

DELTA WING FLUID TURBINE

TECHNICAL FIELD

This invention relates to a fluid turbine, including wind turbines and marine turbines, powered by a moving fluid to produce useful mechanical power which can be

- 5 subsequently converted to other forms of power such as electrical power; and relates in particular, but not exclusively, to cross flow small and medium sized turbines for use in urban environments.

BACKGROUND

- 10 Fluid turbines are currently in use to harvest wind and marine energy. Generally, such turbines can have their axis of rotation oriented either horizontally or vertically to the flow direction. While horizontal axis wind turbines (HAWT) are most commonly used in large wind turbines, vertical axis wind turbines (VAWT) have advantages in smaller applications. From here on, references to a VAWT shall be understood to be also
- 15 applicable to and inclusive of all cross flow fluid turbines including marine turbines.

- A parameter that describes the operating condition of a fluid turbine is its tip speed ratio (TSR). For a vertical axis wind turbine (VAWT), this is the ratio of the circumferential (tangential) speed of the blade to the speed of the wind. A VAWT can operate in two
- 20 possible modes: 1) drag mode, where in the TSR is less than 1, and 2) lift mode, where the TSR need not be less than 1. An example of a VAWT operating in drag mode is disclosed in US Patent No. 1,766,765 while US Patent No. 1,835,018 discloses an example of a VAWT operating in lift mode.

VAWT have become a popular choice for small and medium sized wind turbines producing energy in the kilowatt range. However, at smaller scales the aerodynamic performance of airfoils and wings deteriorates dramatically. For example, the maximum lift-coefficient of an airfoil reduces from 1.6 at large scales to 0.6 at smaller scales.

5

FIG. 1 (prior art) gives an axial view of a VAWT blade, defines the various terms used to describe the operation of a VAWT. It shows the blade at the instant when the phase angle ϕ is 150° . The arrow along the chord of the blade represents the relative airflow over the blade due to the rotational movement of the blade. Its length represents the tangential speed of the blade. The arrow shown horizontally from left to right, represents the free stream wind speed and direction. The TSR as shown in FIG. 1 is 1.5, i.e., the length of the tangential speed of the blade arrow is 1.5 times the length of the arrow represent by the wind. Vector addition of these two arrows gives the resultant arrow, which represents the resultant relative wind experienced by the blade. Thus, the angle of attack α is the angle between the resultant wind velocity arrow and blade chord arrows, which in this instant is 23.4° .

An airfoil (such as the blade of a VAWT) experiencing airflow over it at an angle α experiences lift as well as drag. By definition, lift is perpendicular to the relative wind and drag is parallel to it. Shown in FIG. 1 is the line of action of lift, represented by the black dashed arrow. Together with the moment arm, represented by the black dashed line, it can be seen that at the current condition, an anticlockwise torque is produced by the lift. At the same time, the blade experiences drag, which is in the same direction as the black arrow. The corresponding drag moment arm length is represented by the

20

length of the black arrow. It can be seen that in the condition shown, the moment arm of lift is shorter than that of drag. Thus, in order for the resultant torque produced to be anticlockwise, i.e., positive torque in the intended direction of rotation of the VAWT, the lift force has to be much larger than the drag force, in order to compensate for the shorter lift moment arm.

For a typical unswept airfoil, the range of α within which the lift is much higher than drag is from a few degrees to about 20° , beyond which stall occurs, i.e., the lift force decreases drastically while the drag force increases drastically. The black shaded sectors depicted in FIG. 2 (prior art) show the range of phase angle within which such a condition occurs, where there is likelihood that positive torque is produced.

In a condition of higher TSR, for example $TSR = 2.5$, the range of phase angle within which angle of attack, α is less than 20° is larger. By a similar derivation, it can be shown that when TSR is greater than 3, α is always less than 20° . Beyond this TSR, however, a detrimental effect is that the lower α , the shorter the lift moment arm, while the drag moment arm approaches its maximum value (equal to the turbine radius). Thus, if the VAWT is allowed to spin up to a high TSR in the hope of having more margin for α to remain within 20° , it will reach a point where the lift moment arm is so short that the positive lift torque just merely overcomes the negative drag torque, in spite of the fact that lift force may be several tens of times larger than drag force. This is the self-limiting characteristic of a VAWT. In practice, VAWTs usually stop accelerating when TSR reaches about four to five.

