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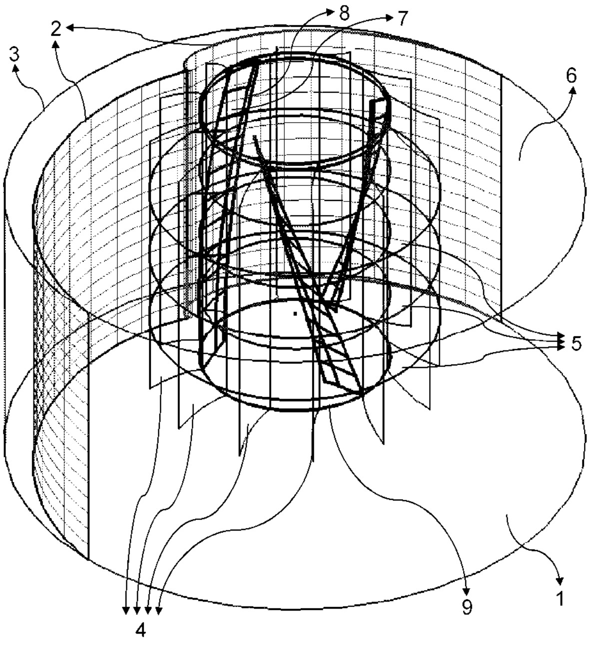

FIGURE 1

(57) Abstract: The deduction of the Betz's theory for an axis of rotation orthogonal to the direction of the fluid leads to identify the best geometry, angles and surfaces to achieve the maximum possible transfer of energy from the fluid stream to the rotor of a real-world VAWT. From this study originates the described wind turbine, characterized by its stator, obtained by combining cycloidal (4) and conical (1-5-6) surfaces, which represents a simplification and optimization compared to similar systems, with an emphasis on conveying a pre-determined fraction of the flow in the axial direction, in contrast to other stators which are only aimed to produce jets orthogonally to the axis of rotation thus generating turbulence and mandating the rotor itself the burden to discharge the air. The stator does not require electromechanical orientation systems thanks to the mobile collector (3) in the shape of a double-pitch cardioid and grooved inner surface (2), free to swing around the fixed central body for self-positioning down- wind, capable of producing a back

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flow with horizontal and vertical velocity components equal to those up-wind and to keep stationary and coaxial the cyclonic air flow which moves the rotor. By virtue of the fact that the passive phase is eliminated and replaced by a continuous lift contribution, the hollow rotor blades are designed with functional curved surfaces for being orthogonal to the flow lines during the entire rotation: in the laminar flow region the portion of the blades invested by the fluid is in fact convex (7), not concave as in all VAWTs. The high efficiency is maintained by the pressure gradient obtained between the outside air and the core of the vortex, thanks to which the laminar motion is stationary at any wind regime and the slowing of the stream caused by the presence of the turbine is greatly reduced with respect to any other type of wind generators of identical interception area.

CYCLONIC-FLOW WIND TURBINE WITH STATORIC AND ROTORIC ELEMENTS

TECHNICAL FIELD

The invention relates to a turbine realized according to the preamble of claim 1.

This disclosure relates in general to Aeolian generators and in particular to vertical axis wind turbines.

BACKGROUND OF THE INVENTION AND PRIOR ART

The Betz's limit (16/27 ≈ 59.3%) and the condition on the ideal ratio (3:1) between inlet and outlet fluid speeds, as is known, can be deduced using the so called *actuator disk* model, where the turbine is constituted by a thin, zero-inertia disk, free to rotate about its axis, through which air flows in axial direction.

The deduction of the Betz's limit rests on energy balance considerations applicable to any wind turbine, with either horizontal axis (HAWT) or, as we have demonstrated, vertical axis (VAWT), having a substitute of the actuator disk, but, as it has been stated, the actuator disk theory, although useful for establishing the limit of efficiency, is not of help in designing high-performance real-world turbines. This is incorrect.

