

TURBINE DEVICE AND SYSTEM FOR HARVESTING TIDAL ENERGY FROM WATER CURRENTS

Cross Reference to Related Application(s)

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The present disclosure claims the benefit of Singapore Patent Application 10202204221U filed on 22 April 2022, which is incorporated in its entirety by reference herein.

10 Technical Field

The present disclosure generally relates to a turbine device and system for harvesting tidal energy from water currents. More particularly, the present disclosure describes various embodiments of the turbine device and a turbine system comprising an array
15 of the turbine devices for harvesting tidal energy from water currents.

Background

Tidal energy is a renewable energy produced by the natural rise and fall of tides
20 caused by the gravitational interactions between the Earth, the sun, and the moon. Tidal turbine systems draw energy from water currents in the seas and oceans in a similar way to wind turbines drawing energy from air currents or wind. As water is denser than air, tidal energy compared to wind energy can produce exponentially more energy for the same turbine properties like diameter and rotor speed. Tidal energy is
25 also more predictable and consistent than other renewable energy sources like wind or solar energy, both of which are intermittent and less predictable.

Tidal turbine systems are mainly deployed in temperate waters, such as around Europe and USA, where the tidal velocity, such as 5 m/s and above, is higher and
30 there is more tidal energy to capture. Figure 1 shows existing tidal turbines 100. However, these tidal turbines 100 are mounted to the seabed and deep divers are required to maintain and repair the tidal turbines 100, resulting in high maintenance costs.

These tidal turbines 100 are also designed to produce power only in one direction of the water currents, either upstream or downstream. But changes in the gravitational interactions would result in changes in the direction of the water currents every 6 to 8 hours. Thus, these unidirectional tidal turbines 100 would produce power in only one direction for about 10-12 hours per day. When the direction changes, the turbine rotor would experience greater stresses and, in some cases, the turbine rotor may even rotate in the reverse direction and cause damage to the tidal turbine 100.

In tropical waters such as around Singapore and Southeast Asia, the tidal velocity is much lower – up to around 1.5 to 2 m/s – and there is less tidal energy to capture. Deploying existing tidal turbines 100 in tropical waters would not be economically viable due to the high manufacturing and maintenance costs of the tidal turbines 100 and the relatively low power output from them.

Therefore, in order to address or alleviate at least one of the aforementioned problems and/or disadvantages, there is a need to provide an improved turbine device for harvesting tidal energy from water currents.

Summary

According to a first aspect of the present disclosure, there is a turbine device for harvesting tidal energy from water currents. The turbine device comprises: an elongated turbine body having a longitudinal reference vector; and a plurality of turbine blades joined to the turbine body. Each turbine blade comprises: a side edge, wherein the turbine blade is twisted around the turbine body such that the side edge is oblique to the reference vector; a first end curving away from the turbine body and in a first rotational direction with respect to the reference vector; a second end opposite to the first end, the second end curving away from the turbine body and in a second rotational direction with respect to the reference vector, the second rotational direction opposite to the first rotational direction; a first concave area defined by the side edge and the first end, the first concave area configured to rotate the turbine blade in the second rotational direction with respect to the reference vector in response to water currents

attacking the first concave area; and a second concave area defined by the side edge and the second end, the second concave area configured to rotate the turbine blade in the first rotational direction with respect to the reference vector in response to water currents attacking the second concave area, wherein tidal energy from the water currents is harvestable from said rotations of the turbine blades.

According to a second aspect of the present disclosure, there is a turbine system for harvesting tidal energy from water currents, the turbine system comprising an array of the turbine devices.

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A turbine device and a turbine system for harvesting tidal energy from water currents according to the present disclosure are thus disclosed herein. Various features and advantages of the present disclosure will become more apparent from the following detailed description of the embodiments of the present disclosure, by way of non-limiting examples only, along with the accompanying drawings.

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Brief Description of the Drawings

Figure 1 is an illustration of an existing tidal turbine.

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Figures 2A to 2D are illustrations of a turbine device according to embodiments of the present disclosure.

Figure 3 is an illustration of a turbine system according to embodiments of the present disclosure.

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Figures 4A to 4D are illustrations of the turbine system in use with pylon structures.

Figure 5 is an illustration of another use of the turbine system.

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Figures 6A to 6C are illustrations from computational fluid dynamics simulations of the turbine system.

