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(56) Documents Cited:
WO 2007/100639 A2 **WO 2001/092720 A1**

(58) Field of Search:
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Other: **EPODOC, WPI**

(54) Title of the Invention: **A modular turbine assembly**
Abstract Title: **A buoyant modular turbine assembly**

(57) The invention relates to a flowing-water driveable turbine assembly 4 for location in river or sea areas with unidirectional and bidirectional, water flows. The turbine assembly 4 is modular and comprises a turbine support 6 with positive buoyancy in water. The turbine support 6 is arranged to be anchored by an anchoring system 8 to a water bed. The turbine assembly comprises turbine modules 10 each with positive buoyancy in water. The turbine modules are detachably docked with the turbine support. The combined positive buoyancy of the turbine support and the turbine modules in water has an upward force to constrain the turbine support and the turbine modules to a position of floating equilibrium against a downward force of an anchoring system. Each turbine module has a duct (26 figure 4) and a flowing-water driveable turbine (28 figure 4) mounted in the duct. The duct is for directing water through the turbine to generate power from water flow. Later embodiments relate to a turbine support assembly, a turbine module, an anchoring system, method of assembling the modular turbine assembly and a method of repair or maintenance to the modular turbine assembly.

FIGURE 1

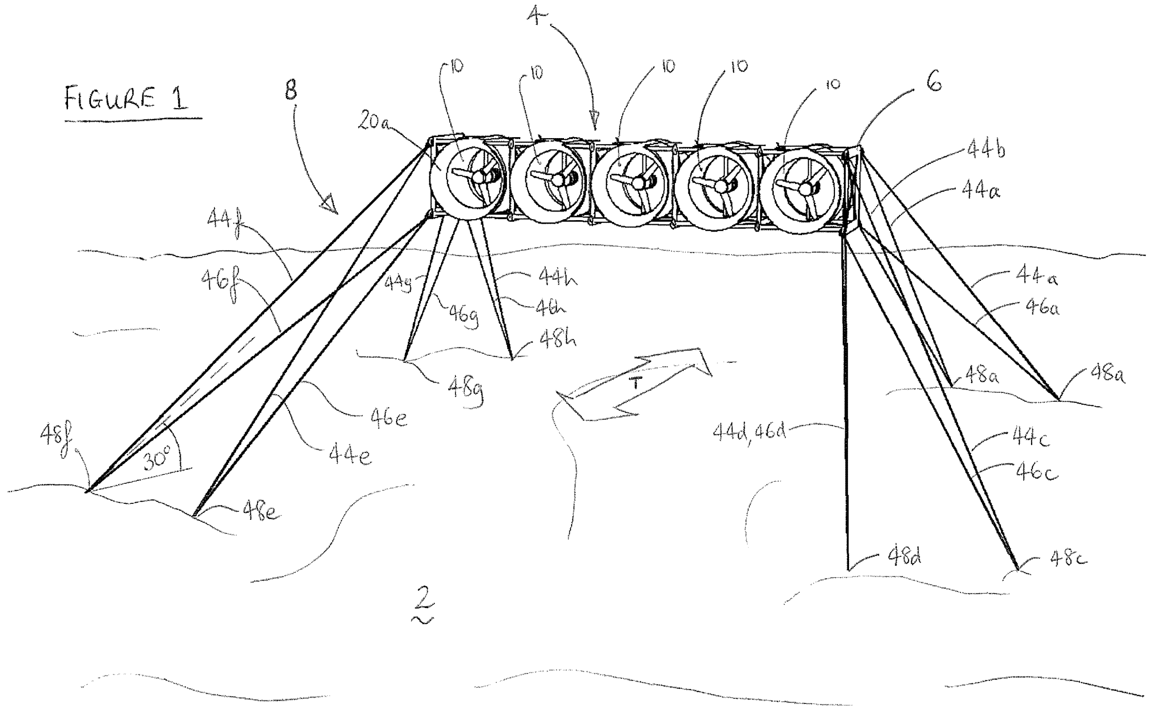

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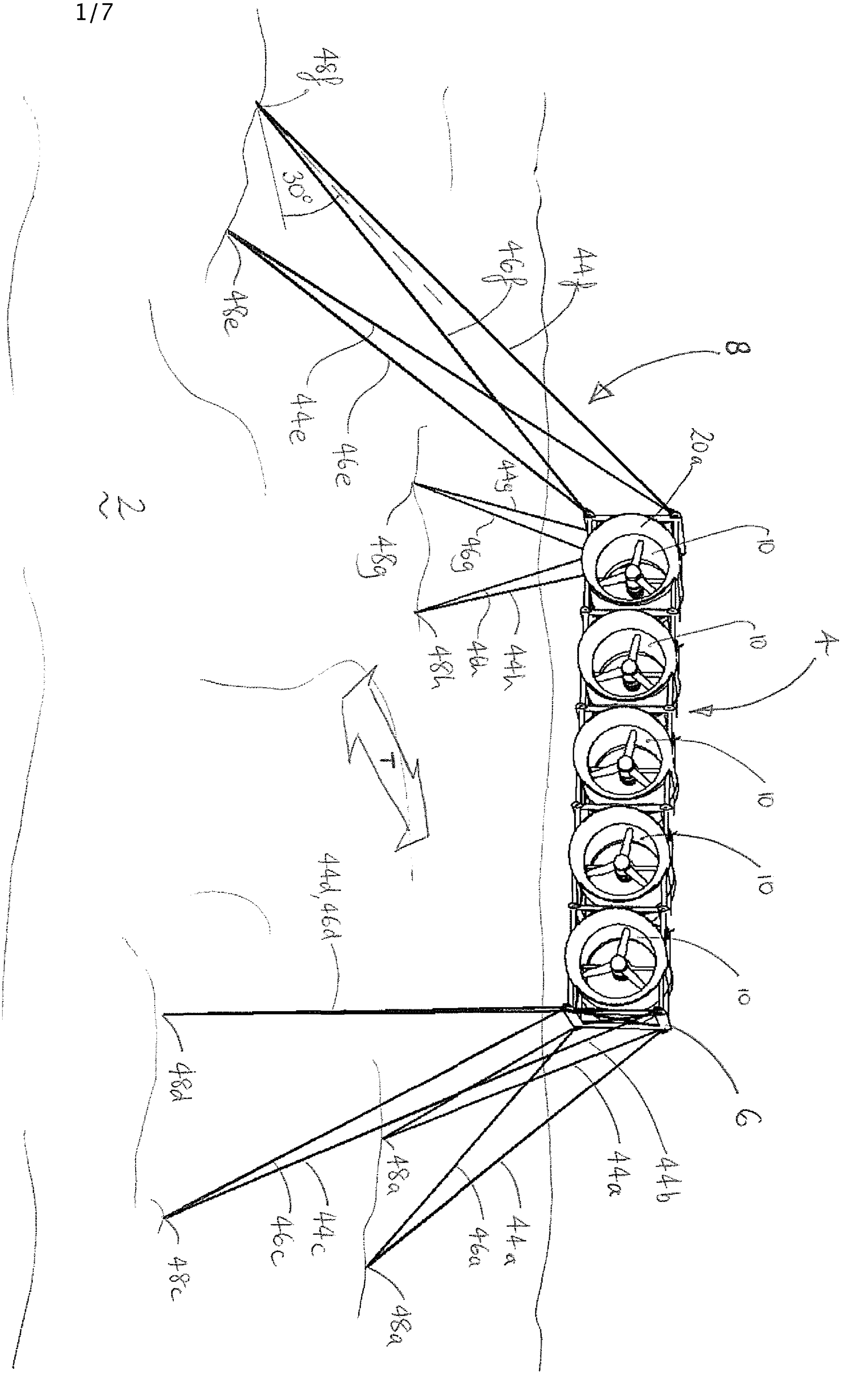
FIGURE 1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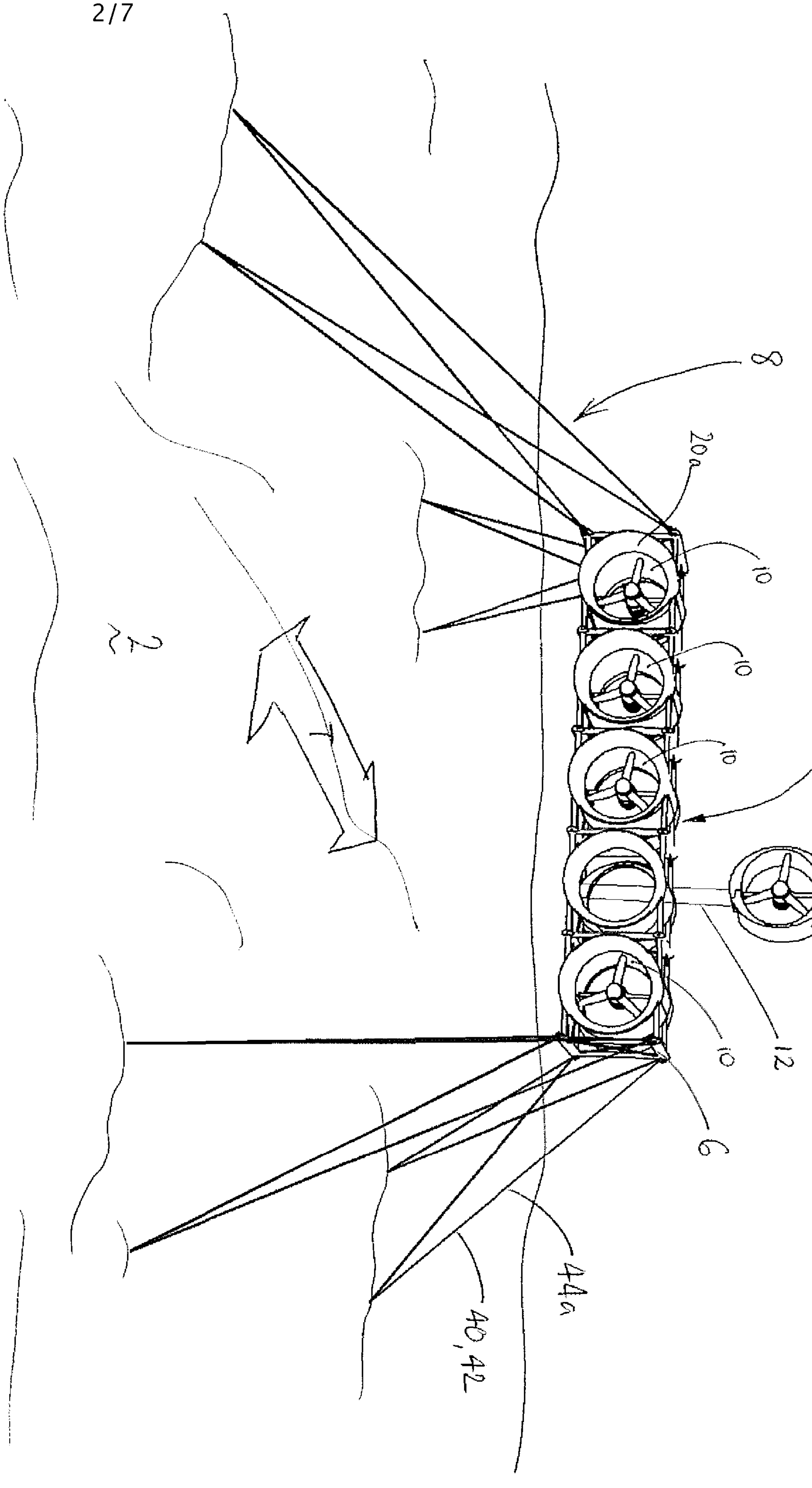