The Betz's actuator disk may be figured out as a blind disk, with its axis parallel to the flow lines, the whole surface of it being therefore perpendicular to the motion of fluid particles. The surface of the actuator disk, being orthogonal to the flux, could absorb all the available power (100%), but in order to be able to rotate for converting the kinetic energy lost by the air into mechanical energy, it must be divided into several wedges and each wedge must be rotated about its radial axis by an angle which we set equal to 19° 28' 16". It is the angle whose sine value is 1/3. With this condition the velocity vector of air molecules hitting the blades decomposes into two components: the first component, the one doing work, will ultimately result orthogonal to the axis of rotation, the other component, equal to one third of the initial velocity, parallel to that axis. The Betz's condition of speeds ratio is thus met. In order to regain perpendicularity between flow lines and the surface of the actuator disk let us imagine to increase indefinitely the number of wedges, by reducing their surfaces that become infinitesimal, and which, therefore, can be considered again perpendicular to the flow lines, though allowing air to pass through the disk with a residual velocity equal to one third of that of the incident air.

Under these terms, it is evident how Betz's actuator disk is only an ideal concept useful for calculating the theoretical limit of 59.3%, but it allows us to state which are the inescapable hypotheses for achieving a high mechanical efficiency of any turbine:

1. *constancy of the angle of incidence between flow lines and blade surface during rotation*
2. *perpendicularity of incidence of flow lines on blade surface*
3. *constancy and uniformity of distribution of the flow action over the whole blade surface*
4. *flow lines crossing the rotor parallel to the axis of rotation, i.e.*
5. *no dispersion of flux tube in crossing the rotor (continuity).*

The first assumption alone should not leave any doubt on which is the true reason why a VAWT cannot compete in terms of efficiency with HAWTs, even neglecting known considerations about passive phase of upwind travel or absence of lift of the blades which, to variable extents, affect all vertical axis wind turbines.

Many efforts have been made for increasing the efficiency of real-world turbines, typically by the use of air conveyors housing the rotor, following the general idea of creating a region of low pressure in order to guide a stronger airflow onto the rotor blades. In all cases, it has turned out that an equivalent turbine having a swept surface equal to the area intercepted by the conveyor of the considered turbine had a better efficiency. The rather obvious conclusion is that the Betz's theory remains valid and the flux tube to be considered has a diameter closer to that defined by the conveyor than to that of the inner rotor: there is no way to get around the energy balance of the airflow taken at great distance upstream and downstream from the turbine.

Why then this disclosure should be more efficient of known VAWTs? The answer could be because it substantially meets the above mentioned hypotheses, its architecture, as we shall see, analytically complying in geometric and “topologic” terms with all the stated conditions. However, one may say that the true reason is that the novel device is not a vertical axis wind turbine!

The distinction between horizontal and vertical axis turbines commonly subtends an “anthropic” reference to the ground because wind blows parallel to the Earth surface, though, more correctly, it should refer to the main direction of the flow lines. In the novel turbine, the air flow moving the rotor crosses it axially, as in all HAWTs.

This distinctive characteristic may be best described starting again from the actuator disk of Betz’s theory. Being a zero-inertia disk, there is an alternative way to that of ideally slicing it into an infinite number of wedges to ensure that a fluid, non-viscous and incompressible, moving parallel to the axis of rotation transfers a fraction of the kinetic energy and continues its motion with a velocity reduced by two-thirds. It is sufficient to cut the disc in correspondence of a radius and, maintaining parallel to each other the cut edges thereof, to slide them along the axis of rotation separating them by a distance equal to one third of the circumference. A helix of desired properties is thus obtained. The loss of perpendicularity of flow lines onto the surface of the disc can be recovered by acting on the airflow itself before it reaches the blades. The new turbine obeys to an inescapable compliance to the above stated conditions by taking into account what just described.

To those skilled in the art it is known the need to correct and adjust the flow before it acts on the blades of a vertical axis turbine, usually by placing around the rotor a stator, of generally cylindrical appearance, composed of fixed or mobile deflectors. Ideally, the semi-cylindrical part exposed to the wind should intake the air and direct the flow on the central turbine. Among the most representative examples known to the inventor we cite Patent Publication No. US3938907-A, US4047834-A, US4236866-A, US5391926-A, US5852331-A, US6015258-A, US20020047276-A1, WO03083294-A1, US6740989-B2, US20060275105-A1, AU2006233265-A1 and WO2015004588-A1. Major drawbacks of those designs are represented by the fact that the exhaust of the air occurs through the downwind openings of the stator. The expected internal air vortex induced by the stator, and with it the lift effect on the blades which would contribute to the less efficient thrust mechanism, is limited to at most 270 degrees of rotation: inevitably, the blades have to move upstream for more than a quarter of rotation against almost stationary air, and, above all, to counteract the turbulence that is produced at the point of air discharge where the laminar flow is abruptly interrupted. In other words, all these devices are not able to comply with the condition indicated by the first of the five assumptions previously enounced, which requires that the angle of incidence between the flow lines and the surface of the blades remains unchanged for 360 degrees.