Figures 7A to 7C are illustrations from design and computational fluid dynamics simulations of a turbine device with two turbine blades.

Figures 8A to 8C are illustrations from design and computational fluid dynamics
5 simulations of a turbine device with three turbine blades.

Figures 9A to 9C are illustrations from design and computational fluid dynamics simulations of a turbine device with four turbine blades.

10 Figures 10A to 10C are illustrations from design and computational fluid dynamics simulations of a turbine device with five turbine blades.

Figure 11 is an illustration comparing thrust forces of turbine devices with different number of turbine blades.

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Detailed Description

While parts of the present disclosure will be described in conjunction with the embodiments provided herein, it will be understood that they are not intended to limit
20 the present disclosure to these embodiments. On the contrary, the present disclosure is intended to cover alternatives, modifications and equivalents to the embodiments described herein, which are included within the scope of the present disclosure as defined by the appended claims. Furthermore, in the following detailed description, specific details are set forth in order to provide a thorough understanding of the present
25 disclosure. However, it will be recognized by an individual having ordinary skill in the art, i.e. a skilled person, that the present disclosure may be practiced without specific details, and/or with multiple details arising from combinations of features of particular embodiments. In a number of instances, well-known systems, methods, procedures, and components have not been described in detail so as to not unnecessarily obscure
30 features of the embodiments of the present disclosure.

In embodiments of the present disclosure, depiction of a given element or consideration or use of a particular element number in a particular figure or a reference

thereto in corresponding descriptive material can encompass the same, an equivalent, or an analogous element or element number identified in another figure or descriptive material associated therewith.

- 5 References to “an embodiment / example”, “another embodiment / example”, “some embodiments / examples”, “some other embodiments / examples”, and so on, indicate that the embodiment(s) / example(s) so described may include a particular feature, structure, characteristic, property, element, or limitation, but that not every embodiment / example necessarily includes that particular feature, structure,
10 characteristic, property, element or limitation. Furthermore, repeated use of the phrase “in an embodiment / example” or “in another embodiment / example” does not necessarily refer to the same embodiment / example.

- The terms “comprising”, “including”, “having”, and the like do not exclude the presence
15 of other features / elements / steps than those listed in an embodiment. Recitation of certain features / elements / steps in mutually different embodiments does not indicate that a combination of these features / elements / steps cannot be used in an embodiment.

- 20 As used herein, the terms “a” and “an” are defined as one or more than one. The use of “/” in a figure or associated text is understood to mean “and/or” unless otherwise indicated. The term “set” is defined as a non-empty finite organization of elements that mathematically exhibits a cardinality of at least one (e.g. a set as defined herein can correspond to a unit, singlet, or single-element set, or a multiple-element set), in
25 accordance with known mathematical definitions. The recitation of a particular numerical value or value range herein is understood to include or be a recitation of an approximate numerical value or value range. The terms “first”, “second”, etc. are used merely as labels or identifiers and are not intended to impose numerical requirements on their associated terms.

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Representative or exemplary embodiments of the present disclosure describe a turbine device 200 for harvesting tidal energy from water currents, with reference to Figure 2A. The turbine device 200 includes an elongated turbine body 210 having a

longitudinal reference vector 212, and a plurality of turbine blades 220 joined to the turbine body 210. Each turbine blade 220 has a side edge 222, wherein the turbine blade 220 is twisted around the turbine body 210 such that the side edge 222 is oblique to the reference vector 212 of the turbine body 210.

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Each turbine blade 220 includes a first end 230 and a second end 240 opposite to the first end 230. The first end 230 curves away from the turbine body 210 and in a first rotational direction with respect to the reference vector 212. The second end 240 curves away from the turbine body 210 and in a second rotational direction with respect to the reference vector 212, the second rotational direction opposite to the first rotational direction. For example as shown in Figure 2B, the first end 230 rotates or spirals away from the turbine body 210 in a clockwise direction about the reference vector 212 based on the viewpoint of the reference vector 212. Further as shown in Figure 2C, the second end 240 rotates or spirals away from the turbine body 210 in an anticlockwise direction about the reference vector 212 based on the same viewpoint of the reference vector 212. Further, each of the first end 230 and second end 240 may curve in a semi-circular profile.

