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(71) Applicant *(for all designated States except US)*: **MARINE POWER SYSTEMS LIMITED** [GB/GB]; 27, Downleaze, Cockett, Swansea South Wales SA2 0GQ (GB).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **FOSTER, Graham** [GB/GB]; 27, Downleaze, Cockett, Swansea South Wales SA2 0GQ (GB). **STOCKMAN, Gareth Ian** [GB/GB]; 27, Edgeware Road, Uplands, Swansea South Wales SA2 0NA (GB).

(74) Agent: **CHAPMAN, Molony**; Cardiff Business Technology Centre, Senghennydd Road, Cardiff South Wales CF24 4AY (GB).

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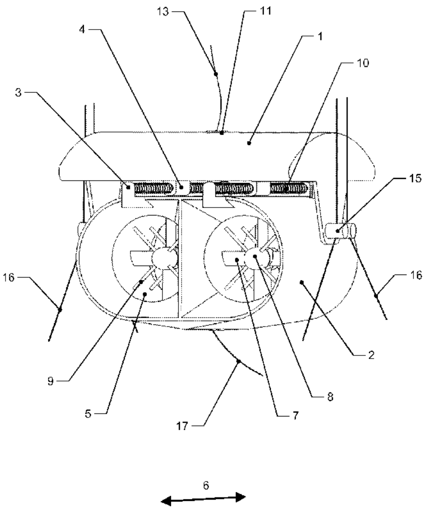
(54) Title: SUBMERSIBLE TURBINE APPARATUS

Figure 4



(57) Abstract: The apparatus comprises a turbine to be driven when submergedin a current of water; lift means for generating a lift force upon the turbine means when the turbine is submerged in the current;securing means for securing the apparatus to a tether; andstabilising means for dynamically stabilising the apparatus in a first configuration in the current when the current flows in a first direction, and in a second configuration when the current flows in a second different direction. The geometrical relationship between thesecuring means, the centre of drag on the apparatus and the centre of lift of the apparatus in the first configuration is different to the corresponding geometrical relationship in the second configuration.

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Submersible turbine apparatus

The present invention relates to submersible turbine apparatus for extracting energy from flowing water, and in particular from marine tidal currents.

In recent years there has been a greater acceptance of the need to exploit renewable energy on a scale where it significantly contributes to global energy production. A combination of government targets, media representation of the issues associated with non-renewable energy sources, and ever increasing energy costs have created a powerful driving force for the development of renewable energy systems.

The negative impacts of fossil fuels on our environment are highly publicised throughout the world, as are the problems and high costs associated with nuclear energy. The harnessing of the huge natural abundance of renewable energy on the other hand is constrained merely by our capability of capturing and supplying it at an economically viable price.

A promising renewable energy source is tidal stream power – a kinetic energy resource available in areas of high tidal flow. Tidal Turbines have emerged as a potentially viable solution for extracting energy from these fast flowing tidal streams, however, current devices have many limitations with no device yet able to exploit the resource in a commercially profitable way.

Existing designs for generating electricity from tidal power can be divided into four main categories: gravity based turbines, pile mounted turbines, floating turbines supported by surface vessels, and hovering turbines that sit in between the seabed and surface. Each of these different approaches has its own inherent advantages and disadvantages.

Gravity based turbines are positioned on the seabed and use the weight of the mounting structure to keep the turbine in position, This approach has some advantages: most types reside well under the surface and therefore away from the influence of waves and do not interfere with shipping; and generally they are of a simple design and construction.

However, gravity based devices also have technical challenges associated with them that tend to mitigate the potential advantages. Installation requires specialist lifting barges that can transport the device to the site and then lower it into position on the sea bed. This is a very difficult and costly operation, especially in areas of fast flowing currents which may be compounded by stormy condition.

The ability to maintain gravity based turbines is also a serious concern. Mechanical and electrical equipment such as generators, gearboxes, pumps and inverters have finite lifetimes and will almost certainly require some degree of maintenance before the end of their life cycle and a change is required. As a result, the same specialist lifting barges that are used to install the devices are required to periodically raise them to the surface for servicing.

Some designs try to alleviate this problem by using a cassette or module containing the main wearable components, but this adds significant complexity to the device and undoes the advantage of simplicity. The part of the device left on the seabed then becomes completely unserviceable and one only has to look at how quickly sunken ships are colonised by marine life to assess how impractical this may be.

Another disadvantage with location on the sea bed comes from the fact that the strongest ocean currents, particularly those arising from tidal streams, are closer to the sea surface. Tidal currents close to the sea bed tend to have considerably lower velocities and therefore lower energy densities due to the drag from the sea bed. Consequently, seabed mounted turbines cannot harness the optimum currents, and efficiency is considerably reduced as a result. An example of a seabed located device with a removable cassette is disclosed in GB2408294A

Pile mounted devices typically comprise a large pole that is piled into the seabed and extends from the sea bed to slightly above the sea surface. The turbine is mounted on the pole and usually can be raised and lowered up or down the pole.

The benefits of this approach are that the turbine is securely positioned in the current flow and the device is extremely unlikely to ever come loose or be overturned by the flow. The turbine is also easy to maintain as it can be brought above the water line for maintenance.

Pile mounted devices do however have several drawbacks. Construction costs are substantial as the driving of large piles into the sea bed is a major civil engineering exercise. The piling operation can also cause significant disturbance to marine life, and planning consent may therefore be withheld in some areas. Removing pilings at the end of the device’s working life is a comparable operation to their installation, so that the de-commissioning costs for pile mounted devices are considerable.

Pile mounted devices have the added disadvantage that sites suitable for their use are limited. Pile mounting in very deep water is not feasible as the installation becomes too difficult and the stresses on the pole from the current too great. The sea bed also has to be of a type suitable for receiving and retaining pilings. An example of a pile mounted device with a mechanism for raising and lowering the turbines is disclosed in WO2000/050768A1.

Surface bound turbine devices have been developed as a way to solve the problems with seabed mounted devices. They typically comprise of a large floating vessel from which a turbine can be suspended and thus exploit a current flow. The advantages of this approach are that the suspended turbines can relatively easily be raised above the waterline for service access, and that the whole device can be towed into position (or away for a major refit) by a relatively small craft. They also can be deployed in deep water by using long mooring lines and they can operate in the fastest flowing area of the current stream.

However, surface devices still have some serious inherent problems. Most obviously they are exposed to the extreme violence that sea is capable of unleashing during the storms and hurricanes often seen in prime sites for their use. This problem is exacerbated by being moored to the sea bed which means they will try to fight the sea rather that ‘riding it out’ as a ship might. Inevitably surface bound devices in exposed locations will be damaged by storms and their use will be limited to sites sheltered from such events.

In addition, surface devices have the disadvantage of being unsightly. Whilst this may not seem of the greatest significance, if the present public reaction to wind farms is any precedent then this may they become a significant factor in the future, and limit the locations in which they can be deployed.

Surface devices also interfere with shipping because they take up a large area on the surface. Even if they can be positioned to avoid major shipping lanes, or if shipping lanes can be moved, accidents are inevitable, with the potential for a great deal of damage to both parties. An example of a surface bound device with retractable turbines is disclosed in US7105942.

Hovering turbine devices have been proposed with some of the advantages of both seabed and surface devices, without the disadvantages. They can be positioned deep enough to be clear of surface waves and shipping, but high enough to reside in the strongest currents, and they can operate in deep water with the use of long mooring lines.

However, hovering devices still have associated difficulties. In order to avoid the maintenance issues of seabed mounted devices they must be raisable and lowerable in as way that is better than simply hoisting the device and its mooring weights out of the water – otherwise specialist lifting cranes similar to those for seabed mounted devices are needed.

Another problem with hovering devices is the difficulty of maintaining them at the desired depth in the current stream. As the current increases, the resultant drag force will tend to pull the device downwards. Unless this tendency is counteracted or small compared to the overall lift possessed by the device, then its height in the water will vary considerably and may result in a collision with the sea bed.

A further problem with hovering devices is the difficulty of maintaining the dynamic stability of the device in the current stream. Generally, dynamic stability is achieved by positioning the centre of drag behind the tethering point relative to the direction of flow. This is easy to achieve if the device only operates in a current that flows in one direction. However, if the current changes direction, as in tidal flows, then the device must be able to turn to maintain a dynamically stable attitude to the flow. If it is now considered that the device must have some sort of power take off cable and will most likely have more than one mooring line, then twisting of the device every time the current turns will result in cable tangles that will render the device unserviceable.

The above problem of dynamic stability is compounded by the fact that the substantial lift force required by a hovering turbine must act through the tethering point or the device will tilt and not directly face the current. In addition the relationship of the tethering point and lift force is itself subject to the rules of dynamic stability: the centre of lift must be some way above, as well as in line with, the tethering point or else the device will have a tendency to roll upside down.

Therefore the centre and magnitude of lift, the centre and magnitude of drag, and the tethering point must all be in a relationship that allows the device to operate in a stable and level manner in the current stream. Furthermore a way must be found to keep this stable relationship when the current direction changes if a hovering device is to be suitable for use in tidal currents.

It can be appreciated that there are considerable difficulties with all types of tidal turbine devices. However, the main disadvantages with sea floor and sea surface devices, such as slower currents close to the sea bed and storms on the sea surface, are absolutely fundamental and cannot be solved by device design. On the other hand, the main problems with hovering devices are of a technical rather than fundamental nature.

It is a reasonable conclusion that hovering type turbine devices offer an optimum solution for extracting energy from tidal streams if the technical problems of maintaining the stability of the device in a bi-directional current can be solved.

There are other considerations that apply to all types of turbine device. The rotation of a turbine about an axis in one direction generates an equal yet opposing torque on the main structure in the opposite direction, requiring a counter-torque in order to maintain stability of the turbine. A solution is side-by-side turbine configurations whereby opposing torques from the individual turbines cancel one another out, maintaining stability of the device.

The harming of marine life, particularly marine mammals such as seals and dolphins, is a concern with devices with exposed blades. Current thinking suggests that the relatively slow movement of the blades is unlikely to harm these creatures; however, wind turbines were originally thought not to harm bird life but now planning is being denied for some sites for this very reason. It may be the case that ‘dolphin friendly’ marine turbines are the norm in the future.

As a result of the above considerations, there exists a need to develop an improved tidal turbine capable of generating renewable energy from ocean currents. Such a device should be a hovering tidal turbine as the disadvantages with sea bed and sea surface positioned devices are inherent to where they are situated and cannot be practically solved technically.

Furthermore, to fully address the above criteria and other factors limiting the development of tidal power, an improved hovering tidal turbine should: provide a solution to maintaining dynamic stability in a bi-directional current; be simple and cost effective to manufacture; be easy to position and install using small and non-specialised surface vessels; be easily raisable and lowerable for routine maintenance; be easy to remove and decommission, have a minimal surface presence when operating with only small marking floats; provide a way of enclosing the blades of the turbine to prevent harm to marine mammals and the snagging of mooring or power lines; and be of a multi rotor design to balance torques.