Attempts to achieve internal air circulation along the entire path of the blades are found in CA2349443-A1 and US20100143096-A1. The achievement of this purpose, however, cannot take place by means of long ducts in complex, heavy, air intakes and exhaust chambers, which require active yaw mechanisms and compromise the structural stability and the reliability of the system. The presence of the stator, if on one hand is required, on the other hand it represents a power dissipating element in the form of turbulence and viscous friction: the contact surfaces represented by its fixed parts must be of minimum extension so that the advantages offered by the stator in terms of efficiency are bigger than the pressure losses caused by it.

The correct way to induce a full vortex around the axis of the turbine is shown for example in US20040012207-A1 and CN101387265-B, in which a portion of the air frontally captured acts on the blades when they travel through the leeward part of their journey. The most evident design flaw of solutions of this kind is that the air discharge can only take place at the expense of the energy of the rotor itself and, however, through a rearward opening, which still represents a discontinuity of the vortex. Notice also the absence of a stator of cylindrical symmetry. Even combining this idea of directing the air towards the blades by two diametrically opposite directions together with the stators of the prior art previously cited, it is clear that there is no way to meet the condition expressed by the second of the five assumptions, concerning the action of the flow lines being perpendicular to the surface of the blades during a complete rotation.

In order to conciliate these two aspects one must first of all give up on having vertically arranged rotor blades, i.e. which extend parallel to the axis of rotation, but it is necessary to adopt helical turbines close to those described in US20070258806-A1, US2011006542-

A1 and WO2013006061-A1 or, even better, of Gorlov's type, as in WO9638667-A1, albeit with innovative features that we will see. However, such a kind of turbines, surrounded by a fixed cylindrical stator coupled to a mobile, external, air-conveyor, capable of directing an airflow leeward to said stator, is still not enough.

The moderating action of the stator of a VAWT must not only be that of directing the airflow towards right or left with respect to the radial direction, but also that of diverting it in the axial direction according to a functional pre-defined proportion. The stator, in addition of being composed of vertical walls, must therefore have several horizontal sections consisting of inclined surfaces able to divert the airflow upward, or downward, as suggested in US4508973-A and US2010084867-A1, where, however, this concept is not used to create an ascending air circulation, but only to direct the flow against a propeller mounted on a vertical axis, without benefits with respect to a propeller of equivalent size in free air. In US20070296219-A1 the stator is delimited above and below by conical surfaces, but with opposite inclinations and with the only apparent purpose of compressing the intercepted air to increase its velocity: the thick walls of the stator, disposed in a concentric pattern, and the complexity of the design of the heavy rotor, entail a power loss in the airflow and hinder the discharge of air, thereby, inherently, limiting the power fraction absorbed by this kind of arrangements. Similar considerations apply to Patent Publications No. US2003025334-A1 and US2012175883-A1, both representing, although with substantial differences (and, in the latter case, coarse errors with the units of measure), two sets of concentric elements, fixed and mobile, for generating an internal vortex which can hardly transfer a significant fraction of its kinetic energy (for sure not the thermal one) to a rotor that appears undersized and decentralized compared to the vortex itself, contravening the request of the third of the five assumptions, which imposes a uniform distribution of airflow on the surface of the blades.

Although certain mandatory aspects of the design were apparent, until the present invention it was not been yet achieved the proper combination of elements to induce an aerodynamic lift on both faces of the rotor blades during the whole rotation, in order to realize a complete and homogeneous laminar flow which was perfectly coaxial with the axis of the turbine, obtained by means of a light-weight stator, but which is sufficiently rigid to provide structural support, comprising contact curved surfaces that minimize the travel time and the changes of direction of the airflow, which does not require active yaw mechanisms, expensive materials and continuous maintenance, able to meet all the five necessary assumptions required for the achievement and maintenance of high efficiency independently from the wind speed.