The comparison states that as TSR decreases, the subtended angle of the black shaded sectors decrease. At the limiting case where $TSR = 1$, the lower black shaded sector disappears completely. When TSR is further decreased below 1, drag operation appears. FIG. 3 (prior art) shows the case where the TSR is 0.8.

5

It can be seen in the foregoing explanations that there are large portions of turbine phase where low or even negative torque is produced due to stall. There have been past patents describing different methods of delaying or even completely preventing the angle of attack, α from exceeding the stall angle, beginning from the FIG. 1 of Darrieus' patent.

10 However, any such mechanism increases the complexity of the turbine may be undesirable.

SUMMARY

The present invention circumvents the deterioration of aerodynamic performance by using a delta wing instead of traditional wings. Delta wings are usually used for high-speed flows due to their limitation to maximum lift coefficients of 1.2. However, due to their particular mechanism of using two vortex streaks on the upper side of the wing to create lift, delta wings retain this performance even at low speeds. Hence, the turbine of the present invention uses one or more delta wings in place of each blade of a
20 conventional VAWT.

Apart from the improvement of the aerodynamic performance, additionally, delta wings are easier and more cost-effective to manufacture than wings based on airfoils, and the final product is aesthetically more pleasing.

According to a first aspect, there is provided a fluid turbine comprising: a central shaft; and at least one delta wing, the delta wing connected to the central shaft via an arm and configured to be rotatable about a longitudinal axis of the central shaft.

- 5 The fluid turbine may comprise a plurality of delta wings arranged in layers along the central shaft, each layer comprising a number of delta wings connected to the central shaft via a corresponding number of arms.

Adjacent layers of delta wings may be angularly offset from each other with reference
10 to the longitudinal axis.

The fluid turbine may further comprise a shield configured to shield the at least one delta wing from oncoming fluid. The shield may be configured to be movable according to the direction of the oncoming fluid. The fluid turbine may further comprise a wind
15 vane attached to the shield to move the shield according to the direction of the oncoming fluid.

The at least one delta wing may be rigidly connected to the central shaft via the arm and the central shaft is configured to be rotatable about the longitudinal axis. Alternatively,
20 the at least one delta wing may be rotatably connected to the central shaft via the arm and the central shaft is configured to be non-rotatable.

The at least one delta wing may have a bent edge.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the invention may be fully understood and readily put into practical effect there shall now be described by way of non-limitative example only exemplary

5 embodiments, the description being with reference to the accompanying illustrative drawings.

In the drawings:

FIG. 1 (prior art) is axial view of a VAWT blade defining various terms used to describe the operation of a VAWT;

10 FIG. 2 is an axial view of the VAWT blade of FIG. 1 with a range of phase angles within which $AoA < 20^\circ$, $TSR = 1.5$;

FIG. 3 is an axial view of the VAWT blade of FIG. 1 with a range of phase angles corresponding to lift- and drag-mode operation, $TSR = 0.8$;

FIG. 4 is a first exemplary embodiment of a turbine of the present invention;

15 FIG. 5 is a second exemplary embodiment of a turbine of the present invention having a stack of layers of arm-wing assemblies;

FIG. 6 is the turbine of FIG. 5 wherein the layers of arm-wing assemblies are angularly offset;

FIG. 7 is the turbine of FIG. 5 having a fixed wind shield;

20 FIG. 8 is the turbine of FIG. 5 having a movable wind shield;

FIG. 9 is a computer-generated image of a further exemplary embodiment of a turbine of the present invention;

FIG. 10 is a chart showing comparisons of output power over a range of wind speeds for both delta wing and straight-bladed turbines;

FIG. 11 is a chart showing comparisons of turbine performance efficiency over a range of wind speeds for both delta wing and straight-bladed turbines;

FIG. 12 is a schematic illustration of the flow field over the top of a delta wing taken from "Fundamentals of Aerodynamics", John D. Anderson, 5th edition, McGraw Hill, New York, USA, 2011, page 467, Figure 5.41;

FIG. 13 is a schematic illustration of different embodiments of delta wings taken from "Fundamentals of Aerodynamics", John D. Anderson, 5th edition, McGraw Hill, New York, USA, 2011, page 467, Figure 5.40;

FIG. 14 is a schematic illustration of a bent delta wing;