Attempts to solve some of the above problems have been previously disclosed. For example, W02004083629 A1 discloses a tethered hovering device in which the entire turbine apparatus overturns on its tether in order to align itself with the current direction, but does not permit reconfiguring of the actual apparatus in different current directions.

US20070241566 discloses a hovering device that is selectively fillable with water or air to adjust the buoyancy of the device but has no means to prevent the device tilting in operation or to accommodate changing current directions

US20080012345 discloses a hovering device that is selectively fillable with water or air to adjust the buoyancy and has a layout that permits stable and level operation in a single current direction, but there is no method by which the device accommodate changing current directions

GB2256011 discloses a surface bound device in which a surface float is able to reconfigure itself relative to a nacelle in order to provide operating and servicing configurations, but there is no suggestion of any way for the device to accommodate different current directions.

GB 2441769 discloses a seabed based device with a thruster mechanism for rotating a nacelle relative to a fixed support structure in a vertical axis. The device is not hovering or tethered and is therefore not required to manage the problem of dynamic stability in different current directions

DE102007036810 A1 discloses a pile mounted device with a series of nacelles that are able to rotate about a fixed pylon in a horizontal axis. The device is not hovering or tethered and is therefore not required to manage the problem of dynamic stability in different current directions According to the invention therefore there is provided a novel design of hovering tidal turbine that addresses at least some of the problems and considerations associated with extracting energy from tidal streams, and in particular the ability to accommodate different current directions.

The tidal turbine apparatus according to a first aspect of the invention comprises:

a. turbine means to be driven when submerged in a current of water;
b. lift means for generating a lift force upon the turbine means when the turbine means is submerged in said current;
c. securing means for securing the apparatus to a tether; and
d. stabilising means for dynamically stabilising the apparatus in a first configuration in the current when the current flows in a first direction, and in a second configuration when the current flows in a second

different direction, the geometrical relationship between the securing means, the centre of drag on the apparatus and the centre of lift of the apparatus in the first configuration being different to the corresponding geometrical relationship in the second configuration.

Thus the apparatus comprises more than one body, with the separate bodies being movably connected to each other. At least one of the bodies will be tethered and the other bodies will be untethered and allowed to move relative to the tethered bodies.

A further aspect of the invention provides submersible turbine apparatus comprising

a. turbine means to be driven when submerged in a current of water;

b. lift means for generating a lift force upon the turbine means when the turbine means is submerged in said current;

the apparatus comprising a plurality of bodies which are movably connected to each other, at least one of the bodies being tethered and at least one other of the bodies being untethered and allowed to move relative to the respective tethered body, the movable connection permitting respective tethered and untethered bodies to assume different relative configurations depending on the direction of said current.

The untethered bodies will be able to able to move downstream of the tethered bodies as a result of the drag force placed on them by the current, and this movement can be reversed when the current direction changes so that the movable bodies are always able to position themselves downstream of the tethered bodies.

The movable bodies are also of substantial size so that they contribute a significant proportion of the overall drag of the device. Therefore as the movable bodies move downstream of the tethering point the centre of drag also moves downstream of the tethering point ensuring dynamic stability of the drag force in a bi-directional current.

The lift force required to keep the device hovering at the desired height in the current stream is generated mostly by the tethered bodies in the form of displacement buoyancy. This provides a stable position for the centre of lift that the horizontal position of the tethering point is aligned with so that there is no tendency for the device to tilt as a result of the tethering point and the centre of lift being misaligned.

The vertical position of the tethering point is significantly below the centre of lift to ensure dynamic stability of the lift force, and also directly upstream of the overall centre of drag, to avid tilting of the device by the drag force.

Therefore the ability of the apparatus to reconfigure the relationship between the tethering point and the centre of drag depending on the current direction, whilst simultaneously keeping the centre of lift constant relative to the tethering point and eliminating tilting forces, provides a solution to the problems of dynamic stability and tilting of a tidal turbine device in a bi-directional current stream.

Some embodiments of the invention include dynamic lifting surfaces on the tethered lifting bodies to provide an additional lifting force proportional to the current strength. As the current strength is also proportional to the tendency for the apparatus to be dragged downwards, dynamic lift can contribute greatly to maintaining a level height in the current flow.

Such dynamic lift surfaces are preferably symmetrical about the tethering point so that the lift force generated by them acts through the tethering point and with equal magnitude in both current directions.

In some embodiments of the invention the movable connection between the tethered and moving bodies is achieved by way of a sliding connectors each comprising of a rail and a runner.

In other embodiments the movable connection between the tethered and the moving bodies may be a hinged connection. Of the embodiments that use a hinged connection, some may employ a simple pivoting hinge whilst others may employ hinges in a parallelogram arrangement to maintain the axes of the different bodies in parallel.

Some embodiments employ a centralising mechanism to return the configuration of the tethered and moving bodies to a neutral condition in preparation for receiving a current from the opposite direction. This may take the form of an elastic return means such as one or more springs, or a gravity mechanism where a small buoyancy force is used to make the device tend towards its neutral condition. In both cases the centralising forces are small compared to the drag on the device in the current.

Typically, energy is converted in the apparatus by way of turbines situated in ducts that run through either the tethered or movable bodies. The ducts are also of a venturi shape with the turbine placed at the throat of the venturi so that velocity through the turbine is maximised, improving the efficiency of the turbine. Some embodiments of the invention use twin counter-rotating turbines so that the reaction torques from each cancel out.

As the turbines are ducted the entrance to the ducts may be screened to prevent objects and marine life entering the turbine, preventing harm both to the turbine and to large marine life.

At least one of the bodies may contain an internal volume that can be selectively filled with air or water to adjust the buoyancy of the apparatus. In some of the embodiments of the invention, all of the bodies have adjustable buoyancy so that different bodies can have different buoyancies at different times.

The ability to vary the buoyancy of different bodies at different times allows the apparatus according to the invention to take on buoyancy configurations that are optimised for particular functions. These may include the following:

- A surface configuration in which all the bodies are at maximum buoyancy allowing the device to sit largely clear of the water providing access for servicing and easy transportation across the sea surface;
- An operating configuration in which the tethered lifting bodies are at maximum buoyancy and the movable bodies are at close to neutral buoyancy, therefore allowing the movable bodies to alter the overall position of the centre of drag but not the centre of lift;
- A descending configuration in which the overall buoyancy of the device is set to slightly negative so the device can be lowered to its operating depth in a controlled manner and
- An ascending configuration in which the overall buoyancy is slightly positive so the device can be raised to the sea surface in a safely controlled way.

Some embodiments of the invention include a streamlined boat-shaped hull on the bottom of at least one of the bodies to further improve the transportability of the apparatus across the sea surface in its surface configuration. Additionally some embodiments place emphasis on the layout of the bodies when in their surface configuration to yet further improve the transportability of the device.

The apparatus can be tethered by connecting fixed mooring lines to releasable brakes on the bodies to be tethered. Releasable brakes allow for rapid and easy ascending or descending of the device using the previously mentioned adjustable buoyancy. This is a significant benefit as the mooring weights remain on the sea bed and therefore no specialist lifting equipment is required to raise or lower the device.

Some embodiments use multiple mooring lines positioned up and downstream of the device so that the overall movement of the device as a result of the changing current direction is minimised.

A surface marker buoy is used to manage the mooring lines above the descended apparatus and also provides access to a snorkel line through which air can be pumped into the apparatus. The surface buoy can also contain features such as warning lights and radio antennae.

The surface buoy is small compared to the tidal generator and therefore any forces it is subject to, for example, from currents or surface waves, are not large enough to have any significant effect on the apparatus below. Its small size also gives the surface buoy a small visual profile. Additionally the surface buoy can be constructed from a soft inflatable material ensuring that its presence on the surface is non hazardous to surface vessels in event of an accidental collision.

The above advantageous features of the invention will now be described in more detail by way of a series of preferred embodiments, along with further background description regarding forces acting on submerged bodies, with reference to the accompanying drawings, in which:

Figure 1 is a first schematic view of the forces experienced by a buoyant body positioned in a fluid flow;

Figure 2 is a second schematic view of the forces experience by a buoyant body positioned in a fluid flow;

Figure 3 is a third schematic view of the forces experience by a buoyant body positioned in a fluid flow;

Figure 4 is a perspective view of a first preferred embodiment of a turbine apparatus (a tidal generator) according to the invention;

Figure 5 is a partial cutaway view of a the tidal generator of Figure 5;

Figure 6 is a schematic view of the first step of an installation procedure of a tidal generator of Figure 4;

Figure 7 is a schematic view of the second step of an installation procedure of a tidal generator of Figure 4;

Figure 8 is a schematic view of the third step of an installation procedure of a tidal generator of Figure 4;

Figure 9 is a schematic view of the fourth and final step of an installation procedure of a tidal generator of Figure 4;

Figure 10 is a view showing the forces on a tidal generator according to Figure 4 in a neutral position when there is no current flowing;

Figure 11 is a view showing the forces on a tidal generator according to Figure 4 when experiencing a current from right to left;

Figure 12 is a view showing the forces on a tidal generator according to the Figure 4 when experiencing a current from left to right;

Figure 13 is a perspective view of a second preferred embodiment of turbine apparatus according to the invention in a neutral position with no current flow;

Figure 14 is a perspective view of the embodiment of Figure 13 when experiencing a current flow;

Figure 15 is a perspective view of a third preferred embodiment of turbine apparatus according to the invention in a neutral position with no current flow;

Figure 16 is a perspective view of the embodiment of Figure 15 when experiencing a current flow;

Figure 17 is a perspective view of a fourth preferred embodiment of turbine apparatus according to the invention in a neutral position with no current flow;

Figure 18 is a perspective view of the embodiment of Figure 17 when experiencing a current flow;

Figure 19 is a perspective view of a fifth preferred embodiment of turbine apparatus according to the invention in a neutral position with no current flow and;

Figure 20 is a perspective view of the embodiment of Figure 19 when experiencing a current flow.

In order to provide a clear context for the embodiments of the invention, a preliminary description providing more detail regarding the forces acting on submerged, buoyant bodies in a current stream will be provided initially in the following description, in which reference is made to Figures 1 to 3.

With reference to Figure 1, the basic forces acting on a tethered, buoyant submerged body in current stream with a velocity **V** are: the drag force **D**, the lifting force **L** and the tension from the mooring line **T**.

The drag force **D** on the submerged body will be a function of the body's drag coefficient and the velocity **V** of the current stream. The lifting force **L** will result from the buoyancy of the device and any dynamic lift that the device generates, for example from hydrofoils. The trigonometrical relationship between the lifting force **L** and the drag force **D** will determine the angle **A** of the mooring line.

However, the device position shown in Figure 1 is in practice unachievable and one of two things will actually happen; either the device will remain level and be dragged down toward the seabed (shown in Figure 2) or the device will remain high in the water stream but will tilt upwards (shown in Figure 3).