GENERAL DESCRIPTION OF THE INVENTION

The novel stator of this disclosure refers to the type of wind turbines, theorized by the inventor, qualified as “cyclonic-flow turbines” (in short referred to by the phonetic acronym CEG, *Cyclonic Aeolian Generator*) because the rotor is driven by the self sustained swirling movement of the fluid that is established inside the stator and that proceeds towards one of the ends of the cylindrical rotor space delimited by it.

The turbine of the present invention is realized according to the characterizing part of claim 1.

In particular the stator is composed of two identical truncated-cone surfaces – or other annular surfaces having a given slope to the inner edge – of outer radius 2*R* and inner radius *r*, coaxially placed and separated by a given distance, which constitute the top and bottom bases of the structure, rigidly fixed to each other by a set of vertical walls, whose curved section is an arc of cycloid, radially arranged at regular distances around the inner edge of said truncated-cone surfaces and that extend up to a distance *R* from the axis of symmetry of the stator. On the two bases, along the outer perimeter of radius 2*R*, and along the circle of radius *R* traced by the vertical walls of the stator, a set of roller guides are mounted, which fix and sustain, at the bottom and at the top, a mobile element named *collector*, free to swing longitudinally around the central cylindrical part of the stator, ideally delimited by an outer vertical surface with semi-circular horizontal section and radius 2*R*, and by an inner vertical surface, facing the center of the stator, whose horizontal section is composed of two specular arcs of cardioids, which starting from the two ends of the semi-circle of radius 2*R* meet in a central cusp placed at a distance *R* from the axis of the stator. The inner surface of the collector is ruled with grooves, of suitable depth depending on the material used, the purpose of which is to guide the laminar flow of the boundary layer to climb, with identical slope of the bases, along the inner surface of the collector starting from the two opposite ends toward the central cusp. To complete and stiffen the structural central support, a stack of truncated-cone sections, with the same inclination of the bases, the same internal radius *r* and outer radius *R*, that is, half of that of the bases, are arranged coaxially with the structure, regularly spaced or, for large-size generators, separated by upwardly decreasing distances. Also the internal radius *r* of the stator, for sake of simplicity assumed constant, will in general vary, and with it the diameter of the rotor, wherever the extension in height of the turbine requires such an optimization to compensate for the natural wind speed variation with the altitude.

In general, the hollow rotor has not a central shaft in order to keep free the area which will be occupied by the low pressure core of the vortex. The helical blades are mounted on peripheral cylindrical guides capable of sliding along circular rails fixed on the edges of the rotor space. The inner region of the blades is occluded at the bottom by a right cone, integral with the blades, which completes the truncated cone of the bottom base of the stator, while upwardly it constitutes the opening of the air discharge, exhaust that is assisted by the external ascending current generated by the free flow of the wind not intercepted by the stator and diverted upwards by the upper base of the stator itself.

As we shall see shortly, the choice of the angle of radial deflection, identified by the arc of cycloid which represents the profile of the vertical walls of the stator, and of the axial angle of deflection, constituted by the slope of the truncated-cone sections, as it often happens in fluid dynamics, it is not accidental but is imposed by the extended Betz’s theory. Given the radius *r* of the inner rotor and the number of vertical walls, also the ratio between the inner radius *r* and the outer radius *R* is fixed, as well as the inclination and profile of the helical blades of the turbine.

Wind air intercepted by the two ends of the mobile collector is gradually deflected and directed toward the leeward surface of the cylindrical central part of the stator. A stream of identical flow rate is directly intercepted by the surface exposed to the wind. Short flow conduits (sectors of square or hexagonal cross section and cycloidal side walls) of the stator guide these two air-streams into the inner rotor space, where they assume an ascending swirling motion of cylindrical symmetry.

A rotor of any shape and size sweeps a full cylindrical volume (*Savonius*, HAWT) or a tubular volume (*Darrieus*, *Gorlov*). Therefore, a steady cyclonic flow, confined in the inner rotor, regular and concentric with the axis of rotation of the blades, allows you to maintain a constant angle of incidence between the flow lines and the surface of the blades, as imposed by the first hypothesis.