FIG. 15 is schematic illustrations of different embodiments of delta wings with modification of the camberline;

FIG. 16 is a chart of comparisons of turbine peak performance efficiency C_p as a function of wind speed for a delta wing VAWT and a conventional straight-bladed VAWT with an S8020 airfoil wing;

FIG. 17 is a chart of comparison of turbine performance between a turbine having 3 straight delta wings shapes and a turbine having 3 bent delta wings;

FIG. 18 is an exemplary turbine having 3 bent delta wings;

FIG. 19 is a chart of comparison of turbine performance between the turbine of FIG. 18 and a turbine having 6 bent delta wings as two layers of 3 arm-wing assemblies as a function of tip speed ratio (TSR); and

FIG. 20 is an exemplary turbine having 6 bent delta wings as two layers of 3 arm-wing assemblies.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

Exemplary embodiments of a fluid turbine 10 will be described with reference to FIGS. 4 to 20 below.

The fluid turbine 10 of the present invention uses a general flat plate delta shaped delta wing 1 with a wing swept angle at 60 degrees, mounted at 5 degrees outwards relative to the central shaft 3. The pitch angle can be varied from -15 degrees to 15 degrees. One or more delta wings can be used in place of each single straight blade of a conventional VAWT.

10 A delta wing 1 is here defined as any shape that uses a longitudinal vortex as means of lift generation as shown in FIG. 12. Delta wings usually have a triangular planform, but variations to the shape are possible, as shown in FIGS. 13 and 14, as long as the primary vortex core as a main flow feature on the upper side of the delta wing is preserved.

Delta wings generally provide high lift characteristics at relatively high angle of attack
15 and at large sweep in an effort to reduce the drag. For delta wings, the lift coefficient decrease as the sweep angle decreases. For highly swept delta wings, the flow is dominated by two large counter-rotating leading-edge vortices that are critical to the wing's performance; thus large lift can be generated as well as high angle of attack, thereby delaying stalling. Thus, a characteristic of the delta wing is that its lift
20 coefficient is high even at high angle of attack, α . The delta shape blade can be easily made from metal stamping process and has a relatively flat profile. This makes the blade cheap and easy to produce unlike blades with a precise aerodynamic profile.

A simple exemplary embodiment of the turbine 10 of the present invention as shown in FIG. 4 comprises one or more delta wings 1, each delta wing 1 attached at its centreline to an arm 2 forming an arm-wing assembly 12. Referring to FIG. 15, the trailing edge of each delta wing 1 is preferably bent outward (away from the turbine axis) at a small angle, for example, but not limited to, 15 degrees. The radius of the bend is a substantial fraction of the chord of the delta wing 1, for example, but not limited to, 1/3 of the chord. This arm-wing assembly 12 is attached to a central turbine shaft 3 in such a manner that the delta wings 1 are able to move in a circular locus, i.e., the delta wings 1 are configured to be rotatable about a longitudinal axis of the central shaft as a result of a lift or drag force generated by vortices when fluid passes over the delta wings 1. To allow rotation of the delta wings 1 about the longitudinal axis, the arms 2 may be rigidly fixed to the central shaft 3 while the central shaft 3 is rotatably supported on bearings (not shown); alternatively, the arms 2 may be rotatably attached via bearings (not shown) to the central shaft 3 that is non-rotating.

15

The angle between the normal to the plane of the delta wing 1 and the longitudinal axis of the arm 2 in the horizontal plane is known as the pitch angle of the delta wing 2. This pitch angle need not be zero and it can be varied from -15 degrees to 15 degrees. For balance, two of such arm-wing assemblies 12 can be installed in a diametrically opposed manner with the central shaft 3 at the centre, forming an arm-wing layer 14 of delta wings 1 comprising two arm-wing assemblies 12. Or, the layer 14 of delta wings 1 may comprise three arm-wing assemblies 12 as shown in FIG. 4. The present invention also includes embodiments where a plurality of delta wings 1 are arranged in layers 14 along the central shaft 3 such that the turbine 10 has a stack 4 of layers 14 of delta

20

wings 1, each layer 14 comprising three (as shown in FIG. 5) or more arm-wing assemblies 12.