The scenario shown in Figure 2 arises because in order for the device to remain level the lifting force **L** acting about the tethering point must be small and easily overcome by the levelling effect of the drag force **D**. As a result, the downward component of the tension **T** in the mooring line, in turn caused by the drag **D**, will be greater than the lifting force **L** until the angle **A** of the mooring line is sufficiently acute for the forces to balance.

If the lifting force **L** is increased to keep the device higher in the water then the lifting force acting about the tethering point **T** will be strong enough to also overcome the levelling effect of the drag force **D** and cause the device to tilt upwards, as per the scenario of Figure 3.

In addition to the above considerations, dynamic stability must also be achieved. Dynamic stability applies to many types of system and refers to the forces acting on the system being able to maintain a stable equilibrium condition. Generally this requires the point of action of a force to be in front of the point of origin of the force with respect to the direction of the force. The further in front the point of action is compared to the point of origin, then the more stable the system is.

In the case of a device moored in a current stream experiencing a drag force and/or a lifting force, the point of action will be the tethering point and the point of origin will be the centre of drag and/or lift. Therefore the tethering point **T** must be significantly below the centre of lift **CL** and upstream of the centre of drag **CD** if the device is to remain stable.

Furthermore, to avoid the device having a tendency tilt about the tethering point **T**, the lifting force **L** should act through a point vertically aligned with the tethering point **T** and the centre of drag **CD** should be exactly downstream of the tethering point **T**. The tendency to tilt will increase as the misalignment between the tilting force and the tethering point **T** increases.

The above factors are the main problems which must be overcome when positioning a device such as a turbine in a stream of flowing water. If the device is operating in a current that only flows in a single direction then these problems can be overcome by having a shape that has well separated centres of lift and drag. This could be achieved with the use of large downstream stabilising fins for example, or by the use of separate lifting and working portions of the device.

However the above solution becomes far less practical if the current is bi-directional. In order to maintain a dynamically stable and non tilting position in the flow, a device must be able to re-configure the relationship between the tether, the centre of drag and the centre of lift to accommodate the changing current directions.

If the body is of a fixed geometry, then the only way to change the relationship between the tethering point, the centre of drag and the centre of lift when the current changes direction is for the entire device to swing through 180 degrees. This movement will either be an ‘over’ or ‘under’ movement as a lateral rotation is impractical due to the force balances discussed above.

Rotating a tidal turbine 180 degrees in the vertical plane poses several problems and is not an optimal solution. Some of the main disadvantages are: sufficient depth of water is required; the power take-off cable will have to rotate or have a special compensating mechanism; dynamic lift surfaces will be upside down half of the time unless complex variable pitch mechanisms are used; and the risk of entanglement of the mooring lines increases.

It should also be noted that in a bi-directional current both upstream and downstream mooring lines are likely to be used in order to give more overall positional control to the device. The horizontal distance the device travels when the current direction changes is much reduced with this arrangement. Good positional control of the device is important to limit the movement required by a power removal line and to eliminate the risk of entanglement of the moorings.

The addition of another mooring line does not however solve the problems of tilting or dynamic stability as the downstream mooring line will always tend to slacken allowing the device substantial freedom of movement about the upstream tethering point.

The present invention provides the advantage that the device has a variable geometry that allows it to reconfigure itself depending on the direction of the current. This will be described in illustrative terms in the following description.

With reference to Figure 4, a preferred embodiment of a turbine adapted to operate in a bi-directional current comprises of a tethered lifting body **1**, to which a generator body **2** is slidably mounted by means of elongate rails **3** and co-operating runners **4**. The lifting body **1** is of a shape that generates both displacement buoyancy and dynamic lift when a current flows over it.

Flow-receiving ducts **5** run through the generator body **2** with the openings of the ducts **5** being aligned to face the direction of the current **6** to encourage the current stream to pass through the device.

Inside the flow-receiving ducts **5** are turbines **7** that are turned by the current passing through them. The hubs **8** of turbines **7** contain energy conversion means, such as an electrical generator or a fluid pump, in order to convert the rotation of the turbines **7** into useful energy. Support struts **9** fix the hubs **8** in the centre of the ducts **5**. The ducts **5** may be of a venturi shape, which both allows for decrease in the size of the turbine **7** required and for increase in the speed of the flow through the turbine **7**.

An elastic return means in the form of springs **10** mounted on the rails **3** provides a centralising force to the generator body **2** so that there is always a tendency for the generator body **2** to be aligned centrally relative to the lifting body **1**.

The casing of the lifting body **1** has a hollow interior which can be selectively filled with varying amounts of water and air to adjust the overall buoyancy of the device. An inlet valve **11** allows air to be added to the device; it may be connected to a surface buoy (not shown in Figure 4) via a snorkel line **13**. The snorkel line **13** may also be adapted to include a power line so that the surface buoy could use power from the device to provide functions such as lighting and a radio beacon.

The hollow interior of body 1 may be subdivided into separate chambers. For example, internal baffles **14** (see Figure 5) allow selective filling of various portions of the device to allow buoyancy to be more precisely controlled. They also prevent sloshing, thereby increasing device stability.

The surface buoy **12** (see Figure 7) is generally small compared to the main device, and any forces it experiences from currents or waves will not be large enough to influence the main device. The surface buoy **12** may be constructed from a soft material, for example hypalon, ensuring its presence on the surface is benign to surface vessels in the event of an accidental collision.

Releasable brakes **15** attach the device to mooring lines **16** and allow the device to be positioned at the desired depth in the current **6**. The depth of the device can be adjusted by releasing the brakes **15** and using the buoyancy to either ascend or descend the device. The brakes **15** may be of a “power off no-power on” type, so that they can be left locked for long periods without consuming power. The brakes **15** can be replaced by winches if desired to provide greater depth control, or by any other suitable securing means.

The brakes **15** may be operated from the surface so, in combination with the ability to control the buoyancy from the surface, the depth of the device can be controlled remotely from the surface.

A power umbilical **17** (see Figure 8) is connected to the device to allow the useful energy generated to be removed to a location where it can be used. For example this may be an electrical cable connected to an electricity grid, or a pipe carrying pressurised sea water to a desalination plant.

The underside of the generator body **2** may be adapted to have a boat like hull so that when the device is fully buoyant it can float on the surface of the water and provide access for maintenance. This has the additional benefit of allowing the device to be easily towed by another vessel.

With reference to Figures 6 to 9, a process of installing the first preferred embodiment of the invention will now be described. The following descriptions presume the device is used in the sea in a bi-directional tidal stream, but the system and method can be adapted for other environments.

The first step of installing the device will now be described with reference to Figure 6. Mooring lines **16** are connected to anchor weights **19** and lowered into position on the sea bed **20** in a layout that will allow the device to be installed with the correct orientation to the current **6**. An underwater junction box **21** and power umbilical **17** are also positioned on the sea bed **20**. Floats **22** mark the positions of the top of the mooring lines **16** and power umbilical **17** on the sea surface **23**.

The device is then towed into position between the floats **22** prior to connection to the mooring lines **16** and power umbilical **17**. The device is configured for maximum buoyancy during this process and both the lifting body **1** and the generator body **2** are both full of air in order to make the device as easy as possible to tow across the sea surface **23**.The second step of installing the mooring system will now be described with reference to Figure **7**. The mooring lines **16** are engaged into the brakes/winches **15** and connected to the surface buoy **12**. The surface buoy **12** may be created by the joining together of the floats **22** used to mark the position of the mooring lines **16**. The snorkel line **13** and the power umbilical **17** are also attached at this stage. The mooring lines **16** would normally be kept slack during this process and the device would remain in its fully buoyant configuration.

The third step of installing the mooring system will now be described with reference to Figure 8. The buoyancy of the device is reduced and it is allowed to descend the mooring lines **16**. The descent can be controlled by the brakes/winches **15** and by adding air to compensate for the increased pressure as the device descends. Stops can be added to the mooring lines **16** in a pre-calculated position to simplify the process of setting the final position of the device. The portion of the mooring lines **16** below the brakes/winches **15** would normally be slack at this stage whilst the portion of the mooring lines **16** above the brakes/winches **15** would be in tension.

The fourth step of installing the mooring system will now be described with reference to Figure 9. The brakes/winches **15** are locked fixing the position of the device on the mooring lines 16. The buoyancy of the lifting body **1** is increased to its maximum by filling it completely with air. The buoyancy of the generator body **2** is set to exactly neutral buoyancy. The increased overall buoyancy causes the device to rise and tension the portion of the mooring lines **16** below the brakes/winches **15**, whilst the portion of the mooring lines **16** above the brakes/winches **15** will slacken. The exact amount of slack between the brakes/winches **16** and the surface buoy **12** can be adjusted to the desired amount by pulling or letting mooring line **16** through the surface buoy **12**. This step completes the installation process.

Once the device has been installed, it is ready to begin operation. How the device re-configures itself in a bi-directional current stream is explained by way of example with reference to Figures 10 to 12.

With a relatively low current flow, the device can adopts a neutral configuration (Figure 10). The generator body **2** remains in a central position relative to the lifting body **1** due to the centralising tendency provided by the springs **10**.

As the generator body **2** is set to completely neutral buoyancy when the device is operational, the only lifting force **L** is generated by the displacement buoyancy of the lifting body **1**. This means that the centre of lift **CL** will be through the volumetric centre of the lifting body, which is vertically in line with and above the brakes **15** (the effective tethering point **T**). Therefore the lift force **L** is dynamically stable and the tension in the mooring lines **16** will be equal.

With reference to Figure 11, the configuration of the device when experiencing a current **6** from right to left is shown. The slidable mounting of the generator body **2** allows it to move downstream of the lifting body **1** as a result of the drag force **D** placed on it by the current **6**. The magnitude of the drag force **D** is such that it can overcome the centralising tendency provided by the springs **10**. The movement of the large surface area of the generator body **2** will lead to the overall centre of drag **CD** moving downstream with it. Thus the centre of drag **CD** will be significantly behind the tethering point **P** and dynamic stability of the drag force **D** will be achieved.

The vertical positioning of the brakes **15** and therefore the tethering point **P** is such that the device is horizontally aligned with the centre of drag **CD** so that there is essentially no resultant tilting moment arising from the drag force **D**.

The tension **T** in the mooring lines **16** is transferred to the upstream mooring lines **16,** resulting in slackening of the downstream mooring lines. The surface buoy **12** will be dragged downstream until the mooring lines **16** above the brakes **15** become taut.

As the current increases, the lifting body **1** generates a dynamic lift force as well as a displacement lift force. The shape of the lifting body **1** is a horizontally symmetrical hydrofoil so that the dynamic lift force generated is the same in both current directions. This also means that the centre of the lift force is horizontally central and therefore acts through the same point as the centre of displacement lift. The displacement and dynamic lift forces can therefore be thought of as a single overall lift force **L** that increases in magnitude as the speed of the current **6** increases.

The increase in lift force **L** as the speed of the current **6** increases offsets the increase in the downward component of the tension **T** in the mooring lines **16** and results in the device being far more positionally stable than it would be without the benefit of dynamic lift.