FIGURE 2

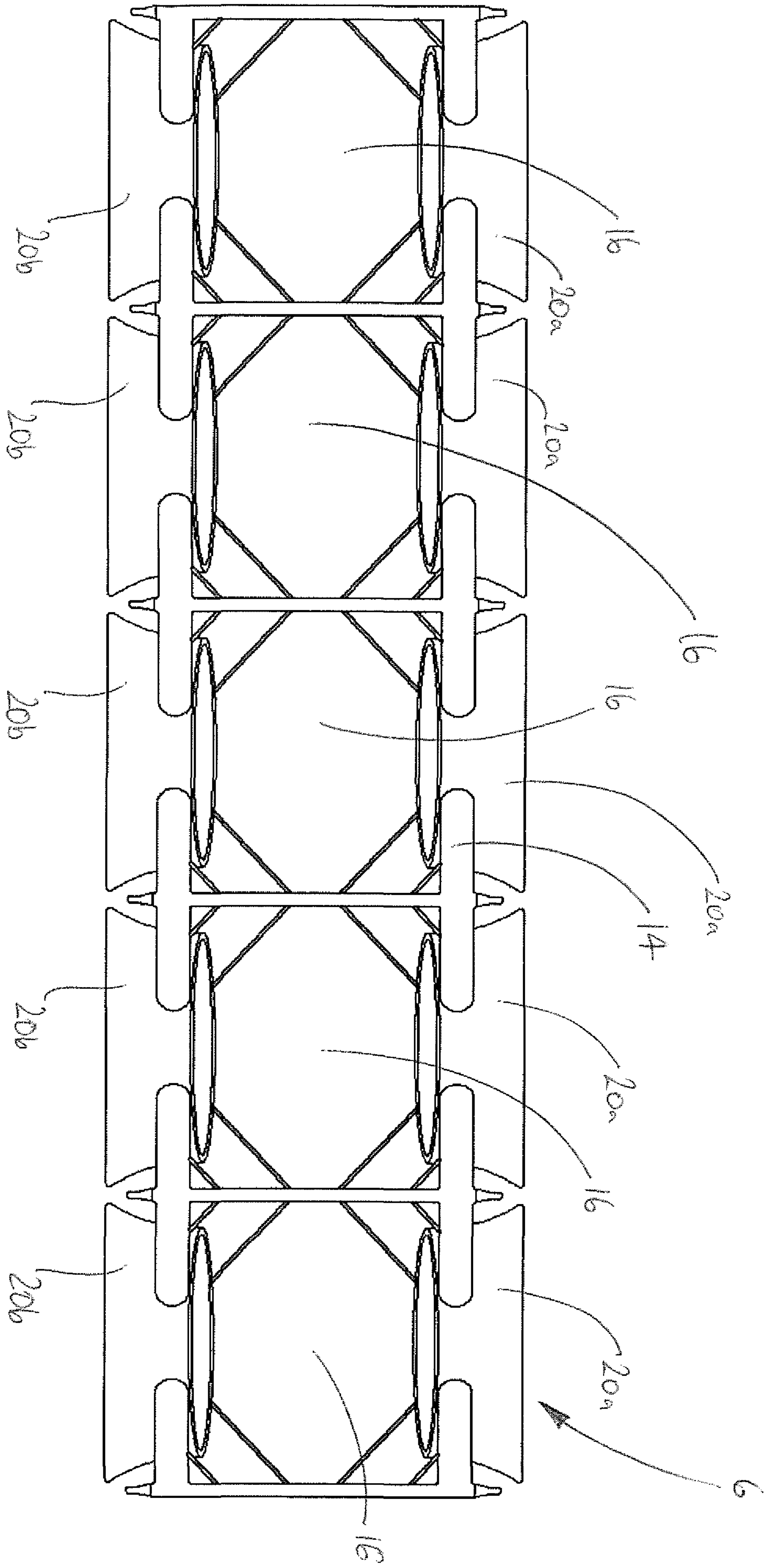


FIGURE 3

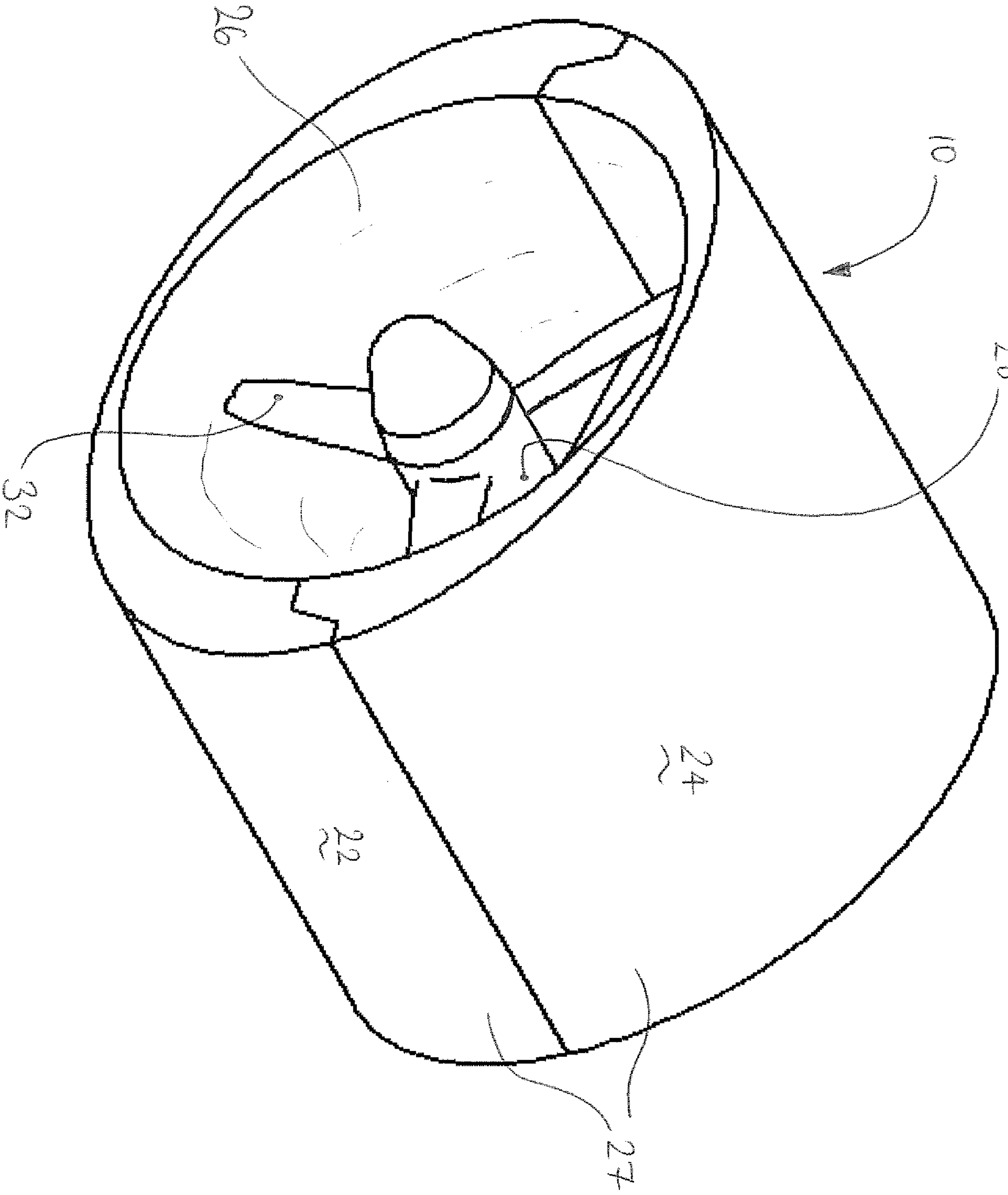
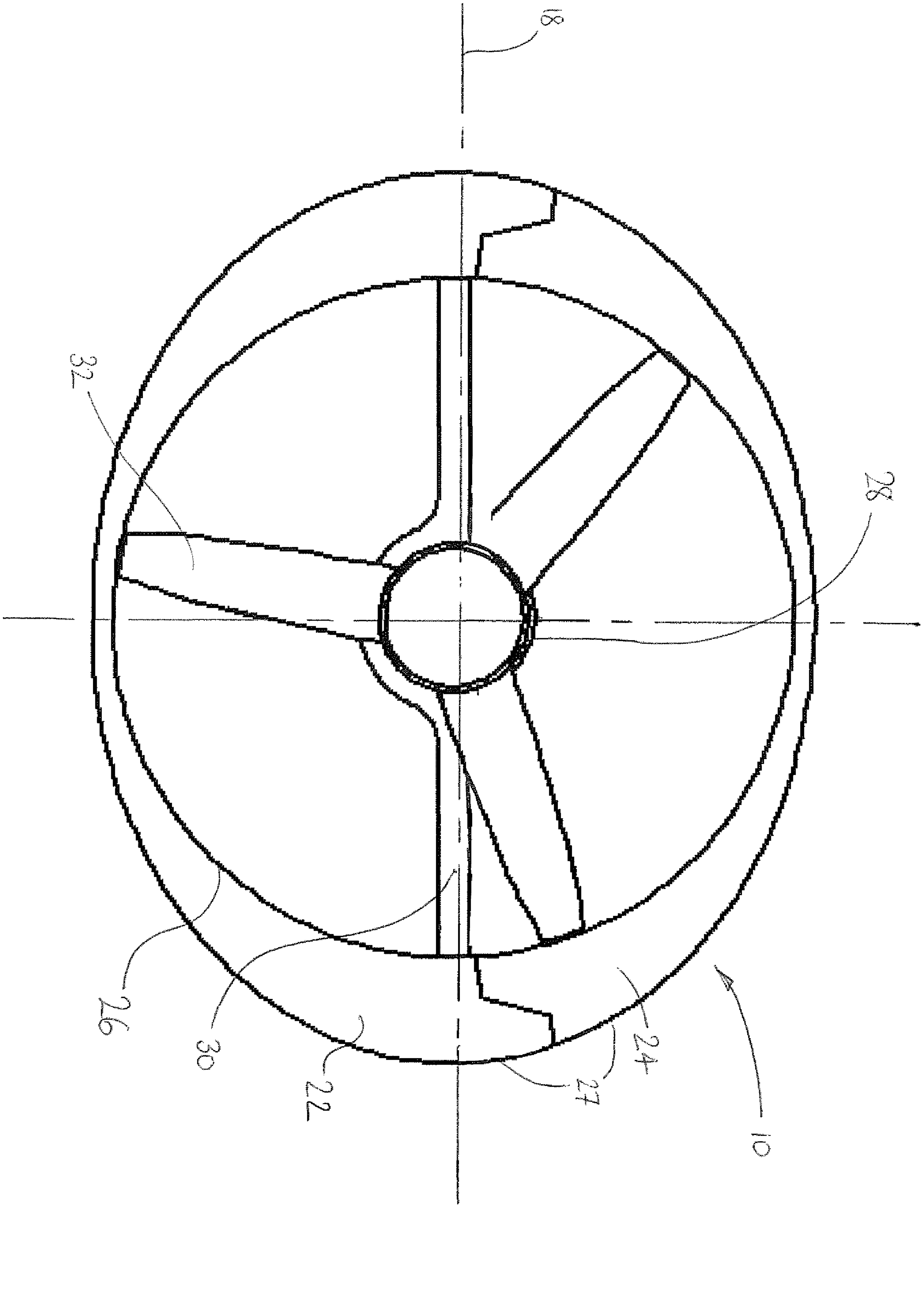