In embodiments where a stack 4 of arm-wing layers 14 are provided, adjacent arm-wing
5 layers 14 may be arranged without any angular offset, i.e., a higher arm 2 is configured to be directly above a lower arm 2 of a adjacent arm-wing layers 14, as shown in FIG. 5. Alternatively, adjacent layers 14 may be arranged with an angular offset as shown in FIG. 6, where an upper arm 2 is angularly offset from a lower arm 2 of adjacent arm-wing layers 14. For the configuration having an angular offset, the additional advantage
10 is that the fluctuation of torque with phase will be reduced.

As the delta wings 1 rotate about their loci, they may enter regions where retarding torque is produced. Thus, at such regions, it may be desirable to shield the delta wings 1 from oncoming fluid with a shield 5 shown in FIG. 7. The shield 5 may be fixed, for
15 example, in the case where the wind or fluid flow direction comes from a fixed constant azimuth, as shown in FIG. 7. Alternatively, the shield 5 may be configured to be movable according to the direction of the wind or fluid, as shown in FIG. 8. To do so, a wind vane 6 may be provided to be attached to the shield 5 as a means of moving the shield 5 according to the direction of the wind or fluid.

20

From results obtained in a wind tunnel test, it observed that the delta wing turbine 10 has good self-starting ability and it can keeps rotating at even high breaking force compare to straight bladed profile (SD8020) turbine.

FIG. 16 shows wind tunnel test results of turbine output power and performance efficiency on delta wing and straight bladed VAWT as a function of the wind speed. The output power and performance efficiency is much higher than normal straight bladed turbine.

5

FIG. 10 and FIG. 11 show wind tunnel tests of turbine output power and performance efficiency on delta wing and straight bladed VAWT over a range of wind speeds and TSR. The output power and performance efficiency is much higher than normal straight bladed turbine at low TSR. By avoiding complex pitch variation mechanism, it is expected to be more reliable and less costly than conventional VAWTs of comparable performance. Furthermore, FIG. 11 shows that the peak performance is attained at a narrower range of tip-speed ratio. This facilitates the choice of generator as the peak performance of the generator can be optimized to the rpm of the wind turbine.

15 Wind tunnel measurements were conducted to study the overall turbine performance.

FIG. 17 shows the comparison on turbine efficiency C_p vs. wind speed between a turbine having straight delta wings and a turbine having bent delta wings as shown in FIG. 18. It was found that the performance is improved with a bent trailing edge.

20 The effects of number of delta wings 1 on turbine performance were also studied. FIG. 19 shows the comparison between a 3-bladed wind turbine (single layer 14 of three arm-wing assemblies, as shown in FIG. 18) and a 6-bladed wind turbine (two layers 14 of three arm-wing assemblies 12 in each layer 14, as shown in FIG. 20) as a function of the

tip speed ratio (TSR). The performance is significantly improved with increasing number of delta wings 1.

Whilst there has been described in the foregoing description exemplary embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations in details of design, construction and/or operation may be made without departing from the present invention. For example, while it has been described above that the delta wings may have a bent trailing edge, the delta wings may alternatively be provided with a bent leading edge.

CLAIMS

1. A fluid turbine comprising:

a central shaft; and

at least one delta wing, the delta wing connected to the central shaft via an

5 arm and configured to be rotatable about a longitudinal axis of the central shaft,

wherein the at least one delta wing has a bent edge.

2. The fluid turbine of claim 1, comprising a plurality of delta wings arranged in layers

along the central shaft, each layer comprising a number of delta wings connected

10 to the central shaft via a corresponding number of arms.

3. The fluid turbine of claim 2, wherein adjacent layers of delta wings are angularly offset from each other with reference to the longitudinal axis.

15 4. The fluid turbine of any preceding claim, further comprising a shield configured to shield the at least one delta wing from oncoming fluid.

5. The fluid turbine of claim 4, wherein the shield is configured to be movable according to the direction of the oncoming fluid.

20

6. The fluid turbine of claim 5, further comprising a wind vane attached to the shield to move the shield according to the direction of the oncoming fluid.

7. The fluid turbine of any preceding claim, wherein the at least one delta wing is rigidly connected to the central shaft via the arm and the central shaft is configured to be rotatable about the longitudinal axis.
- 5 8. The fluid turbine of any one of claims 1 to 6, wherein the at least one delta wing is rotatably connected to the central shaft via the arm and the central shaft is configured to be non-rotatable.