Figure 12 shows the configuration of the device when the current direction is reversed. Essentially it is a symmetrical reversal of the configuration of Figure 11 with the generator body **2** moving the opposite way relative to the lifting body **1**.

The ability of the device to reconfigure itself ensures that stable and level operation in a bi-directional current stream can be maintained at all times. No matter what the strength or direction of the current, the tethering point **T** always remains significantly below and vertically aligned with the centre of lift **CL**, and also significantly upstream and aligned with the centre of drag **CD**.

Whilst the description so far has emphasised the need for alignment of the forces acting on the device and the tethering point **T**, it should be noted that in practice the device will be able to tolerate some degree of tilt and therefore the strictly exact alignment of the forces is not necessary. It may not be practical either to perfectly align the forces as, for example, when both up and downstream mooring lines **16** are used, the releasable brakes **15** cannot be positioned directly on top of each other. The important consideration is that any tilting tendencies should be kept small compared to the overall lift **L** and drag **D** forces.

With reference to Figures 13 and 14, a second embodiment of the invention will now be described. The second embodiment operates in a similar manner to the first so it will be described with reference to the description for the first embodiment (and like features are denoted by like reference numerals).

Instead of the single top-mounted lifting body **1** of the first embodiment, separate side-mounted lifting bodies **24** are provided. This arrangement may provide advantages when the device is in its surface (fully buoyant) configuration, because the lifting bodies **24** can act as outriggers which will provide a more stable platform.

In order to prevent large objects and marine life entering the interior **7** of the generator body **25**, the entrances **5** have screens **30** placed over them. Such an arrangement of screens may be provided in any of the embodiments of the invention.

As with the first embodiment, the device can reconfigure itself automatically in response to a changing current direction by the generator body **25** sliding downstream relative to the lifting bodies **24**. Again as with the first embodiment, this has the effect that both the lift and drag forces are in a dynamically stable relationship at all times. Figure 13 illustrates the second embodiment in a neutral position and Figure 14 illustrates the configuration of the device when it is subject to a current flow.

All other aspects of the second embodiment operate in a similar manner to those described in the first embodiment.

With reference to Figures 15 and 16, a third embodiment of the invention will now be described. The third embodiment also operates in a similar manner to previous embodiments so it will be described with reference to the previous embodiments (and like features are denoted by like reference numerals).

This third embodiment employs side lifting bodies **26** mounted to a central generator body **27** in a similar way to the second embodiment. However, instead of the sliding mounting of the second embodiment, the third embodiment uses a hinged mounting to allow the generator body **27** to move relative to the tethered lifting bodies **26**.

The hinged connection comprises of connecting arms **28** that are attached to both the lifting bodies **26** and the generator body **27** by rotating joints **29**. In the third embodiment the connecting arms **28** are in a parallelogram arrangement to keep the axes of the generator body **27** and the side lifting bodies **26** parallel, however, a straightforward pivoting hinge may also be used.

The neutral configuration of the third embodiment is shown in Figure 15 and the configuration when subject to a current flow is shown in Figure 16.

All other aspects of the third embodiment operate in a similar manner to those described in previous embodiments.

With reference to Figures 17 and 18, a fourth embodiment of the invention will now be described. The fourth embodiment also operates in a similar manner to previous embodiments so it will be described with reference to the previous embodiments (and like features are denoted by like reference numerals). This fourth embodiment has a central lifting body **31** with a top volume that includes a dynamic lifting surface **32** in a similar fashion to the first embodiment. A pair of generator bodies **33** is hingeably attached to either side of the lifting body **31**. The hinge arrangement is a simple pivoting hinge as opposed to the parallelogram arrangement of the third embodiment.

The hinged connection comprises of connecting arms **34** that mount the generator bodies **33** to the central lifting body **31** via rotating joints **35**. In the fourth embodiment it is intended that the only rotating joints **35** are those on the central lifting body **31** but additional rotating joints **36** can be added where the connecting arms **34** attach to the generator bodies **33** if required.

The pivoting hinge arrangement of the fourth embodiment gives the advantage that the turbine changes direction with the current - therefore a single direction turbine, as opposed to the bi-directional turbines of previous embodiments, can be used.

The fourth embodiment uses two mooring lines **16** arranged upstream and downstream relative to the current 6. This layout gives good positional stability with respect to the changing current direction but means that the device is not so well constrained in a plane perpendicular to the current **6**. A central slot **37** allows the mooring lines to pass through the centre of the device and also houses the releasable brakes **15**.

The lifting body **31** also comprises a lower hull portion **38** of sufficient buoyancy to be able to support the lifting body **31** clear of the water when the device is on the sea surface and set to maximum buoyancy. The lower hull **38,** combined with the generator bodies **32** when they are fully buoyant, enables the device to adopt a trimaran layout making for easy towing across the sea surface.

The neutral configuration of the fourth embodiment is shown in Figure 17 and the configuration when subject to a current flow is shown in Figure 18.

All other aspects of the fourth embodiment operate in a similar manner to those described in previous embodiments.

With reference to Figures 19 and 20, a fifth embodiment of the invention will now be described. The fifth embodiment also operates in a similar manor to previous embodiments so it will be described with reference to the previous embodiment (and like features are denoted by like reference numerals).

This fifth embodiment uses rotatable side fins **39** mounted to a combined generator and lifting body **40**. A pair of mooring lines **16** is positioned up and down stream and run through the centre of the combined lifting body and generator in a similar way to the fourth embodiment. The releasable brakes **15** are in the centre of the combined lifting and generator body (not visible in Figures 19 and 20).

The rotatable side fins **39** are able to rotate so that they can swing downstream and align themselves with the current direction **6**. The large surface area of the side fins **39** in both horizontal and vertical planes means that the centre of drag will move downstream with them. Therefore the centre of drag will always remain significantly downstream of the tethering point and dynamic stability of the drag force will be achieved.

The combined generator and lifting body **40** creates both displacement buoyancy and dynamic lift in a similar way to the lifting bodies of the second and fourth embodiments. It is also horizontally symmetrical so that the centre of lift from both lift sources is through the centre of the device and therefore above and in-line with the tethering point. Therefore dynamic stability of the lift forces is achieved.

The hinges **41** are angled downwards so that in the neutral position the side fins **39** are lower than they are when the current is flowing. The side fins **39** are also slightly negatively buoyant so that they will tend to fall toward the neutral position and self centralise when the current is not flowing. The hinges **41** could also be angled upwards and the side fins **39** could be made slightly positively buoyant to achieve the same effect. In both cases the tendency to centralise is easily overcome by the drag placed on the side fins by the current **6**.

The neutral configuration of the fifth embodiment is shown in Figure 19 and the configuration when subject to a current flow is shown in Figure 20.

All other aspects of the fifth embodiment operate in a similar manner to those described in previous embodiments.

Whilst the invention has been described with reference to a series of preferred embodiments, modifications of these embodiments are envisaged. For example, changing the number of ducts is possible for all the embodiments, as are changes to the turbine layout and positioning. Changing the number and/or position of the mooring lines is clearly possible as indicated by the various embodiments. The shape of the lifting bodies, generator bodies and side fins could all vary considerably. Changing the number and/or the position of the rails on the sliding embodiments is a possible adaptation, as would be substituting the springs for another equivalent type of elastic or resilient return means. Similarly the number and/or position of the hinged arms on the hinged embodiments may be changed.

Claims

1. A submersible turbine apparatus, the apparatus comprising:

    a. turbine means to be driven when submerged in a current of water;
    b. lift means for generating a lift force upon the turbine means when the turbine means is submerged in said current;
    c. securing means for securing the apparatus to a tether; and
    d. stabilising means for dynamically stabilising the apparatus in a first configuration in said current when said current flows in a first direction, and in a second configuration when said current flows in a second different direction, the geometrical relationship between the securing means, the centre of drag on the apparatus and the centre of lift of the apparatus in the first configuration being different to the corresponding geometrical relationship in the second configuration.

2. Apparatus according to claim 1, wherein the stabilising means can be configured to ensure that the securing means is substantially upstream of a position about which a resultant drag force acts in both the first and second current directions when said turbine means is submerged.

3. Apparatus according to claim 1 or 2, wherein the securing means is arranged substantially upon an axis along which a resultant lift force acts when said turbine means is submerged.

4. Apparatus according to claim 3, wherein the securing means is arranged substantially below a point at which the resultant lift force acts.

5. Apparatus according to any preceding claim, wherein the securing means includes means for driving the apparatus along the tether.

6. Apparatus according to any preceding claim, wherein the lift means comprises buoyancy means.

7. Apparatus according to any preceding claim, wherein the lift means comprises means for generating dynamic lift.

8. Apparatus according to claim 7, wherein the means for generating dynamic lift is arranged to generate substantially equal lift in each of the first and second current directions.

9. Apparatus according to claim 6, wherein the securing means is disposed on the buoyancy means.

10. Apparatus according to any preceding claim, which comprises configuration means permitting the stabilising means to move downstream relative to the lift means, depending upon the direction of the current.

11. Apparatus according to claim 10, wherein the configuration means comprises at least one rail upon which said downstream movement is permitted.

12. Apparatus according to claim 10 or 11, wherein the configuration means comprises biasing means for biasing the stabilising means substantially towards an intermediate position of the lift means.

13. Apparatus according to any of claims 1 to 12, wherein the configuration means comprises at least one hinged connection between the lift means and the stabilising means to permit the stabilising means to move relative to the lift means in the current.

14. Apparatus according to any of claims 1 to 12, wherein the configuration means comprises at least one arm hinged to the lift means to permit the stabilising means to move relative to the lift means in the current.

15. Apparatus according to claim 14, wherein the hinged arm is inclined relative to a vertical axis, such that the stabilising means can return to a neutral position when there is no current.

16. Apparatus according to any preceding claim, wherein the stabilising means comprises at least one turbine means disposed in at least one passage which permits flow of said current in both first and second current directions.

17. Apparatus according to any preceding claim, further comprising adjustment means for selectively adjusting the lift force generated by the lift means.

18. Apparatus according to claim 17, wherein the adjustment means comprises at least one chamber that is selectively fillable with water to adjust the magnitude of the lift force.

19 A submersible turbine apparatus, the apparatus comprising

a. turbine means to be driven when submerged in a current of water;

b. lift means for generating a lift force upon the turbine means when the turbine means is submerged in said current;

the apparatus comprising a plurality of bodies which are movably connected to each other, at least one of the bodies being tethered and at least one other of the bodies being untethered and allowed to move relative to the respective tethered body, the movable connection permitting respective tethered and untethered bodies to assume different relative configurations depending on the direction of said current.

20. A system for generating electrical power, the system comprising a submersible turbine apparatus according to any preceding claim.

21. A method of generating electrical power, the method comprising deploying apparatus according to any of claims 1 to 19 in a current of water with the turbine means submerged in said water so as to drive said turbine means, and generating electrical power from said driven turbine means.