Each turbine blade 220 includes a first concave area 232 defined by the side edge 222 and the first end 230. The first concave area 232 is configured to rotate the turbine blade 220 in the second rotational direction with respect to the reference vector 212 in response to water currents attacking the first concave area 232. Each turbine blade 220 includes a second concave area 242 defined by the side edge 222 and the second end 240. The second concave area 242 is configured to rotate the turbine blade 220 in the first rotational direction with respect to the reference vector 212 in response to water currents attacking the second concave area 242. Preferably, the first concave area 232 and second concave area 242 of each turbine blade 220 are approximately equal in size.

When the turbine device 200 is deployed in the sea or ocean, the turbine device 200 is arranged such that water currents flow towards the turbine device 200 in a crossflow direction, i.e. crossing or perpendicular to the elongated turbine body 210. This orientation enables the water currents to fully attack the concave areas 232,242 that

are facing the water currents and cause the turbine blades 220 to rotate. Tidal energy from the water currents can be harvested from said rotations of the turbine blades 220.

For example as shown in Figure 2B, when water currents flow towards the first concave area 232 of a turbine blade 220, the water currents force against the first concave area 232, as indicated by the arrow AA. The attacking water currents cause the turbine blade 220 to rotate in the anticlockwise direction with respect to the reference vector 212 based on the viewpoint of the reference vector 212, as indicated by the arrow BB.

When the water currents change direction every 6 to 8 hours due to changes in the gravitational interactions, and the water currents flow towards the second concave area 242 instead, as shown in Figure 2C. The attacking water currents cause the turbine blade 220 to rotate in the clockwise direction with respect to the reference vector 212 based on the same viewpoint of the reference vector 212. Accordingly, the turbine blades 220 can rotate to generate power at any time of the day regardless of the direction of the water currents.

The turbine device 200 may have two, three, four, or more turbine blades 220 joined to the turbine body 210. The turbine blades 220 may have equal intervals of angular separation with respect to the reference vector 212. For each turbine blade 220, the first end 230 and the second end 240 are rotationally offset from each other by one interval of angular separation.

In some embodiments as shown in Figures 2B and 2C, the turbine device 200 has three turbine blades 220a, 220b, 220c angularly separated from each other at 120° intervals. Further, the first end 230 and the second end 240 of each turbine blade 220 are rotationally offset from each other by 120°. This rotational offset optimizes the twisting of the turbine blade 220 around the turbine body 210 and optimizes the rotations of the turbine blade 220 under water currents. The turbine device 200 is able to produce higher power output and has better starting characteristics in both ebb and flood tidal directions and at low tidal velocities.

The turbine blades 220 are arranged such that the concave areas 232,242 of each turbine blade 220 faces the other turbine blade 220. At least some of the concave areas 232,242 is always exposed to the water currents at any rotational position of the turbine device 200. As such, the turbine device 200 is able to rotate and produce power
5 continuously.

In one example as shown in Figure 2B, each turbine blade 220 has a first concave area 232 and a first convex area on the reverse side. Likewise, each turbine blade 220 has a second concave area 242 and a second convex area on the reverse side.
10 Further with reference to Figure 2D, when the water currents are flowing towards the turbine device 200 as indicated by the arrow AA, the bottom part of the turbine device 200 has higher pressure than the top part, resulting in rotation of the turbine blades 200 as indicated by the arrow BB.

15 Using the first turbine blade 220a as an example, the first concave area 232 and second convex area of the first turbine blade 220a both face against the water currents. However, because of the blade curvature, the first concave area 232 takes in the water flow and experiences more thrust force than the second convex area. The stronger thrust force causes the first turbine blade 220a to rotate as indicated by the arrow BB.

20 Additionally, when the first concave area 232 of the first turbine blade 220a faces the water currents, the first convex area of the second turbine blade 220b also faces the water currents. As the water flows towards the first convex area of the second turbine blade 220b, the first convex area of the second turbine blade 220b bends the water
25 flow away from the second turbine blade 220b. The first convex area of the second turbine blade 220b may bend the water flow towards the first concave area 232 of the first turbine blade 220a, thereby facilitating rotation of the first turbine blade 220a.

Representative or exemplary embodiments of the present disclosure also describe a
30 turbine system 300 for harvesting tidal energy from water currents, with reference to Figure 3. The turbine system 300 includes an array of turbine devices 200. In some embodiments, the array of turbine devices 200 include one row of turbine devices 200.

