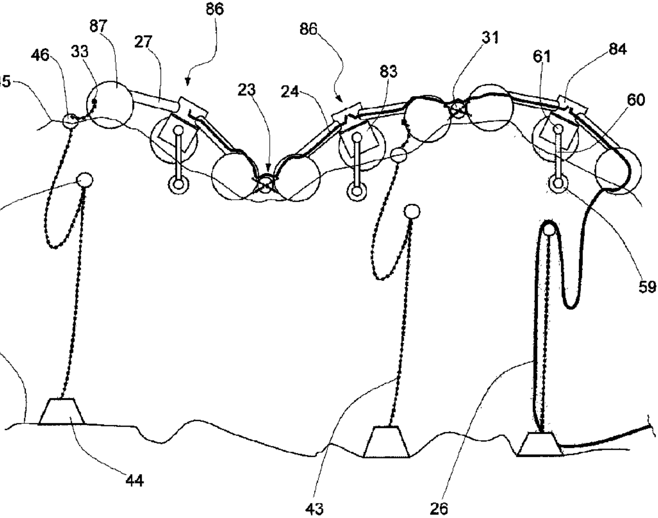


FIG. 13



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