Figure 1

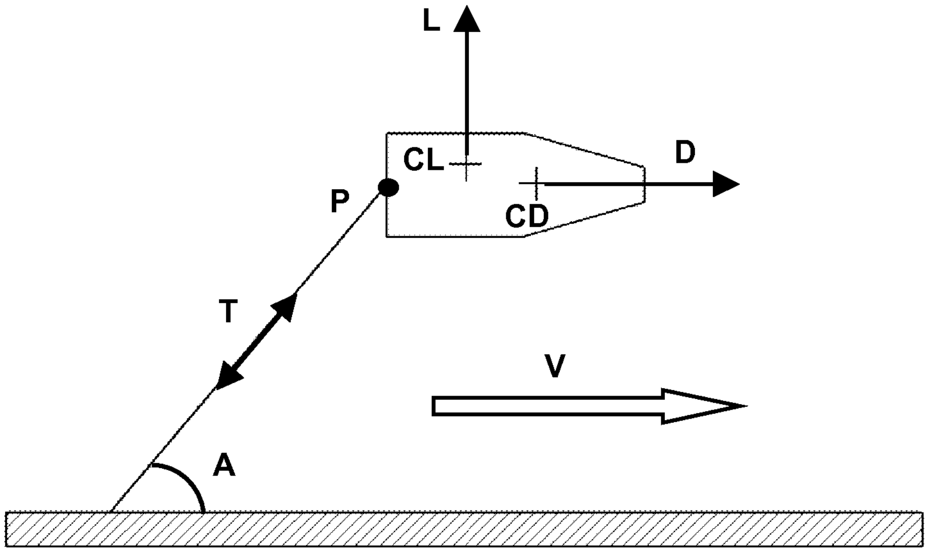

Figure 2

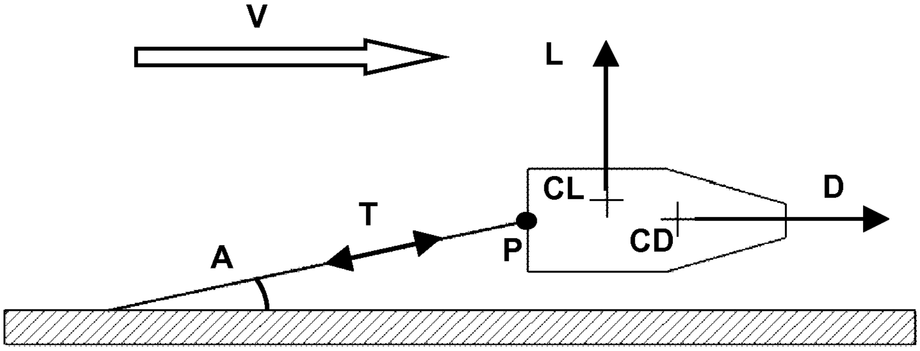

Figure 3

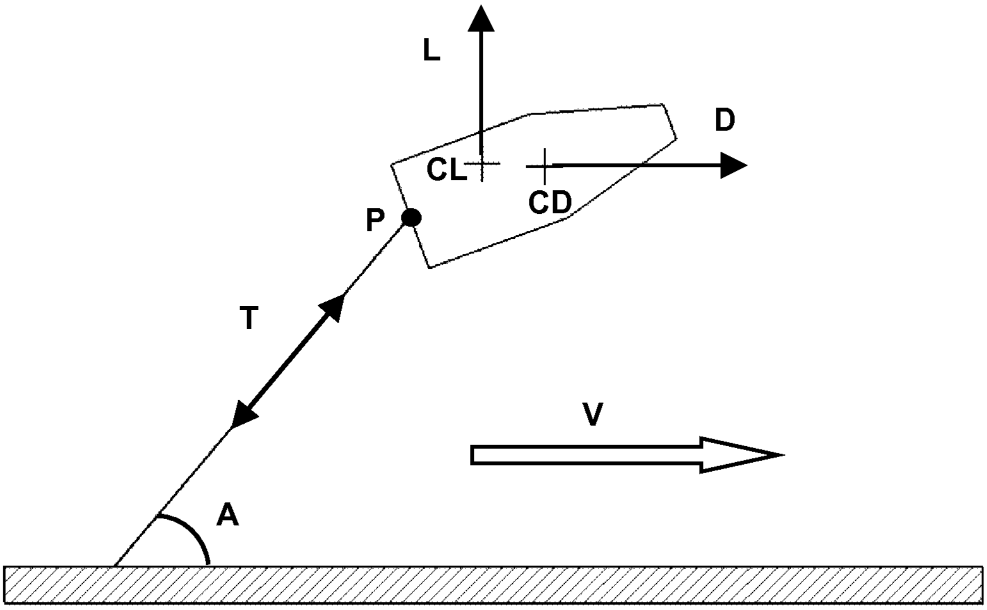

Figure 4

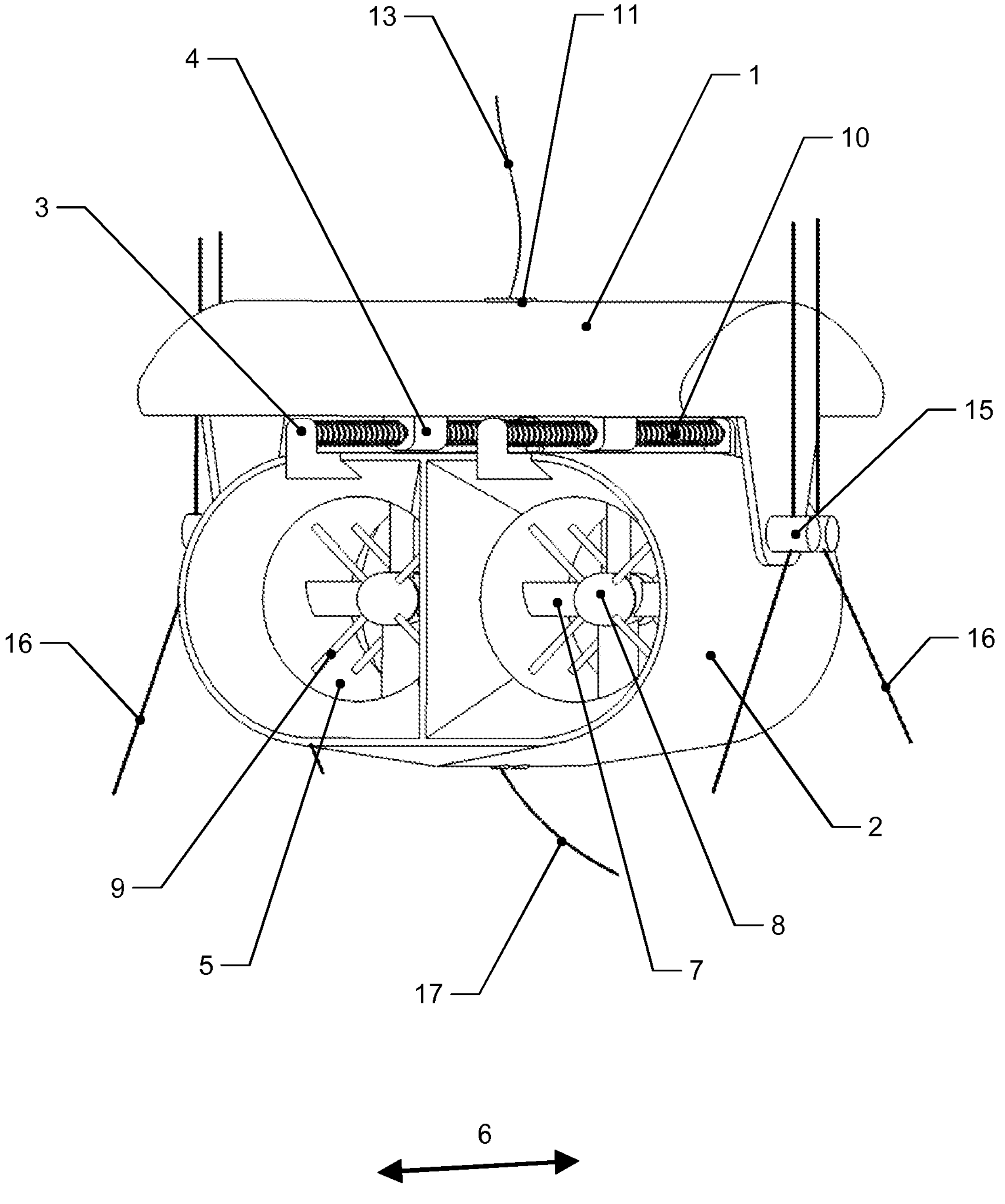

Figure 5

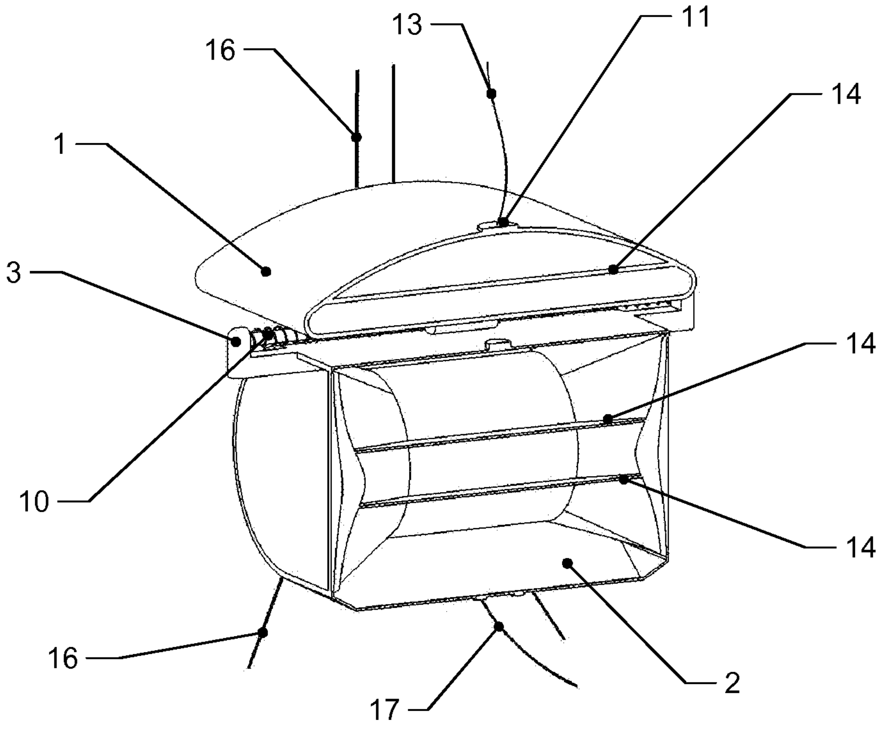