In some embodiments, the array of turbine devices 200 include plural rows of turbine devices 200 that are arranged in parallel.

Each row of turbine devices 200 includes plural turbine devices 200 that are arranged
5 in series. Suitable mechanisms are used to connect the turbine devices 200 in series
and to convert the rotations of the turbine devices 200 into electrical energy. For
example, the turbine system 300 includes an actuation shaft and a gear mechanism
for connecting each row of turbine devices 200 in series. More specifically, the turbine
10 devices 200 in each row can be modularly connected to the actuation shaft with the
gear mechanism to transfer the rotational power to a common power generator.
Multiple rows may also be connected to the common power generator to convert
mechanical motion of the rotating turbine devices 200 into electrical energy. Each
turbine device 200 may be configured to be removable from the row during operation
15 of the turbine system 300, such as in case of failure and for replacement or repair,
thereby ensuring reliable power supply from the turbine system 300. For example, the
gear mechanism may include a clutch or other suitable elements for decoupling the
faulty turbine device 200 from the row without affecting the other turbine devices 200
during operation.

20 In some embodiments as shown in Figure 3, the turbine system 300 includes a
buoyant structure 310 for suspending the array of turbine devices 200. When the
turbine system 300 is deployed in the sea or ocean, the buoyant structure 310 floats
on the water surface while the turbine devices 200 are submerged in the water. The
turbine system 300 is able to automatically adjust itself to changes in the water tide so
25 that the turbine devices 200 remain submerged in the water, thereby harvesting
maximum tidal energy from the water currents. The buoyant structure 310 is preferably
made of a lightweight material such that the weight of the turbine devices 200 acting
downwards on the buoyant structure 310 is balanced by the upward buoyancy force.

30 In some embodiments, the turbine system 300 with the buoyant structure 310 is
installed with vertical support structures 400 in the water, such as pylon structures.
For example as shown in Figure 4A, the turbine system 300 has a row of turbine
devices 200. For example as shown in Figure 4B, the turbine system 300 has multiple

rows of turbine devices that are arranged in parallel. The parallel rows may be spaced apart from each other at intervals of about 1.5 to 2 times of the overall diameter of a turbine device 200.

- 5 It will be appreciated that the turbine system 300 can be scalable to any diameter and height based on the tidal conditions and water depths of the deployment site. For example, the number of rows of turbine devices 200 and the number of turbine devices 200 in each row can be increased. More turbine devices 200 would increase the total rotation area 250, as shown in Figure 4C, the thrust forces on the turbine devices 200,
10 and consequently the power generated by the turbine system 300.

The turbine system 300 with the buoyant structure 310 can be easily transported to the vertical support structures 400 using a floating barge 410 such as shown in Figure 4D. By installing the turbine system 300 between vertical support structures 400 in the
15 water, the water space between the vertical support structures 400, which would otherwise be unused, can be harnessed by the turbine system 300 to generate power from the tidal energy.

As shown in Figures 4A to 4C, the turbine system 300 may include linear guides 320
20 coupled to the buoyant structure 310. The linear guides 320 are engageable with corresponding linear guides 420 on the vertical support structures 320 to facilitate linear movement of the turbine devices 200. More specifically, when the water tide changes, the buoyant structure 310 floating on the water surface moves accordingly relative to the linear guides 420. The linear guides 320 coupled to the buoyant
25 structure 310 move linearly along the linear guides 420, thereby causing the suspended turbine devices 200 to move upwards and downwards. The linear guides 320,420 may include suitable roller mechanisms cooperative with each other to facilitate the linear motion.

30 As the turbine devices 200 are used in water, the turbine blades 220 are preferably treated to resist biofouling and growth of algae. For example, the turbine blades 220 may be painted with antifouling coatings.

It will be appreciated that one or more sets of the turbine system 300 with the buoyant structure 310 can be installed with other offshore structures. For example, in another use case as shown in Figure 5, the turbine systems 300 can be installed underneath a floating platform 500 comprising an array of solar panels 510.