The blades are helices having an angle of axial torsion equal to the complementary of the angle φ = 19° 28' 16'' and their surface at 45° with respect to the radial direction. The air jets that exit the guiding conduits of the stator are constantly slanted upward by an angle φ and directed to the right by 45°. Therefore, the flow lines which hit the peripheral portion of the blades impinge perpendicularly to their surfaces during the whole rotation, as requested by the second hypothesis. Moreover, being the stream lines exiting the flow conduits slightly convergent, the peripheral portion of the upwind surface of the blades is convex in order to ideally be perpendicular to this *primary* injection flow.

The choice of the angle of horizontal injection of 45°, and the consequent orientation of the peripheral edge of the blades, rests on optimization and energy balance considerations, besides being numerically suggested by the value of the Betz's limit itself, 16/27, which may be expressed as the product of the cube of the cosine of the angle φ = 19° 28' 16'' and the sine, or the cosine, of 45°:

$$\frac{16}{27}=\left(\frac{2\sqrt{2}}{3}\right)^3\times\left(\frac{\sqrt{2}}{2}\right)=\cos^3\varphi\times\sin\frac{\pi}{4}$$

As for any real-world turbine, also in the CEG it is convenient to reduce as much as possible the weight of the rotor, and with it the inertia and mechanical frictions, by opting for a small number of blades, lower than the number of flow conduits around the circumference of the rotor. Injected air that misses a blade constitutes the *secondary* injection flow, the energy of which sustains the vortex. Due to the inertia and the load of the electric generator applied to the rotor, the blades do not reach the tangential velocity of the vortex. This means that, during a complete rotation, the entire surface of the blades is subject to a constant lift effect, in compliance with the third hypothesis, and that the blades do not encounter resistance, except for the turbulence generated by the structural elements.

The residual energy associated to the horizontal component of the injection velocity not absorbed by the rotor, let us call it *tertiary* flow, is transferred by viscous friction to the innermost swirling air-mass, which acts on the inner, concave, part of the blades, whose radial extension varies with altitude.

By contrast, the whole energy associated to the vertical component of the injection velocity is not absorbed by the rotor, and composes the axially exiting flow of reduced velocity (one third), as contemplated by the fourth hypothesis.

Talking of real-world fluids and rotors, not whole the energy of the primary, secondary and tertiary flows is transferred to the blades. The unavoidable turbulence sustains an innermost vortex, in proximity of the rotation axis, in a space that is not swept by the blades, wherein the fluid assumes very high speeds. Such a low pressure inner region ensures the confinement of the flux tube during the crossing of the rotor, as requested by the fifth hypothesis. Moreover, as in tornadoes, it favors the reaching of a steady state whereat incoming wind air is pulled toward the turbine and slightly compressed before meeting the blades, incrementing the intrinsic efficiency, as it emerged from CFD analysis. In other words, the observed slowing down in the stream due to the obstacle represented by the turbine is greatly reduced with respect to any other type of wind generators of identical interception area.

Optional characteristics of the turbine and of the method of the invention are contained in the dependent annexed claims, that form an integral part of the present description

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective, schematic, view of a wind generator according to an exemplary embodiment of this invention.

Fig. 2 represents a horizontal section of the stator; the white arrows indicate the flow of the intercepted air, the dotted arrows the movement which the air assumes within the rotor space in the horizontal plane.

Fig. 3 is a perspective and cross-sectional view illustrating a possible embodiment of the lower support base 1 which houses the electrical generator or other energy converter.

Fig. 4 shows the mobile collector, placed on the sliding rails of the base, which consists of an inner ruled surface, in the shape of a double-pitch cardioid 2, and of a semicircular outer surface 3.

Fig. 5 indicates the positioning of the (twelve) vertical walls 4 of cycloidal cross-section along the perimeter of the rotor space.

Fig. 6 shows the (three) truncated-cone sections 5, having the same inclination of the base and half of its diameter, coaxially placed and separated by a regular distance, or, for large-size stators, by an upwardly decreasing distance.

Fig. 7 is a side view of the complete stator with the upper base 6.

Fig. 8 shows a perspective view (a), a side view (b) and top view (c) of the rotor.

DETAILED DESCRIPTION OF AN EXEMPLARY EMBODIMENT

The ensuing description of embodiments has solely illustrative purposes and it is not to be intended as limiting the scope of the claimed invention, which may be practiced in different forms and by operating alternative design choices, though remaining within the scope of the invention as defined in the annexed claims.