Figure 6

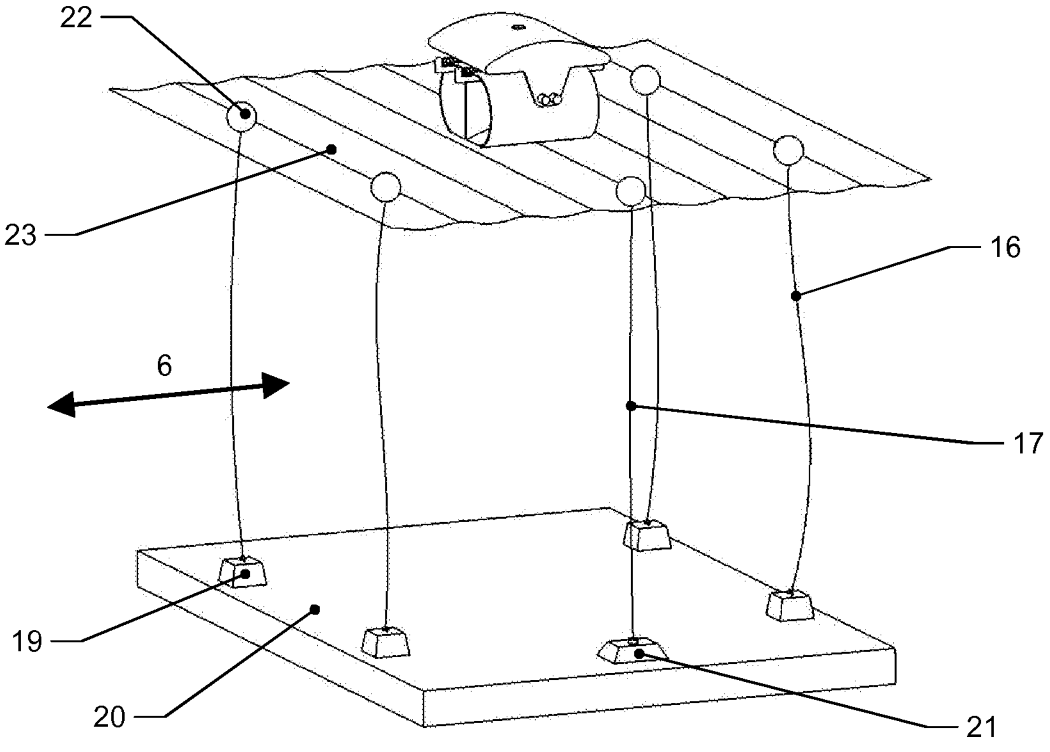

Figure 7

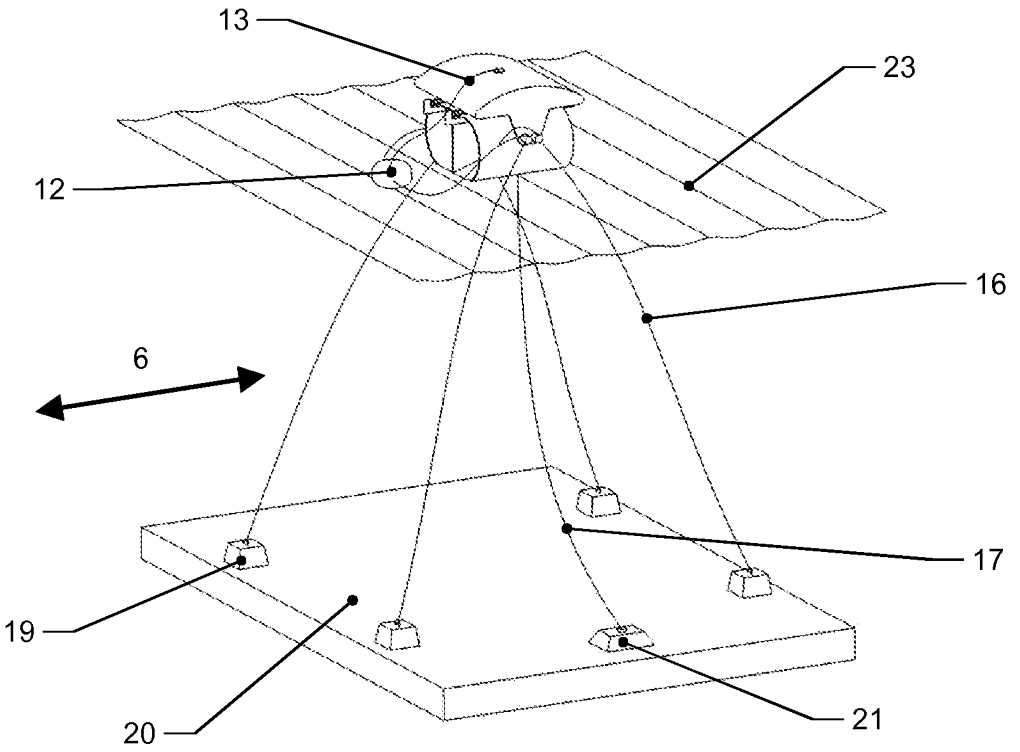

Figure 8

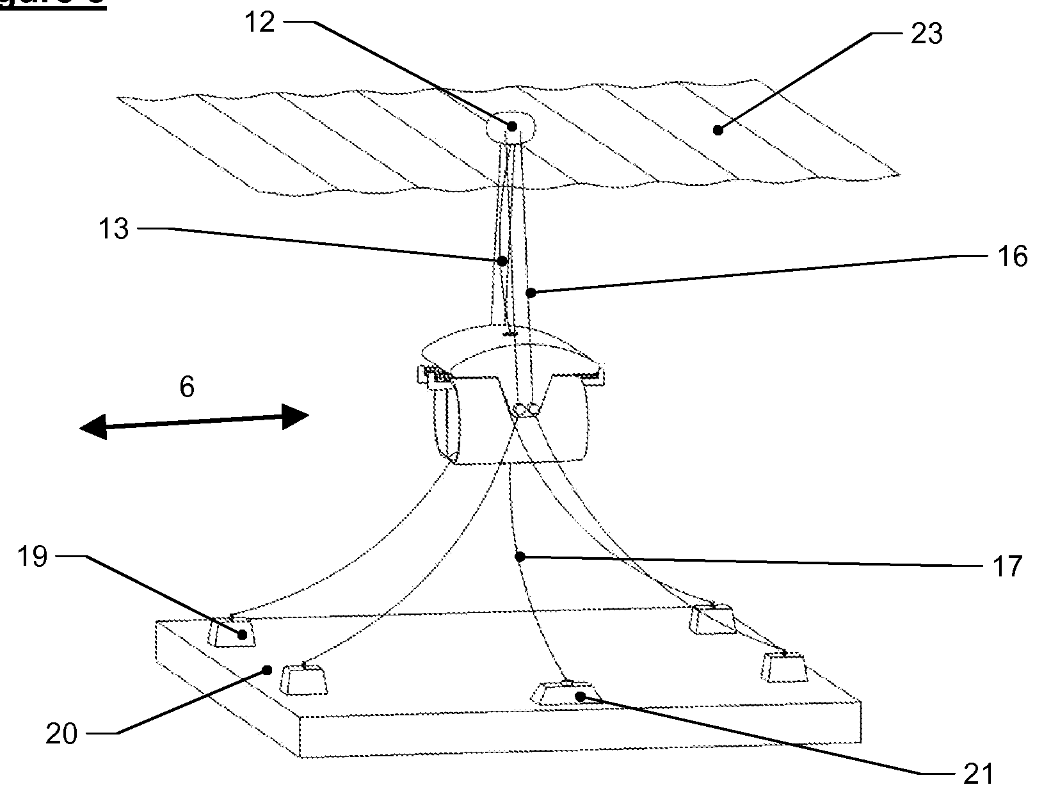

Figure 9

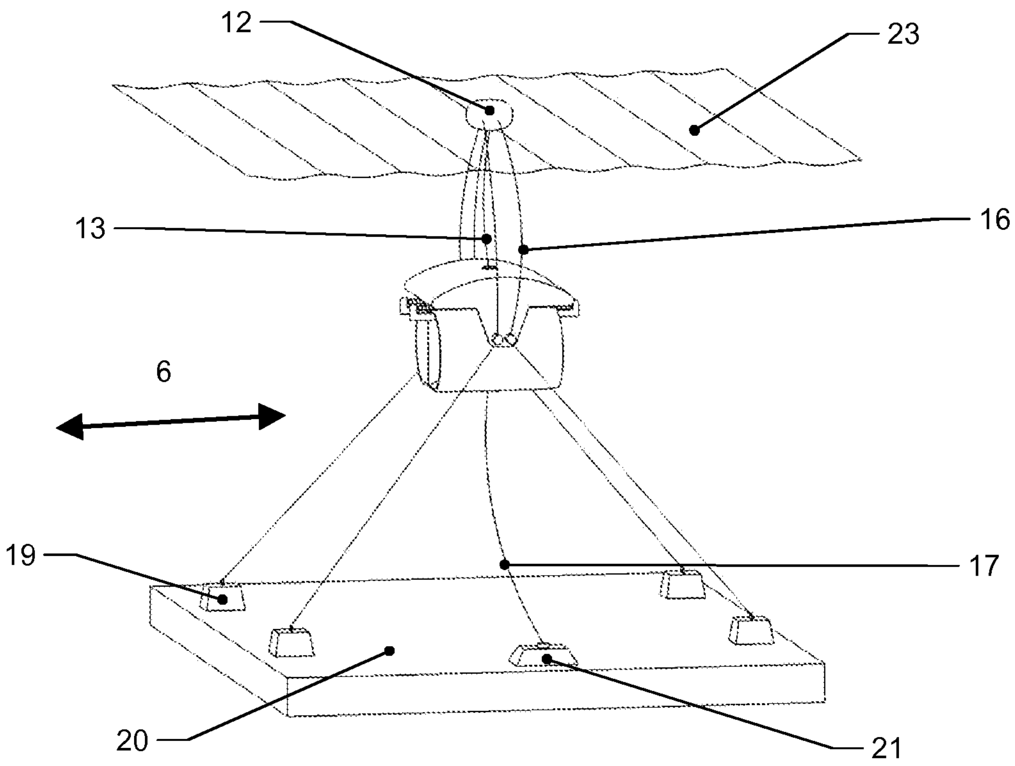

Figure 10

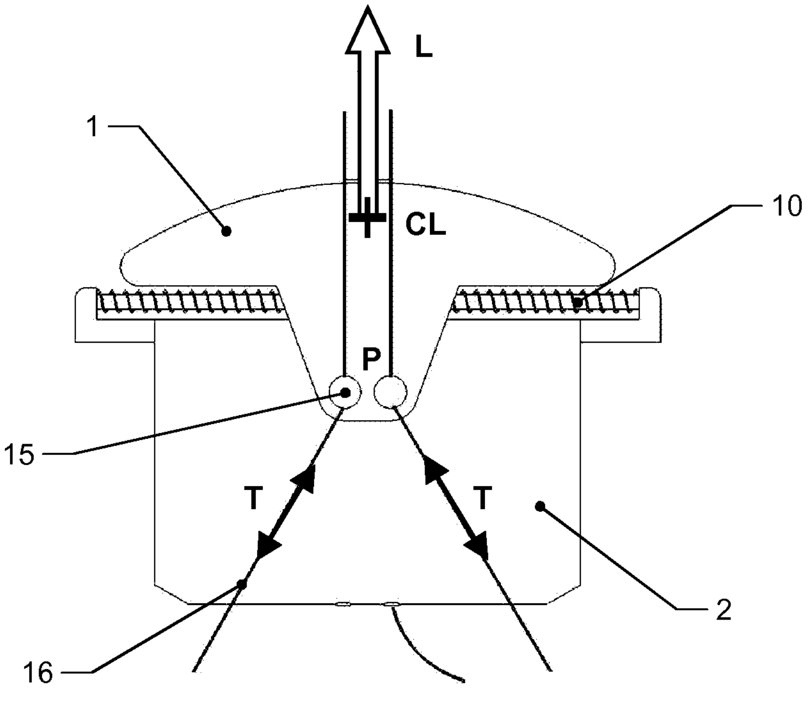