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Computational fluid dynamics (CFD) simulations were done to evaluate the performance of the turbine system 300 when installed with the vertical support structures 400. The turbine system 300 includes one row of turbine devices 200 connected in series. The CFD simulations were done for various tidal velocities from 10 0.3 to 2.5 m/s and in both tidal crossflow directions. As shown in the velocity streamlines and power curve in Figures 6A and 6B, it can be seen that the turbine devices 200 generate equivalent power in both tidal directions for the same tidal velocities. It can also be seen that the turbine devices 200 can start to rotate and generate power at low cut-in speeds as low as 0.3 m/s and in both water flow directions, 15 making the turbine system 300 suitable for power generation in tropical waters with low tidal velocities.

Further as shown in Figure 6C, wake length studies of each turbine device 200 were also analysed through the CFD simulations to evaluate how each turbine device 200 20 affects the performance of other turbine devices 200 in the same row. From the studies, it was found that, when the turbine devices 200 were arranged in an array and spaced apart from each other at gaps of about 0.75 to 1 times of the overall diameter of a turbine device 200, there was minimum wake influence on the power generation from the array of turbine devices 200.

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The overall wake length from the turbine system 300 is about 6 times of the overall diameter of a turbine device 200. This means that a second turbine system 300 with another array of turbine devices 200 can be deployed behind the first turbine system 300 with a spacing of about 6 times of the overall diameter. An array of turbine systems 30 300 can be arranged one behind another with similar spacings between them.

Embodiments herein describe turbine devices 200 and turbine systems 300 for harvesting tidal energy from water currents. These turbine systems 300 can be

integrated with existing support structures 400, such as pylon structures in the water, to extract maximum power from the water currents between the pylon structures. The turbine devices 200 can be used in both crossflow directions of the water currents, thereby enabling the turbine systems 300 to generate power consistently throughout
5 the year.

Compared to the existing tidal turbines 100 which are deployed in temperate waters with tidal velocities of at least 5 m/s, the turbine devices 200 can be deployed in tropical waters with tidal velocities as low as 0.3 m/s. When used in tropical waters with tidal
10 velocities around 0 to 2 m/s, the turbine devices 200 can an efficiency of more than 30%, whereas the existing tidal turbines 100 only achieve only less than 20% efficiency due to their higher minimum tidal velocity. The turbine devices 200 can also operate at lower rpm of about 50 to 90 rpm, whereas the existing tidal turbines 100 operate at about 150 to 200 rpm. The lower rpm of the turbine devices 200 means
15 there is less operational noise in water, thereby minimizing ecological impact and risk of danger to sea animals.

With a lower minimum tidal velocity and higher power output efficiency, the turbine systems 300 are more economically viable for use in tropical waters with low tidal
20 velocities. The turbine systems 300 can be easily transported and deployed on site and the installation and maintenance costs are low. Compared to the existing tidal turbines 100 which are mounted to the seabed, the turbine devices 200 are located closer to the water surface and do not require deep divers for maintenance and repairs.

25 Additional CFD simulations were done to evaluate the performance of different designs of the turbine device 200 with different numbers of turbine blades 220. Figures 7A to 7C illustrate the design and CFD simulations for a turbine device 200 with two turbine blades 220. Figures 8A to 8C illustrate the design and CFD simulations for a turbine device 200 with three turbine blades 220. Figures 9A to 9C illustrate the design
30 and CFD simulations for a turbine device 200 with four turbine blades 220. Figures 10A to 10C illustrate the design and CFD simulations for a turbine device 200 with five turbine blades 220.

As shown in Figure 11, the CFD simulations showed that the turbine devices 200 experienced thrust forces of about 3600 N, 2800 N, 4100 N, and 4200 N, respectively. The three-blade turbine device 200 experienced the lowest thrust force compared to other numbers of turbine blades 220. The thrust force is the axial force applied by the water on a turbine blade 220. The turbine blade 220 should be strong enough to withstand the thrust force during operation. Lower thrust forces have smaller effects on the turbine blade 220 and thereby improve its reliability.

The velocity streamlines and vectors in Figures 7B-7C, 8B-8C, 9B-9C, and 10B-10C show that the maximum velocity increased from 8.27 m/s to 8.81 m/s with increasing number of turbine blades 220. This confirms the increase in power production with increasing number of turbine blades 220. However, as the thrust force experienced by the three-blade turbine device 200 is lower compared to the other turbine devices 200 at the maximum velocity, the three-bladed turbine device 200 can be considered as the optimum design.