FIGURE 4

FIGURE 5



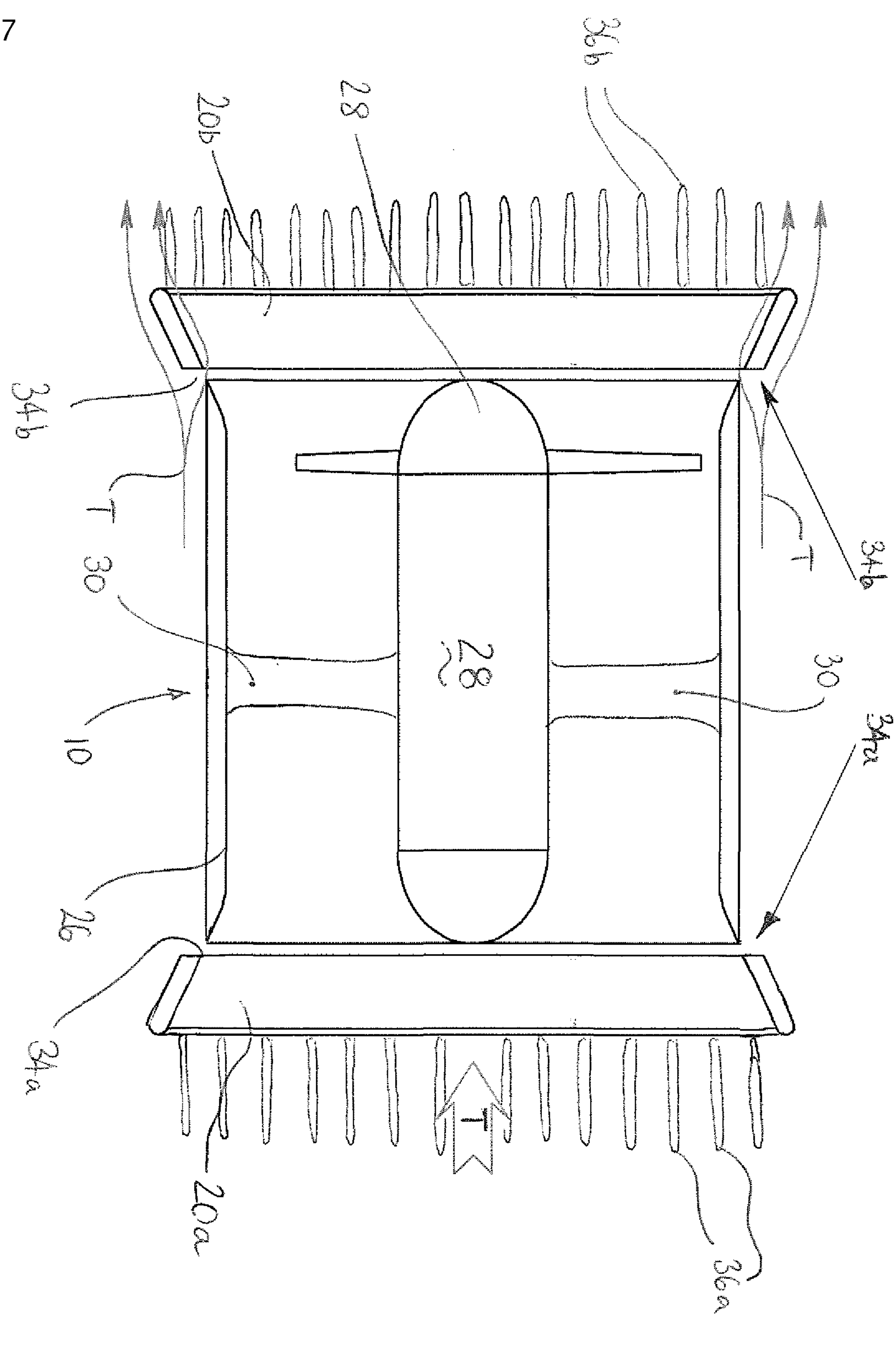


FIGURE 6

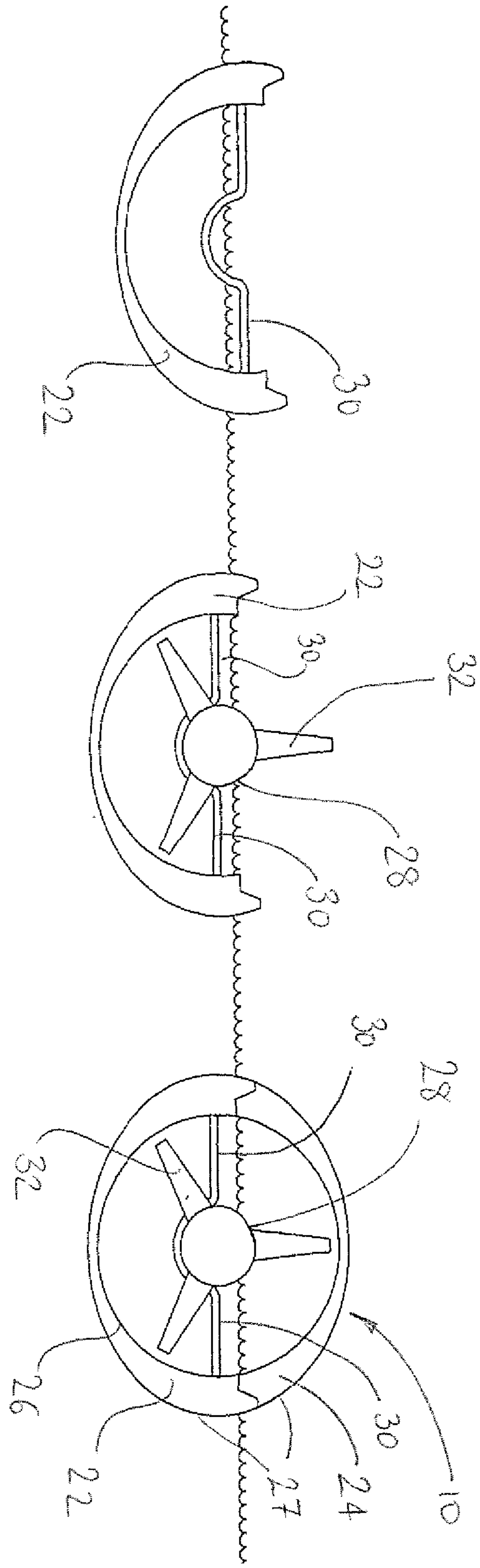


FIGURE 7C

FIGURE 7B

FIGURE 7A

A Modular Turbine Assembly

The present invention relates to a flowing-water driveable turbine assembly to be located in river or sea areas with unidirectional, or bidirectional, water flows to convert the kinetic energy of the water flow into a more easily transferable form of energy, like, for example, hydraulic energy or electrical energy.

It is well known to drive a turbine by flow of water. The extraction of kinetic energy from the water flow causes a reduction in the momentum of the passing water which in turn creates large reaction forces on the turbine. These reaction forces manifest themselves primarily as a drag force acting in the direction of water flow. For example, turbines can typically weigh between 50 and 200 tonnes and can have a rotor diameter between 10 and 21m and the larger turbines may have a drag of around 1MN (equivalent to 100 tonnes) under typical water flow of around 6 knots. Thus, a flowing-water driveable turbine assembly must be firmly anchored. Often turbine assemblies are anchored in deep water to avoid interaction with waves found near the surface or to avoid collisions with boats. However, turbines must be transportable to an anchoring site. Turbine assemblies must also be accessible for maintenance and repair in a reasonable amount of time. These aspects of water-driveable turbine technology pose substantial engineering challenges.

Patent publication No. WO99/02853 discloses a stream turbine to cover large areas of water streams and which can be manufactured in a ship yard and transported to a site of use and be anchored there. The stream turbine as a whole can be floated and towed for maintenance or repair.

Patent publication No.s WO2004/085845 and WO2005/061887 disclose support structures for supporting water current turbines in a sea or river estuary. The support structure with turbines may be floated to the water surface for maintenance or repair.

The present invention provides a modular turbine assembly comprising a turbine support with positive buoyancy in water, wherein the turbine support is arranged to be anchored by an anchoring system to a water bed and a plurality of turbine modules each with positive buoyancy in water, wherein each turbine module is detachably docked with the turbine support, wherein the combined positive buoyancy of the turbine support and the turbine modules in water has an upward force to constrain the turbine support and the turbine modules to a position of floating equilibrium against a downward force of an anchoring system, wherein each turbine module has a duct and a flowing-water driveable turbine mounted in the duct, wherein the duct is for directing water through the turbine and the turbine is for generating power from water flow.

An advantage of the present invention is that all its components can be floated to an anchorage site where they are assembled. The turbine support is submerged and permanently anchored to the water bed. The turbine modules are submerged to detachably dock with the turbine support where they remain until maintenance, repair or replacement is needed. In that event, one turbine module may be floated to the water surface without need of disturbing the rest of the turbine assembly. This saves time, energy and cost. If maintenance or repair is unexpectedly protracted a decision to substitute the defective turbine module can be taken quickly and efficiently. Moreover, if a substitute turbine module is not available then the defective turbine module can be returned to harbour while the rest of the turbine assembly continues to operate uninterrupted.