Figure 11

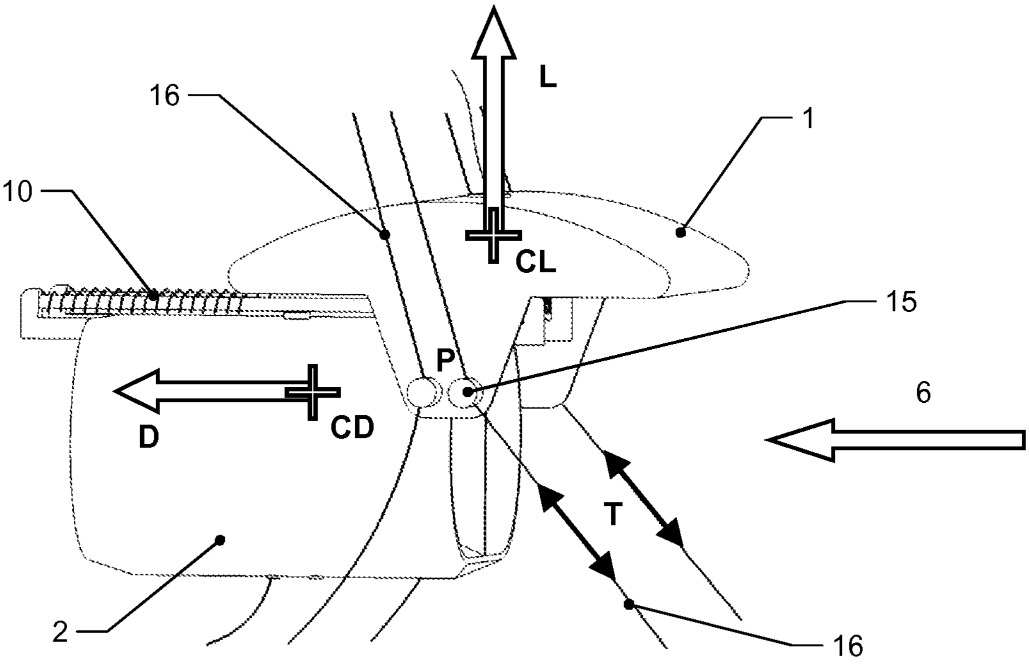

Figure 12

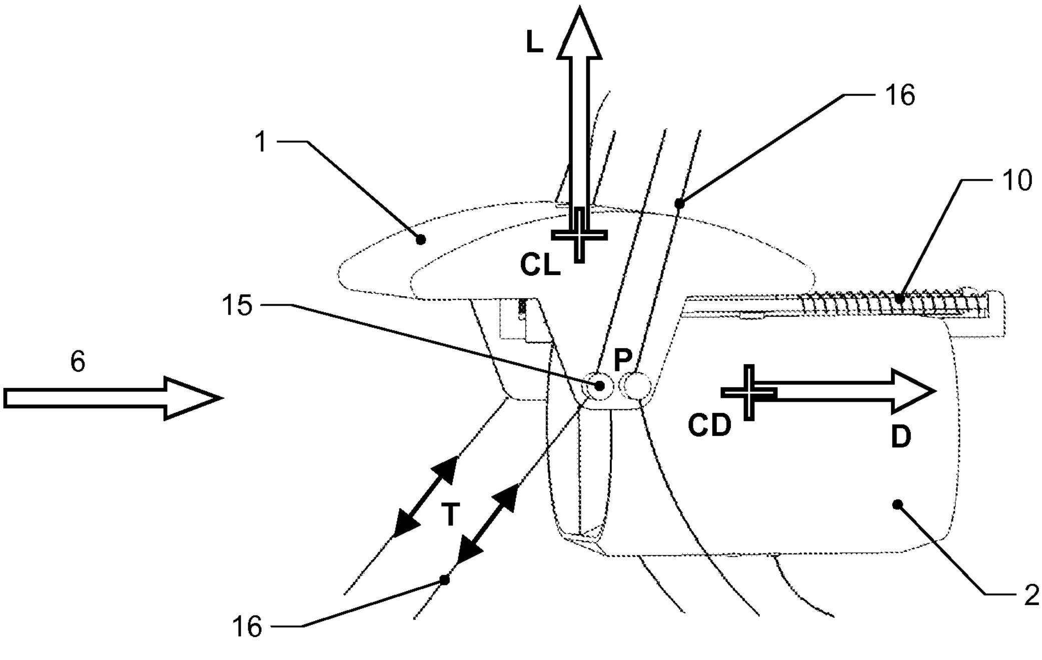

Figure 13

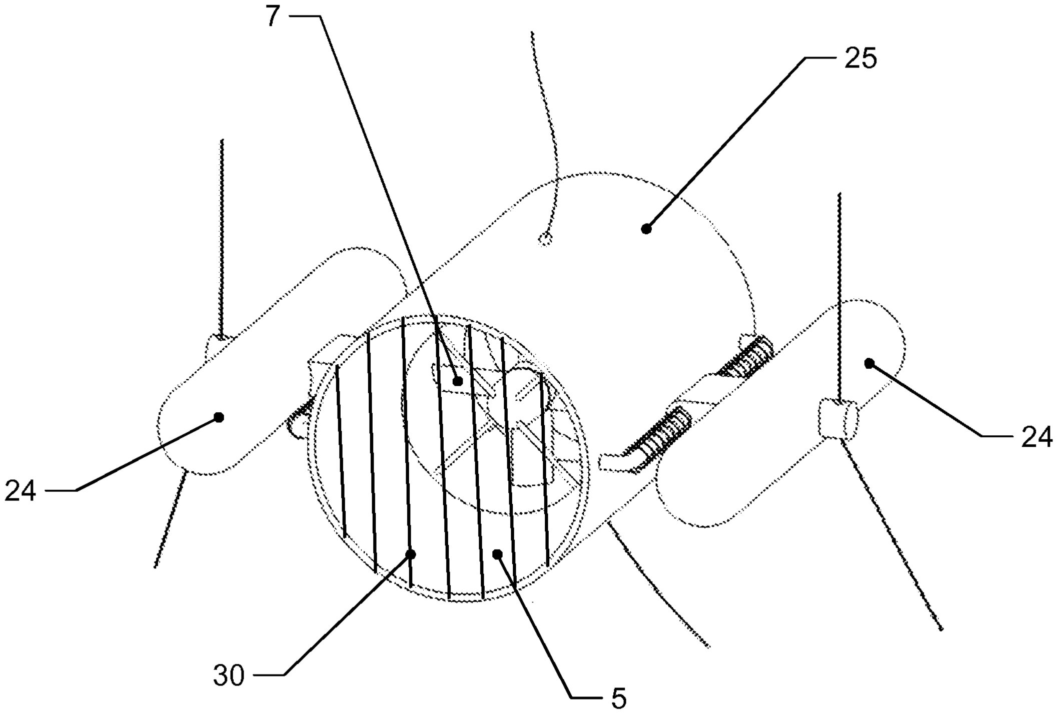

Figure 14

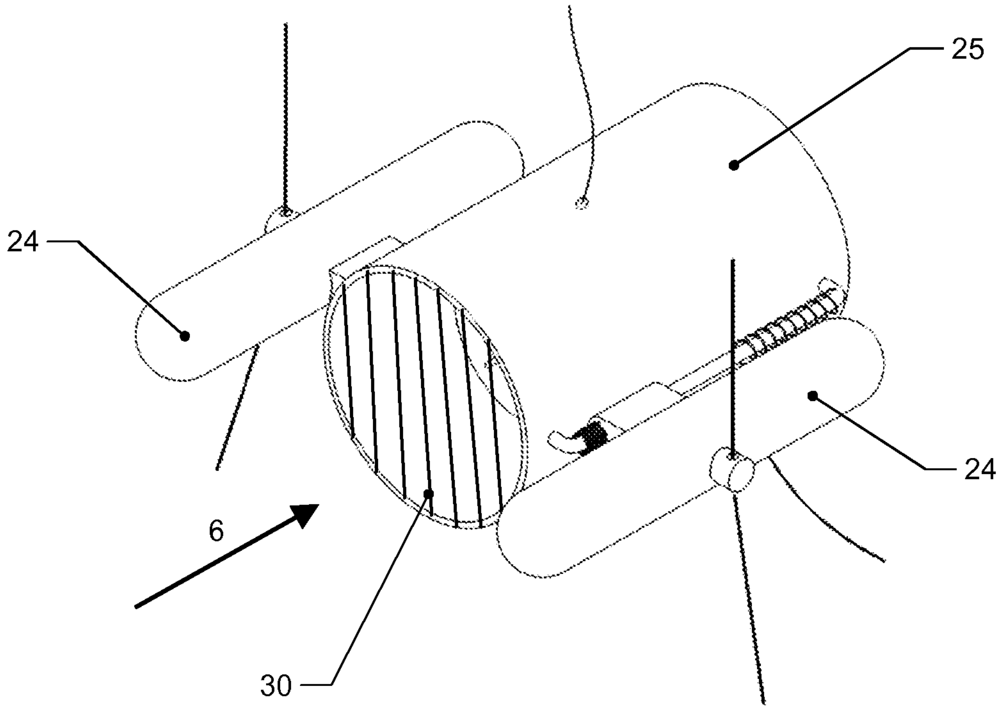

Figure 15