The turbine device 200 and parts thereof can be fabricated by various manufacturing methods, such as casting, injection moulding, laser cutting, and CNC machining. In some embodiments, the turbine device 200 or parts thereof or a product comprising the turbine device 200 or parts thereof may be formed by a manufacturing process that includes an additive manufacturing process. A common example of additive manufacturing is three-dimensional (3D) printing; however, other methods of additive manufacturing are available. Rapid prototyping or rapid manufacturing are also terms which may be used to describe additive manufacturing processes.

As used herein, "additive manufacturing" refers generally to manufacturing processes wherein successive layers of material(s) are provided on each other to "build-up" layer-by-layer or "additively fabricate", a 3D component. This is compared to some subtractive manufacturing methods (such as milling or drilling), wherein material is successively removed to fabricate the part. The successive layers generally fuse together to form a monolithic component which may have a variety of integral sub-components. In particular, the manufacturing process may allow an example of the

disclosure to be integrally formed and include a variety of features not possible when using prior manufacturing methods.

Additive manufacturing methods described herein enable manufacture to any suitable size and shape with various features which may not have been possible using prior manufacturing methods. Additive manufacturing can create complex geometries without the use of any sort of tools, moulds, or fixtures, and with little or no waste material. Instead of machining components from solid billets of plastic or metal, much of which is cut away and discarded, the only material used in additive manufacturing is what is required to shape the part.

Suitable additive manufacturing techniques in accordance with the present disclosure include, for example, Fused Deposition Modelling (FDM), Selective Laser Sintering (SLS), 3D printing such as by inkjets and laserjets, Stereolithography (SLA), Direct Selective Laser Sintering (DSLS), Electron Beam Sintering (EBS), Electron Beam Melting (EBM), Laser Engineered Net Shaping (LENS), Electron Beam Additive Manufacturing (EBAM), Laser Net Shape Manufacturing (LNS), Direct Metal Deposition (DMD), Digital Light Processing (DLP), Continuous Digital Light Processing (CDLP), Direct Selective Laser Melting (DSLM), Selective Laser Melting (SLM), Direct Metal Laser Melting (DMLM), Direct Metal Laser Sintering (DMLS), Material Jetting (MJ), NanoParticle Jetting (NPJ), Drop On Demand (DOD), Binder Jetting (BJ), Multi Jet Fusion (MJF), Laminated Object Manufacturing (LOM), and other known processes.

The additive manufacturing processes described herein may be used for forming components using any suitable material. For example, the material may be metal, plastic, polymer, composite, or any other suitable material that may be in solid, liquid, powder, sheet material, wire, or any other suitable form or combinations thereof. More specifically, according to exemplary embodiments of the present disclosure, the additively manufactured components described herein may be formed in part, in whole, or in some combination of materials suitable for use in additive manufacturing processes and which may be suitable for the fabrication of examples described herein.

As noted above, the additive manufacturing process disclosed herein allows a single component to be formed from single or multiple materials. Thus, the examples described herein may be formed from any suitable mixtures of the above materials. For example, a component may include multiple layers, segments, or parts that are
5 formed using different materials, processes, and/or on different additive manufacturing machines. In this manner, components may be constructed which have different materials and material properties for meeting the demands of any particular application. In addition, although the components described herein are constructed entirely by additive manufacturing processes, it should be appreciated that in alternate
10 embodiments, all or a portion of these components may be formed via casting, machining, and/or any other suitable manufacturing process. Indeed, any suitable combination of materials and manufacturing methods may be used to form these components.

15 Additive manufacturing processes typically fabricate components based on 3D information, for example a 3D computer model (or design file), of the component. Accordingly, examples described herein not only include products or components as described herein, but also methods of manufacturing such products or components via additive manufacturing and computer software, firmware or hardware for
20 controlling the manufacture of such products via additive manufacturing.

The structure of the product may be represented digitally in the form of a design file. A design file, or computer aided design (CAD) file, is a configuration file that encodes one or more of the surface or volumetric configuration of the shape of the product.
25 That is, a design file represents the geometrical arrangement or shape of the product.