Another advantage of the present invention is that the turbine assembly can accept any type of flowing-water driveable turbine (i.e. axial flow turbine or cross flow turbine) once it is fitted to a turbine module. This means that, if desired, different turbines from different manufacturers, can operate alongside each other without modification to the turbine support. This improves flexibility in repair and maintenance and reduces cost, time and energy.

In a variant of the present invention, the modular turbine assembly may comprise only one turbine module. This would typically be when the turbine module assembly is used for testing or prototyping, although there may be other reasons, like, for example, when all but one of the turbine modules have been detached from the turbine support for maintenance or repair.

Water generally flows in one direction in a river whereas tidal flow at sea generally causes water flow in two directions. Preferably, the turbine is driveable by water flowing in either direction through the duct. This has the advantage that the turbine assembly is able to harness the kinetic energy of unidirectional river water flow or bidirectional tidal water flow at sea.

The duct reduces the effects of change in tidal flow angle, off-axis water flow and wave interaction by straightening and aligning water flow with the axis of the turbine. Preferably the duct defines a hollow generally cylindrical bore, wherein the turbine is a horizontal axis turbine with a rotor co-axial with the duct, and wherein the rotor is matched to the internal diameter of the duct.

Preferably, the duct is in fluid communication with a flared annular section at each end of the duct and wherein each flared annular section tapers towards the duct. Depending on the water flow direction, the down-flow flared annular section scoops water into the duct and the other emits water. This can increase water flow through the duct.

Preferably, the flared annular sections are mounted upon the turbine support. This can reduce the size, weight and complexity of the turbine modules.

Preferably, boundaries between the duct and the flared annular sections have at least one gap to promote water flow augmentation around where water flows into the flared annular section down-flow from the duct. This reduces water eddies by re-establishing a boundary layer connection between water flow and the diffuser i.e. the down-flow flared annular section. A reduction in water eddies is beneficial because it may reduce parasitic energy losses and drag. The at least one gap may be one gap or a series of gaps or slots.

Preferably, the at least one gap is an annular gap. This can promote water flow augmentation around the whole circumference of the diffuser i.e. the down-flow flared annular section

Preferably, each flared annular section has an array of transverse vanes. The vanes help prevent ingress of marine flora, fauna and debris and guide such objects clear of the duct. The vanes help straighten the water flowing into the turbine.

Preferably, the turbine module is streamlined to reduce interaction with upward and downward wave motion in the water surrounding the turbine module. Wave motion, particularly upward and downward wave motion, can put significant force on the anchoring system of a turbine assembly and, over time, can damage or weaken the anchoring system. This is especially so when the turbine assembly is under load of tidal flow. Interaction with wave motion is to be reduced as much as possible by, for example, anchoring the turbine assembly in deep water i.e. 40m of water. Streamlining the turbine modules has the advantage of further reducing wave interaction by presenting a decreased horizontal cross-sectional area.

Preferably, the positive buoyancy of the turbine module is localised above and below the duct. The turbine module can float on its side with an increased horizontal cross-sectional area because the streamlined profile naturally lies flat upon the water surface. This improves stability, and reduces the draft, of the turbine module when it is being towed in water.

Preferably, the turbine module is elongate in the direction of water flow through the duct and wherein an external surface of the turbine module has a generally elliptical transverse cross-sectional profile. An elliptical profile is an example of a streamlined profile that helps to reduce interaction with upward or downward wave motion by presenting a decreased horizontal cross-sectional area.

Preferably, the turbine is removable through a removable side of the turbine module. Complete access to the turbine in open water, and even removal of the turbine by floating crane, may be highly beneficial in saving time, energy and cost in repair or maintenance to the turbine module.

Preferably, each turbine module is adapted to dock with the turbine support in a positive location arrangement. This has the advantage of automating the docking process because the turbine module finds its own docking location as it is lowered into the turbine support. The process may be further automated by latches to fix the turbine module docked to the turbine support. Alternative fixing means, like, for example, a lock or a pin may be employed.

Preferably, the turbine support is adapted to dock with three to five turbine modules.

Preferably, the positive buoyancy of the support structure and/or the turbine module is variable. The buoyancy of the support structure or turbine module may be reduced to facilitate submerging, especially if a remote access vehicle is to be used instead of a winch. When the turbine support or the turbine module is assembled with the turbine fully assembly the buoyancy may be increased to stiffen the anchoring system. Variable buoyancy presents the operator with advantageous flexibility.

According to another aspect of the present invention, the turbine support is provided separately for assembly with the modular turbine assembly.

According to another aspect of the present invention, the turbine module is provided separately for assembly with the modular turbine assembly.

According to another aspect of the present invention, an anchoring system may be provided for anchoring the modular turbine assembly to a water bed. The anchoring system comprises at least three anchoring cables anchored to points on a water bed covering a footprint greater in width and in length than the turbine support. The enlarged footprint improves the stability of the turbine assembly.

Preferably, the upward force of the combined positive buoyancy of the turbine support and the turbine modules causes tensile forces in the anchoring cables. This provides stiffer resistance to heave under water flow.

Preferably, the anchoring system has at least six pairs of anchoring cables, wherein ends of each pair of anchoring cables are fixed to a respective anchor point on the water bed, wherein the anchoring cables of each pair of anchoring cables diverge from said anchoring point to where opposite ends of the anchoring cables are fixed to a pair of mutually spaced points of the turbine support, and wherein at least three pairs of anchoring cables are fixed to each end of the elongate support structure. This provides greater stability in water flow.

Preferably, an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is no more than about 60 degrees. More preferably, an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is no more than about 45 degrees. This is to provide an anchoring system with vertical stability and without tending to pull the anchoring points out of their holes in the water bed.

Preferably, an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is no less than about 10 degrees. More preferably, an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is no less than about 15 degrees. This is to provide an anchoring with horizontal stability and which also provides clearance under the turbine support for water flow. This can reduce heave on the turbine support.

Preferably, an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is 30 degrees +/- 15 degrees.

Preferably, the anchoring cables are streamlined and/or equipped with vortex suppressants. This may reduce, or even eliminate, vortex induced vibration caused by water flow around the anchoring cables. It is also to reduce the hydrodynamic drag of the anchoring cables.

According to another aspect of the present invention, a method of assembling the modular turbine assembly in open water comprises the steps of: towing the turbine support to an anchorage site; anchoring the turbine support to a water bed with an anchoring system; towing the plurality of turbine modules to the anchorage site; submerging one of the turbine modules to dock with the turbine support; and repeating the last step until the full complement of turbine modules is docked with the turbine support.

The depth of the turbine assembly depends on turbine size and the conditions of the anchoring site. The minimum submerged depth could be 1m in a river or in a sheltered position. In certain conditions the depth may be less than 1m whereby the turbine support is not entirely submerged. Preferably, the method of assembling a modular turbine assembly comprising an additional step of submerging the turbine support between steps of towing it and anchoring it.

Preferably, the last step of the method of assembling a modular turbine assembly in open water is performed by force of a winch with at least one pull line and wherein the winch is mounted upon the turbine support. This is a reliable way of ensuring the turbine module docks with the turbine assembly.

Alternatively, the last step of the method of assembling a modular turbine assembly in open water is performed by force of a remote operated submergible vehicle.

This is a suitable alternative if a winch is not fitted to the turbine support, or it is inoperable.

Preferably, the positive buoyancy of the turbine module is reduced when submerged by a remote access vehicle and increased after docked with the turbine support. This makes it easier for the remote access vehicle to submerge the turbine module.

Preferably, the method of assembling a modular turbine assembly in open water is performed with the anchoring system described above due to its inherent resistance to heave under water flow.

According to another aspect of the present invention, a method of repair or maintenance to the modular turbine assembly comprises the steps of tethering one of the turbine modules for controlled floatation to the water surface; detaching the turbine module from the turbine support; floating the turbine module to the water surface; and performing repair or maintenance work upon the turbine module or submerging a substitute turbine module to dock with the turbine support.

Preferably, the method of repair or maintenance to a modular turbine assembly is performed by force of a winch with at least one pull line wherein the winch is mounted upon the turbine support. This is a reliable way of ensuring the turbine module docks with the turbine assembly.

Alternatively, the method of repair or maintenance to a modular turbine assembly is performed by a remote operated submergible vehicle. This is a suitable alternative if a winch is not fitted to the turbine support, or it is inoperable.