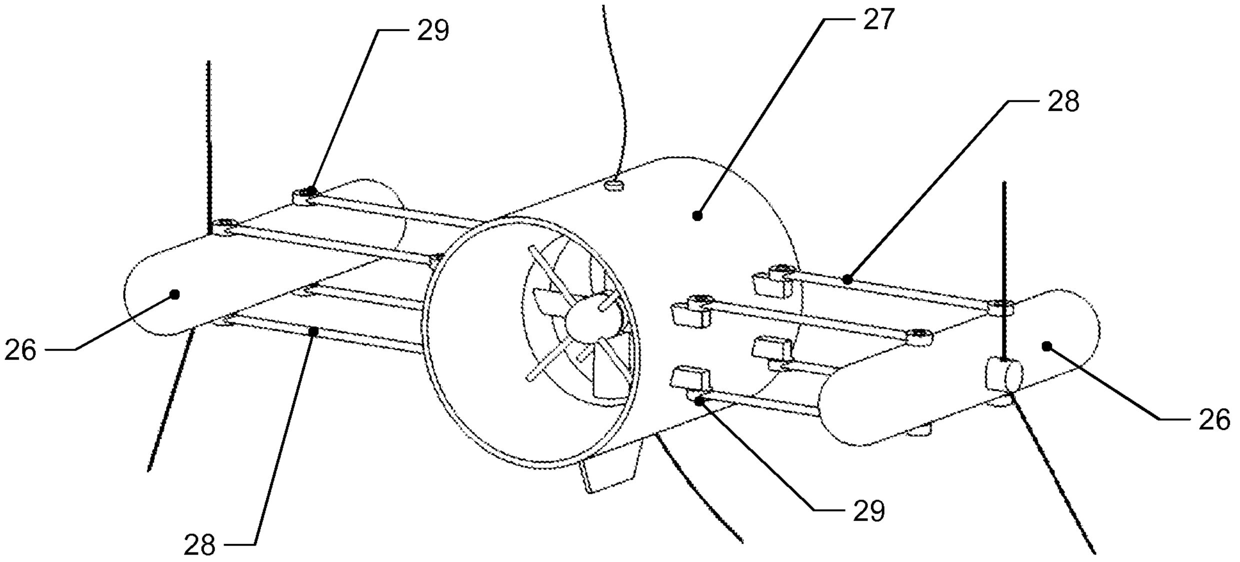

Figure 16

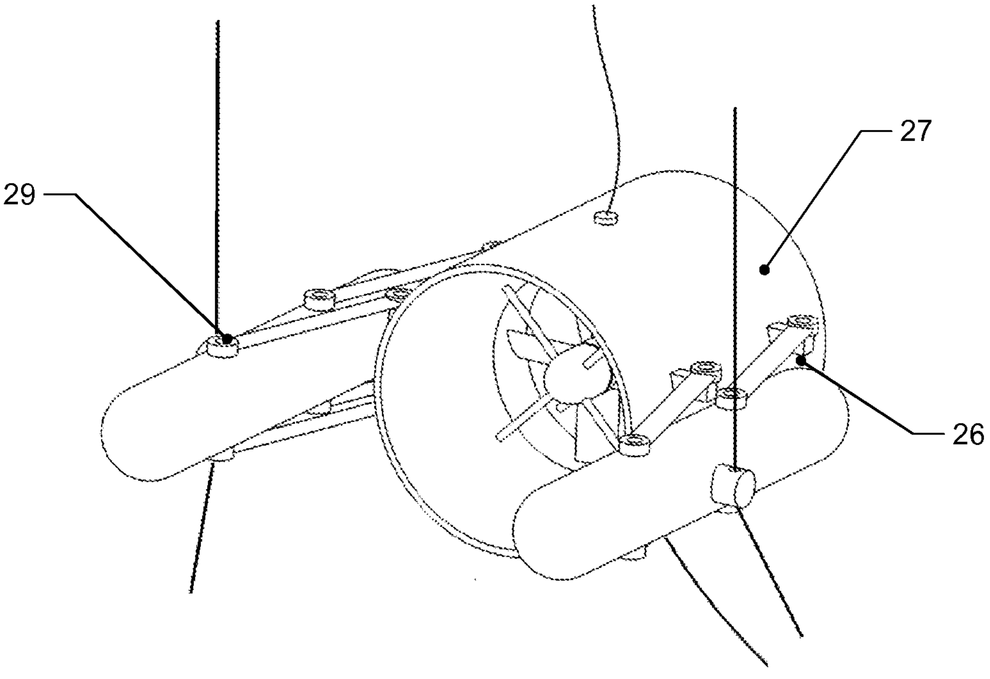

Figure 17

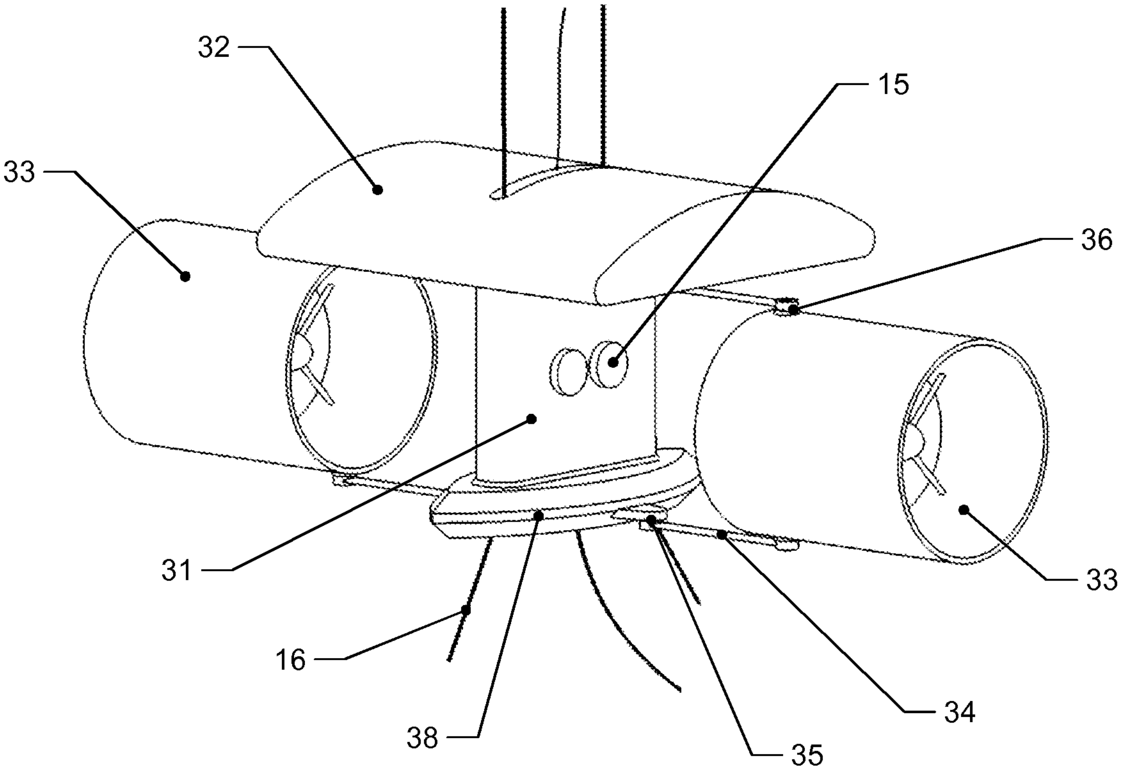

Figure 18

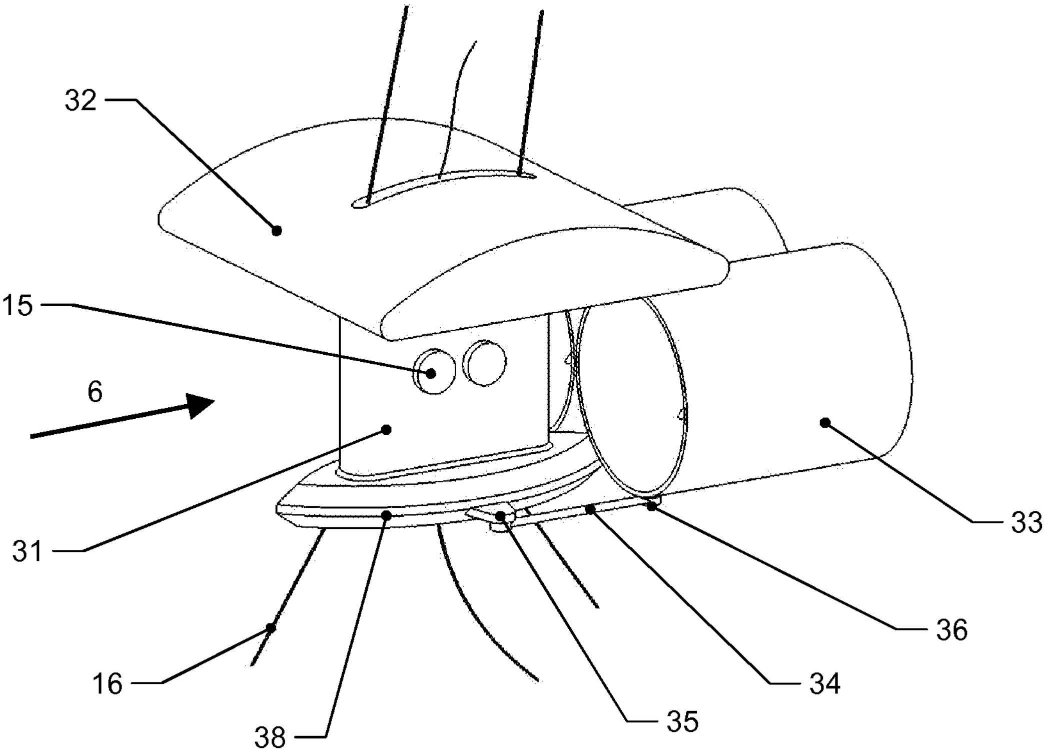

Figure 19

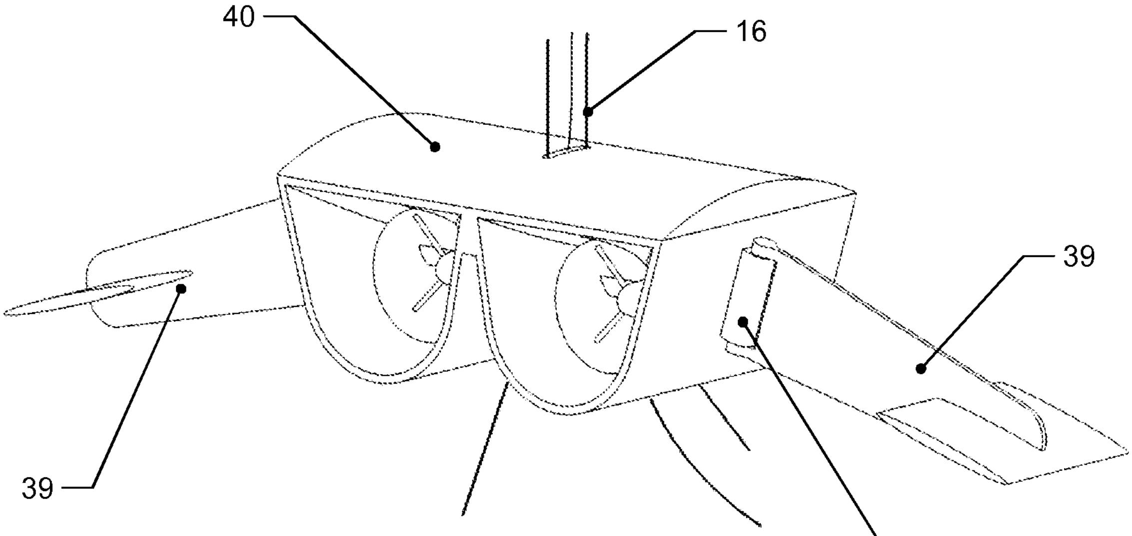

Figure 20