Design files can take any now known or later developed file format. For example, design files may be in the Stereolithography or "Standard Tessellation Language" (.stl) format which was created for Stereolithography CAD programs of 3D Systems, or the
30 Additive Manufacturing File (.amf) format, which is an American Society of Mechanical Engineers (ASME) standard that is an extensible markup-language (XML) based format designed to allow any CAD software to describe the shape and composition of any 3D object to be fabricated on any additive manufacturing printer. Further examples

of design file formats include AutoCAD (.dwg) files, Blender (.blend) files, Parasolid (.x_t) files, 3D Manufacturing Format (.3mf) files, Autodesk (3ds) files, Collada (.dae) files and Wavefront (.obj) files, although many other file formats exist.

- 5 Design files can be produced using modelling (e.g. CAD modelling) software and/or through scanning the surface of a product to measure the surface configuration of the product. Once obtained, a design file may be converted into a set of computer executable instructions that, once executed by a processor, cause the processor to control an additive manufacturing apparatus to produce a product according to the
- 10 geometrical arrangement specified in the design file. The conversion may convert the design file into slices or layers that are to be formed sequentially by the additive manufacturing apparatus. The instructions (otherwise known as geometric code or “G-code”) may be calibrated to the specific additive manufacturing apparatus and may specify the precise location and amount of material that is to be formed at each stage
- 15 in the manufacturing process. As discussed above, the formation may be through deposition, through sintering, or through any other form of additive manufacturing method.

- The code or instructions may be translated between different formats, converted into
- 20 a set of data signals and transmitted, received as a set of data signals and converted to code, stored, etc., as necessary. The instructions may be an input to the additive manufacturing system and may come from a part designer, an intellectual property (IP) provider, a design company, the operator or owner of the additive manufacturing system, or from other sources. An additive manufacturing system may execute the
- 25 instructions to fabricate the product using any of the technologies or methods disclosed herein.

- Design files or computer executable instructions may be stored in a (transitory or non-transitory) computer readable storage medium (e.g., memory, storage system, etc.)
- 30 storing code, or computer readable instructions, representative of the product to be produced. As noted, the code or computer readable instructions defining the product that can be used to physically generate the object, upon execution of the code or instructions by an additive manufacturing system. For example, the instructions may

include a precisely defined 3D model of the product and can be generated from any of a large variety of well-known CAD software systems such as AutoCAD®, TurboCAD®, DesignCAD 3D Max, etc. Alternatively, a model or prototype of the product may be scanned to determine the 3D information of the product. Accordingly, by controlling an additive manufacturing apparatus according to the computer executable instructions, the additive manufacturing apparatus can be instructed to print out the product.

In light of the above, embodiments include methods of manufacture via additive manufacturing. This includes the steps of obtaining a design file representing the product and instructing an additive manufacturing apparatus to manufacture the product according to the design file. The additive manufacturing apparatus may include a processor that is configured to automatically convert the design file into computer executable instructions for controlling the manufacture of the product. In these embodiments, the design file itself can automatically cause the production of the product once input into the additive manufacturing apparatus. Accordingly, in this embodiment, the design file itself may be considered computer executable instructions that cause the additive manufacturing apparatus to manufacture the product. Alternatively, the design file may be converted into instructions by an external computing system, with the resulting computer executable instructions being provided to the additive manufacturing apparatus.

Given the above, the design and manufacture of implementations of the subject matter and the operations described in this specification can be realized using digital electronic circuitry, or in computer software, firmware, or hardware, including the structures disclosed in this specification and their structural equivalents, or in combinations of one or more of them. For instance, hardware may include processors, microprocessors, electronic circuitry, electronic components, integrated circuits, etc. Implementations of the subject matter described in this specification can be realized using one or more computer programs, i.e., one or more modules of computer program instructions, encoded on computer storage medium for execution by, or to control the operation of, data processing apparatus. Alternatively or in addition, the program instructions can be encoded on an artificially generated propagated signal, e.g., a

machine-generated electrical, optical, or electromagnetic signal that is generated to encode information for transmission to suitable receiver apparatus for execution by a data processing apparatus. A computer storage medium can be, or be included in, a computer-readable storage device, a computer-readable storage substrate, a random or serial access memory array or device, or a combination of one or more of them. Moreover, while a computer storage medium is not a propagated signal, a computer storage medium can be a source or destination of computer program instructions encoded in an artificially generated propagated signal. The computer storage medium can also be, or be included in, one or more separate physical components or media (e.g., multiple CDs, disks, or other storage devices).