Preferably, the positive buoyancy of the turbine module is reduced when submerged by a remote access vehicle and increased after docked with the turbine support. This makes it easier for the remote access vehicle to submerge the turbine module.

According to another aspect of the present invention, the turbine support may be provided by towing the turbine support to an anchorage site and anchoring the turbine support to a water bed with an anchoring system, preferably the anchoring system described above.

According to another aspect of the present invention, the turbine module may be provided by towing the turbine module to the anchorage site and submerging the turbine modules to dock with the turbine support.

An embodiment of the modular turbine assembly of the present invention will now be described with reference to the drawings of which:

Figure 1 is a perspective view of an embodiment of the modular turbine assembly of the present invention anchored to a sea bed;

Figure 2 is a perspective view a turbine module docking with a turbine support of the modular turbine assembly of Figure 1;

Figure 3 is a plan view of the top of the turbine support;

Figure 4 is perspective view of the turbine module;

Figure 5 is a front elevation view of the turbine module;

Figure 6 is a cross-sectional view of the turbine module with a flared annular section at each end; and

Figure 7A to 7C show three stages of disassembling the turbine module.

Referring to Figure 1, there is shown a sea bed 2 in a region of the sea where water flows in two directions due to tidal forces. Submerged in the water is a modular turbine assembly 4 which is for converting the kinetic energy of the flowing water into electrical energy and delivering it to a facility located on shore or offshore. The turbine assembly comprises an turbine support 6 which is positively buoyant in water and which is anchored to the sea bed by an anchoring system 8. The turbine assembly 4 has an array of five turbine modules 10 arranged in a line in the turbine support 6. Each turbine module 10 is positively buoyant in water. Each turbine module 10 is detachably docked to the turbine support 6. The combined positive buoyancy of the turbine support 6 and the five turbine modules 10 has an upward force which constrains them to a position of floating equilibrium against the downward force of an anchoring system 8.

As the turbine assembly of this embodiment is anchored at sea, a double-headed arrow T shows both directions in which the tidal forces cause the water to flow. The modular turbine assembly 4 is orientated with the array of five turbine modules 10 generally in line with arrow T so that as much water as possible flows through the turbine modules in a straight path.

The turbine assembly 4 is described as modular because the turbine modules 10 are interchangeable with each other and are docked to the in the support structure 6 in the same way.

Referring to Figure 2, there is shown a turbine module 10' being pulled downward by a winch on the turbine support with two pull lines 12. The turbine module 10' docks with the turbine support 6. Once docked with the support structure, the turbine module 10' is anchored to the sea bed by the anchoring system unless, or until, at some time in the future the turbine module 10' is detached for maintenance, repair or replacement.

If, or when, maintenance, repair or replacement is required, the turbine module 10' is detached from the turbine support and allowed to float under its own inherent buoyancy in water to the surface. The assent of the turbine module 10' is controlled by the winch with two pull lines 12.

Alternatively, the winch with two pull lines can be substituted by a remote operated vehicle to perform the task of submerging the turbine module to dock with the turbine support. The remote operated vehicle can perform the task of controlled floatation of the turbine module to the surface too.

Referring to Figure 3, the turbine support 6 comprises a frame 14. The frame can be made of any material strong enough to support the turbine modules (i.e. steel, aluminium, fibre reinforced concrete, inflated material or composite). The frame has elements that are filled with buoyant material, or that are attached to buoyant material, to provide the positive buoyancy of the turbine support. The positive buoyancy may be adjusted by means of compressed air or buoyant gel or by another medium pumped from the surface or supplied by sub-sea reservoir. The positive buoyancy of the turbine support 6 is enough to be towed to the anchoring site.

The frame 14 is divided into five turbine module docking bays 16. Each docking bay 16 is accessible through the top of the frame to receive a respective turbine module 10. Each docking bay has a pair of flared annular sections 20a, 20b connected to the frame 14 of the turbine support 6. One flared annular section is located at each end of the docking bay. Each flared annular section tapers towards the docking bay.

Referring to Figures 4 and 5, the turbine module 10 has a major body shell 22 and a minor body shell 24 joined to form a duct 26 which defines a hollow generally cylindrical bore. An external surface 27 of the joined minor and major body shells has a generally elliptical profile transverse the cylindrical bore of the duct. The body shells 24, 26 are filled with buoyant material (i.e. a fluid, solid or a combination of both), or are attached to buoyant material, to provide the positive buoyancy of the turbine module. The positive buoyancy of each turbine module 10 is enough to be towed to an anchoring site.

The turbine module 10 has a water-driveable horizontal axis turbine 28 mounted upon a bracket 30 inside the duct. The turbine has a rotor 32 co-axial with the duct. The rotor is matched to the diameter of the duct. The duct shields the turbine from turbulence caused by adjacent turbines so that the array of five turbine modules may be closely spaced. The turbine is driveable by water flowing in either direction through the duct and generates electrical power.

Returning to Figure 2 in more detail, each turbine module 10 is docked with a respective docking bay 16 in a complementary locating arrangement which automatically orientates a major axis 18 of the elliptical profile of the external surface 27 in a generally upright position in the turbine support 6 where the turbine module is locked in place by a locking mechanism. This reduces the horizontal cross-sectional area of the turbine module. As a result, the turbine module is streamlined to reduce interaction with upward or downward wave motion in the surrounding water.

Electrical connections between the turbine modules 10 and the turbine support 6 are made before or after docking. The electrical power generated by the turbines varies with water flow rate. Each turbine module has electrical power equipment (not shown) for conditioning the electrical power generated by the turbines. The turbine support has electrical power management equipment (not shown) for combining the conditioned electrical power from the five turbine modules. The turbine support's electrical power management equipment includes a step-up transformer (not shown) for transmission of the generated electrical power to a shore, or offshore, facility via a power cable 40. A communication cable 42 from the turbine assembly accompanies the power cable.

Referring to Figure 6, there is shown the duct 26 in fluid communication with the pair of flared annular sections 20a, 20b when one of the turbine modules 10 is docked in one of the docking bays 16 of the turbine support 6. The annular sections are suited for bi-directional water flow. Single headed arrow T indicates a direction of water flow which results in the up-flow annular section 20a performing the role of concentrator to scoop water into the duct and the down-flow annular section 20b performing the role of diffuser to emit water from the duct. This situation will be reversed when the tide changes and water flows through the duct in the opposite direction and arrow T is reversed (i.e. annular section 20b becomes the concentrator and annular section 20a becomes the diffuser).

The geometry of the annular sections 20a, 20b is matched to the water flow requirements of the turbine. The annular sections may be made of steel, aluminium, fibre reinforced concrete, inflated material or composite. The annular sections are connected may contribute the positive buoyancy of the turbine support.

The boundaries between the duct 26 and the flared annular sections 20a, 20b each have an annular gap 34a, 34b. The gaps enable water flowing outside the turbine module to enter the diffuser (i.e. the down-flow annular section 20b in this example) by venturi effect. This promotes water flow augmentation which reduces water eddies by re-establishing a boundary layer connection between water flow and the diffuser. A reduction in water eddies is beneficial because it reduces parasitic energy losses and drag.

The ends of the flared annular sections 20a, 20b facing away from the duct 26 are each equipped with an array of transverse vanes 36a, 36b. The vanes help prevent ingress of debris into the duct and help straighten the water flowing into the turbine 28. The vanes induce a rotational flow into the water flow to increase the energy extraction of the turbine.

Referring to Figure 7A, the positive buoyancy of the turbine module 10 is localised about the major axis 18 of the elliptical external surface 27. As a result, the turbine module tends to float on the water surface with an increased horizontal cross-sectional area. This improves stability, and reduces the draft, of the turbine module when it is being towed at sea.

Referring to Figure 7B, the major body shell 22 has positive buoyancy to enable removal of the minor body shell 24 while the major body shell and the turbine 28 remain afloat. Removal of the minor body shell allows complete access to the turbine, and even removal of the turbine by floating crane, for the purpose of repair or maintenance to the turbine module, as is shown by Figure 7C.

Returning in more detail to Figure 1, the anchoring system 8 comprises eight pairs of anchoring cables 44a, 46a - 44h, 46h. Each pair of anchoring cables includes an upper anchoring cable 44 and a lower anchoring cable 46. Two pairs of anchoring cables are fixed to each corner edge of the frame 14 of the turbine support 6 (i.e. the upper anchoring cable of each pair is fixed to the corner edge above where the lower anchoring cable of each pair is fixed to the corner edge). The other ends of each pair of anchoring cables are permanently fixed to a respective anchor point 48a - 48h on the sea bed.

The anchoring cables 44a, 46a - 44h, 46h of each pair of anchoring cables converge from the frame 14 of the turbine support 6 to their respective anchoring points 48a - 48h. The mean angle of inclination of the anchoring cables of each pair of anchoring cables with respect to the horizontal is approximately 30 degrees.

The anchor points 48a - 48h are arranged about the turbine support 6 to suit the sea bed topography and to maintain the turbine support in a generally horizontal position. The anchor points cover a footprint greater in width and in length than the turbine support.

The upward force of the combined positive buoyancy of the turbine support 6 and the five turbine modules 10 cause tensile forces along the full length of the anchoring cables 44a, 46a - 44h, 46h.

The anchoring cables may be (preferably high performance) synthetic rope, steel / wire rope, chain, solid metallic rod or solid composite rod.

The anchoring cables are equipped with vortex suppressants to reduce their hydrodynamic drag and reduce any vibration caused by water flow. For example, a vortex suppression system may be fibre or tape strands incorporated or attached to the anchoring cables. The fibre or tape strands stream with the water flow to form a fairing, or a hydrofoil. Rotating faired sections which fit over the anchoring cables and align with the water flow, spiral sections either fitted to or incorporated into the structure of the anchoring cable, or other proprietary vortex suppression systems are also suitable.

Returning to Figure 2, the power cable 40 and the communication cable 42 from the turbine assembly are incorporated within the upper anchoring cable 44a.

The modular turbine assembly is assembled at sea by towing the turbine support to an anchorage site, submerging it, and anchoring it to the sea bed with the anchoring system where it remains permanently. The five turbine modules are towed to the anchorage and submerged, each one in turn, to dock with the turbine support.

To recap, the following are important features of at least some preferred embodiments of the present invention, and each can be provided independently or in different embodiments.

A tethered sub-sea installation base which, when populated with devices, in itself comprises a small array of horizontal axis Tidal Energy Convertors (TECs). The base is for use at deep water sites (over 40msw) and enables the TECs to be positioned at the optimum depth dictated by the compromise between power output (strongest current found close to the surface) and adverse structural and flow influences from wave interaction. Alternatively, the base may be used at shallower sites where it is submerged very close to, or even slightly protruding above (provided the TECs are submerged), the water surface.

As an integral part of the design a method is disclosed of installing and retrieving the TECs using buoyant modules into which individual TECs are loaded. The loaded modules are then towed to site and connected to the sub-sea base electrically and via a pull in line. The module is pulled sub-sea by the pull in line and interfaces with and locks into the sub-sea base.

An alternative to the above method, the buoyant modules may be driven to and retrieved from the PMSS by means of a Remote Operated Vehicle (ROV) specifically designed for the purpose and having the required thrust capability. This may include the use of variable buoyancy within the buoyant module to reduce the quantity of thrust required to drive the module subsea.

The turbine support may be a permanently installed buoyant subsea structure PMSS comprising:

- Structural space frame which may be of steel, aluminium or composite construction – the elements of which may be sealed to form pressure vessels, or may be filled with, surrounded by, or have attached buoyant material (including air or other gas) providing all or part of the buoyancy required to support the structure.
- 'Conical' diffuser and concentrator sections – the precise geometry of the concentrator and diffuser can be matched to the flow requirements of the TEC.
- The diffuser and concentrator sections can be suited to bi-directional flow
- The diffuser and concentrator sections can incorporate 'slots' to enable flow augmentation to re-establish boundary layer connection within the diffuser.
- The diffuser and concentrator sections may be constructed from steel, aluminium, fibre reinforced concrete, inflated material (i.e. 'hyperlon' or similar), composite (i.e. glass or other fibre reinforced plastic).
- The diffuser and concentrator sections may contribute to the buoyancy of the PMSS
- Buoyancy of the PMSS may be adjustable by means of compressed air or buoyant gel or other medium pumped from the surface or supplied from a subsea reservoir.
- Step up transformer for transmission of generated electrical power to shore or offshore processing facility via power cable.
- Power conditioning and switching equipment as required to combine and transmit the output of one or more tidal energy convertors as electrical power.

The anchoring system is a tension spread mooring system (TSM)

- Sea-bed fixing points which may be drag anchors; gravity anchors; suction piles; pinned template structures; attachment to sub-sea geographical features;
- Tension members which may be high performance synthetic rope such as UHMwPE (i.e. dyneema); steel / wire rope; chain; solid metallic rod (i.e. nitronic 50; 17-4pH; 316 stainless steel etc.)
- Vortex Induced Vibration (VIV) suppression system which may be fibre or tape strands incorporated or attached to the tension member which streams with the flow to form a fairing ('hairy' or 'ribbon' fairing); Rotating faired sections which fit over the tension member and align with the flow; Spiral sections either fitted to or incorporated into the structure of the tension member, or other proprietary vortex suppression system.
- Power transmission cable incorporating power conductors and communications (i.e. fibre optic or conventional signal pair conductors)
- The power transmission and communication cables may be incorporated into one or more of the tension members (i.e. the structural cable casing may act as tension member(s)).

The turbine module is a buoyant module (BM)

- Parallel annular duct matched to TEC to reduce the effects of off axis flow and wave interaction by straightening and aligning current flow with the TEC axis.
- Once installed the BM Integrates with the 'conical' diffuser and concentrator sections (which form part of the PMSS) to enhance performance over that achievable in open ocean conditions.
- BM's installed into the subsea structure by sub-sea pull in lines, buoyancy control or a combination of the two.
- The BM has an elliptical (or otherwise non-circular) distribution of volume to reduce the horizontal area presented to wave motions, and to give stability when on the surface.

- The BM can contain power conditioning equipment as required for each individual TEC to enable the power produced to be fed to the centralised step up transformer for onward transmission.
- The BM can be split to allow installation of the TEC by means of overhead crane. This minimises the crane capacity required.

Power for sub-sea operations:

Power to drive the subsea winches may be provided by equipment permanently or temporarily fitted to the sub-sea structure, or may be provided by means of an umbilical connection from a surface ship, or by specially equipped Remote Operated Vehicle (ROV).

Protection against object ingress. Vanes on the concentrator and diffuser may provide some or all of the following functions:

- Prevent the ingress of marine fauna, flora and flotsam/debris
- Guide objects clear of the duct and sub-sea structure
- Further straighten the flow into the turbine blades
- Induce counter rotational flow into the water stream to increase the energy extraction potential.

The vanes are not a fundamental part of the design but may have significant efficiency benefits if considered as part of the turbine design as it may allow significantly higher rotor speeds and therefore lighter, lower cost generators. The design of the vanes may simply look similar to two traditional ‘cow catchers’, mirrored and joined on the centre-line to form an inlet guard – one such unit at each end to catch and guide any objects clear of the inlet to the turbine duct.

As noted above, each feature may be provided independently and applied to other embodiments or aspects.

Claims

1. A modular turbine assembly, comprising:

a turbine support with positive buoyancy in water, wherein the turbine support is arranged to be anchored by an anchoring system to a water bed; and

a plurality of turbine modules each with positive buoyancy in water, wherein each turbine module is detachably docked with the turbine support,

wherein the combined positive buoyancy of the turbine support and the turbine modules in water has an upward force to constrain the turbine support and the turbine modules to a position of floating equilibrium against a downward force of an anchoring system,

wherein each turbine module has a duct and a flowing-water driveable turbine mounted in the duct, wherein the duct is for directing water through the turbine and the turbine is for generating power from water flow.

2. A modular turbine assembly as claimed in claim 1, wherein the turbine is driveable by water flowing in either direction through the duct.