Although additive manufacturing technology is described herein as enabling fabrication of complex objects by building objects point-by-point, layer-by-layer, typically in a vertical direction, other methods of fabrication are possible and within the scope of the present subject matter. For example, although the discussion herein refers to the addition of material to form successive layers, one skilled in the art will appreciate that the methods and structures disclosed herein may be practiced with any additive manufacturing technique or other manufacturing technology.

In the foregoing detailed description, embodiments of the present disclosure in relation to a turbine device and a turbine system for harvesting tidal energy from water currents are described with reference to the provided figures. The description of the various embodiments herein is not intended to call out or be limited only to specific or particular representations of the present disclosure, but merely to illustrate non-limiting examples of the present disclosure. The present disclosure serves to address at least one of the mentioned problems and issues associated with the prior art. Although only some embodiments of the present disclosure are disclosed herein, it will be apparent to a person having ordinary skill in the art in view of this disclosure that a variety of changes and/or modifications can be made to the disclosed embodiments without departing from the scope of the present disclosure. Therefore, the scope of the disclosure as well as the scope of the following claims is not limited to embodiments described herein.

Claims

1. A turbine device for harvesting tidal energy from water currents, the turbine device comprising:

5 an elongated turbine body having a longitudinal reference vector; and
a plurality of turbine blades joined to the turbine body, each turbine blade comprising:

a side edge, wherein the turbine blade is twisted around the turbine body such that the side edge is oblique to the reference vector;

10 a first end curving away from the turbine body and in a first rotational direction with respect to the reference vector;

a second end opposite to the first end, the second end curving away from the turbine body and in a second rotational direction with respect to the reference vector, the second rotational direction opposite to the first rotational direction;

15 a first concave area defined by the side edge and the first end, the first concave area configured to rotate the turbine blade in the second rotational direction with respect to the reference vector in response to water currents attacking the first concave area; and

20 a second concave area defined by the side edge and the second end, the second concave area configured to rotate the turbine blade in the first rotational direction with respect to the reference vector in response to water currents attacking the second concave area,

25 wherein tidal energy from the water currents is harvestable from said rotations of the turbine blades.

2. The turbine device according to claim 1, wherein the turbine blades have equal intervals of angular separation with respect to the reference vector.

30 3. The turbine device according to claim 2, wherein for each turbine blade, the first end and the second end are rotationally offset from each other by one interval of angular separation.

4. The turbine device according to any one of claims 1 to 3, comprising two turbine blades having equal intervals of angular separation with respect to the reference vector.
- 5 5. The turbine device according to any one of claims 1 to 3, comprising three turbine blades having equal intervals of angular separation with respect to the reference vector.
6. The turbine device according to any one of claims 1 to 3, comprising four turbine
10 blades having equal intervals of angular separation with respect to the reference vector.
7. The turbine device according to any one of claims 1 to 3, comprising five turbine
15 blades having equal intervals of angular separation with respect to the reference vector.
8. A turbine system for harvesting tidal energy from water currents, the turbine system comprising an array of turbine devices, each turbine device according to any one of claims 1 to 7.
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9. The turbine system according to claim 8, wherein the array of turbine devices comprises one or more rows of turbine devices that are arranged in parallel, each row of turbine devices comprising a plurality of turbine devices that are arranged in series.
- 25 10. The turbine system according to claim 8 or 9, further comprising a buoyant structure for suspending the array of turbine devices.
11. The turbine system according to claim 10, further comprising linear guides coupled to the buoyant structure.
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12. The turbine system according to any one of claims 8 to 11, further comprising an actuation shaft and a gear mechanism for connecting each row of turbine devices in series.

13. The turbine system according to claim 12, wherein the gear mechanism is configured for decoupling a faulty turbine device from the respective row of turbine devices during operation of the turbine system.

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14. A computer program comprising computer executable instructions that, when executed by a processor, cause the processor to control an additive manufacturing apparatus to manufacture a product comprising the turbine device according to any one of claims 1 to 7.

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15. A method of manufacturing a product via additive manufacturing, the method comprising:

obtaining an electronic file representing a geometry of the product wherein the product comprises the turbine device according to any one of claims 1 to 7; and

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controlling an additive manufacturing apparatus to manufacture, over one or more additive manufacturing steps, the product according to the geometry specified in the electronic file.