3. A modular turbine assembly as claimed in either one of claims 1 or 2, wherein the duct defines a hollow generally cylindrical bore, wherein the turbine is a horizontal axis turbine with a rotor co-axial with the duct, and wherein the rotor is matched to the internal diameter of the duct.

4. A modular turbine assembly as claimed in claim 3, wherein the duct is in fluid communication with a flared annular section at each end of the duct and wherein each flared annular section tapers towards the duct.

5. A modular turbine assembly as claimed in claim 4, wherein the flared annular sections are mounted upon the turbine support.

6. A modular turbine assembly as claimed in either one of claims 4 or 5, wherein boundaries between the duct and the flared annular sections have at least one gap to promote water flow augmentation around where water flows into the flared annular section down-flow from the duct.

7. A modular turbine assembly as claimed in claim 6, wherein the at least one gap is an annular gap.

8. A modular turbine assembly as claimed in any one of claims 4 to 7, wherein each flared annular section has an array of transverse vanes.

9. A modular turbine assembly as claimed in any one of the previous claims, wherein the turbine module is streamlined to reduce interaction with upward and downward wave motion in the water surrounding the turbine module.

10. A modular turbine assembly as claimed in claim 9, wherein the positive buoyancy of the turbine module is localised above and below the duct.

11. A modular turbine assembly as claimed in either of claims 9 or 10, wherein the turbine module is elongate in the direction of water flow through the duct and wherein an external surface of the turbine module has a generally elliptical transverse cross-sectional profile.

12. A modular turbine assembly as claimed in any one of the previous claims, wherein the turbine is removable through a removable side of the turbine module.

13. A modular turbine assembly as claimed in any one of the previous claims, wherein the turbine generates electrical power and the turbine assembly has electrical power management equipment for transmission of generated electrical power through a power cable.

14. A modular turbine assembly as claimed in claim 13, wherein a communication cable from the turbine assembly accompanies the power cable.

15. A modular turbine assembly as claimed in any one of the previous claims, wherein each turbine module is adapted to dock with the turbine support in a positive location arrangement.

16. A modular turbine assembly as claimed in any one of the previous claims, wherein the turbine support is adapted to dock with three to five turbine modules.

17. A modular turbine assembly as claimed in any one of the previous claims, wherein the turbine support is fully submerged in water.

18. A modular turbine assembly as claimed in any one of the previous claims, wherein the positive buoyancy of the support structure and/or the turbine module is variable.

19. A turbine support for assembly with the modular turbine assembly of any one of the previous claims.

20. A turbine support as claimed in claim 19, wherein the turbine support is sufficiently buoyant in water to be towed by a boat.

21. A turbine module for assembly with the modular turbine assembly of any one of claims 1 to 18.

22. A turbine module as claimed in claim 21, wherein the turbine module is sufficiently buoyant in water to be towed by a boat.

23. An anchoring system for anchoring the modular turbine assembly of any one of claims 1 to 18 to a water bed, the anchoring system comprising at least three anchoring

cables anchored to points on a water bed covering a footprint greater in width and in length than the turbine support.

24. An anchoring system as claimed in claim 23, wherein the upward force of the combined positive buoyancy of the turbine support and the turbine modules causes tensile forces in the anchoring cables.

25. An anchoring system as claimed in claim 24, wherein the at least three anchoring cables are at least six pairs of anchoring cables, wherein ends of each pair of anchoring cables are fixed to a respective anchor point on the water bed, wherein the anchoring cables of each pair of anchoring cables diverge from said anchoring point to where opposite ends of the anchoring cables are fixed to a pair of mutually spaced points of the turbine support, and wherein at least three pairs of anchoring cables are fixed to each end of the elongate support structure.

26. An anchoring system as claimed in claim 25, wherein an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is no more than about 60 degrees.

27. An anchoring system as claimed in claim 25, wherein an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is no more than about 45 degrees.

28. An anchoring system as claimed in claim 25, wherein an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is no less than about 10 degrees.

29. An anchoring system as claimed in claim 25, wherein an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is no less than about 15 degrees.

30. An anchoring system as claimed in claim 25, wherein an angle of inclination of the anchoring cables from the water bed and with respect to the horizontal is 30 degrees +/- 15 degrees.

31. An anchoring system as claimed in any one of claims 23 to 30, wherein the anchoring cables are streamlined and/or equipped with vortex suppressants.

32. A method of assembling the modular turbine assembly of any one of claims 1 to 18 in open water, comprising the steps of:

a) towing the turbine support to an anchorage site;

b) anchoring the turbine support to a water bed with an anchoring system;

c) towing the plurality of turbine modules to the anchorage site;

d) submerging one of the turbine modules to dock with the turbine support; and

e) repeating step (d) until the full complement of turbine modules is docked with the turbine support.

33. A method of assembling a modular turbine assembly in open water as claimed in claim 32, comprising the additional step of submerging the turbine support between steps (a) and (b).

34. A method of assembling a modular turbine assembly in open water as claimed in either one of claims 32 or 33, wherein step (d) is performed by force of a winch with at least one pull line and wherein the winch is mounted upon the turbine support.

35. A method of assembling a modular turbine assembly in open water as claimed in either one of claims 32 or 33, wherein step (d) is performed by force of a remote operated vehicle.

36. A method of assembling a modular turbine assembly in open water as claimed in claim 35, wherein the positive buoyancy of the turbine module is reduced when

submerged by remote operated vehicle and increased after the turbine module is docked with the turbine support.

37. A method of assembling a modular turbine assembly in open water as claimed in any one of claims 32 to 36, wherein step (b) is performed with the anchoring system of any one or claims 24 to 32.

38. A method of repair or maintenance to the modular turbine assembly of any one of claim 1 to 18, comprising the steps of:

a) tethering one of the turbine modules for controlled floatation to the water surface;

b) detaching the turbine module from the turbine support;

c) floating the turbine module to the water surface; and

d) performing repair or maintenance work upon the turbine module or submerging a substitute turbine module to dock with the turbine support.

39. A method of repair or maintenance to a modular turbine assembly as claimed in claim 38, wherein step (a) is performed by force of a winch with at least one pull line and wherein the winch is mounted upon the turbine support.

40. A method of repair or maintenance to a modular turbine assembly as claimed in claim 38, wherein step (a) is performed by a remote operated vehicle.

41. A method of repair or maintenance to a modular turbine assembly as claimed in claim 40, wherein the positive buoyancy of the turbine module is reduced when submerged by remote operated vehicle and increased after the turbine module is docked with the turbine support.

42. A method of repair or maintenance to a modular turbine assembly as claimed in claim any one of claims 38 to 41, wherein step (d) is performed in open water.

43. A method of providing the turbine support of either one of claims 19 to 20, comprising the steps of:

a) towing the turbine support to an anchorage site; and

b) anchoring the turbine support to a water bed with an anchoring system.

44. A method of providing the turbine support as claimed 43, wherein step (b) is performed with the anchoring system of any one or claims 23 to 31.

45. A method of providing the turbine module of any one of claims 21 to 22, comprising the steps of:

a) towing the turbine module to the anchorage site; and

d) submerging the turbine module to dock with the turbine support of either one of claims 19 to 20.

46. A modular turbine assembly substantially as hereinbefore described with reference to the drawings.

47. A turbine support substantially as hereinbefore described with reference to the drawings.

48. A turbine module substantially as hereinbefore described with reference to the drawings.

Application No: GB1108051.2 **Examiner:** Mr Haydn Gupwell
Claims searched: 1-48 **Date of search:** 31 May 2011

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
Y	1-3, 9, 13, 15, 17-24, 31 & 43-45	WO2007/100639 A2 (KUEHNLE MANFRED R) see whole document especially the figures noting buoyant turbine units 5 each having a duct shown generally as item 12, buoyant turbine support 44 (see buoyancy tanks 28) and anchoring system 15.
Y	1-3, 9, 13, 15, 17-24, 31 & 43-45	WO01/92720 A1 (HAMMERFEST STROEM AS; JOHANSEN HARALD; FREDRIKSEN SVEIN) see whole document especially the figures noting turbine support C with buoyant turbines A which may be detachable and anchoring system E & F.

Categories:

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

Field of Search:

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

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

B63B; E02B; F03B

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

EPODOC, WPI

International Classification:

Subclass	Subgroup	Valid From
None		