The new stator according to the present invention is shown schematically in Fig. 1, and in more detail in the sequence of drawings of Fig. 3, 4, 5, 6 and 7.

Fig. 3 illustrates a possible embodiment of the lower support base 1, housing and protecting the electrical generator and the transmission elements, substantially constituted by a truncated-cone surface of outer radius $2R$ and inner radius r, with an inclination from the horizontal plane of an angle β such that:

$$\tan\beta = \tan\varphi \cos^{-1}\frac{\pi}{4} = \frac{1}{2} \qquad (\beta = 26^\circ\ 33'\ 54'')$$

where

$$\cos\varphi = \frac{2\sqrt{2}}{3} \qquad \sin\varphi = \frac{1}{3} \qquad (\varphi = 19° \; 28' \; 16'').$$

Along the outer perimeter of the base and along the circumference of radius *R* two sets of roller guides are mounted, which will support the mobile element of the stator.

Fig. 4 shows the mobile collector, placed on the sliding rails of the base, which consists of an inner surface 2, in the shape of double-pitch cardioids, whose horizontal section has equation

(1) $$\left[(x+R)^2 + y^2 - 2a(x+R)\right]^2 = 4a^2\left[(x+R)^2 + y^2\right],$$

delimited by the two points $P(0,2R)$, $Q(0,-2R)$ and the central cusp $C(-R,0)$, and of a semicircular outer surface 3 of radius 2*R*. The inner surface of the collector is ruled with grooves, the purpose of which is to guide the laminar flow of the boundary layer to rise along the inner surface of the collector, starting from the two opposing ends toward the central cusp, of a height difference equal to that of the base between its outer and inner edges. With reference to Fig. 2 we set $D = 2R\sin\frac{\pi}{12}$, having chosen for this exemplary embodiment twelve vertical walls to delimit the rotor space. As a function of this *scaling factor D*, the coefficient *a* of equation (1), which defines the inner surface of the collector, can be numerically expressed by:

(2) $$a = \frac{5}{4}\frac{\sqrt{6}+\sqrt{2}}{\sqrt{5}+1}\cdot D \approx 1.492 \cdot D.$$

The following proportions also apply:

(3) $$R = \frac{D}{2}\left(\sin\frac{\pi}{12}\right)^{-1} = \frac{\sqrt{6}+\sqrt{2}}{2}\cdot D \approx 1.932 \cdot D$$

(4) $$r = \sqrt{R^2 - \left(\frac{D}{4}\right)^2} - \frac{D}{4}\left(1+\frac{\pi}{2}\right) = \left[\sqrt{2+\sqrt{3}-\frac{1}{16}} - \frac{1}{4}\left(1+\frac{\pi}{2}\right)\right]\cdot D \approx 1.273 \cdot D$$

(5) $$d = 2r\sin\frac{\pi}{12} \approx 0.659 \cdot D \qquad or \qquad d = \frac{r}{R}D.$$

Fig. 5 indicates the positioning of the twelve vertical walls 4 along the perimeter of radius *r* of the rotor space. The horizontal section of each wall is represented by an arc of cycloid of parametric equation:

(6) $$x = \frac{D}{4}(\theta + \sin\theta) \qquad y = \frac{D}{4}\cos\theta$$

with $0 \le \theta \le \frac{\pi}{2}$, of length $\frac{\sqrt{2}}{2}D$. By differentiating equations (6) with respect to the parameter *θ*, we find that the velocity along the trajectory, across the flow conduit identified by two adjacent walls, forms in the horizontal plane an angle $\alpha(\theta) = \arctan\frac{dy}{dx} = \frac{\theta}{2}$ with respect to the starting direction $\alpha(0) = 0$. Hence:

$$\alpha\left(\frac{\pi}{2}\right) = \frac{\pi}{4}.$$

On a horizontal plane, the flow lines within each conduit enter the rotor space with a constant inclination of 45° toward the right side of the radius of the cylindrical space at the injection point.

Fig. 6 shows three truncated-cone sections 5, having the same inclination of the base, *β*, same inner radius, *r*, and half of its outer radius, *R*, coaxially placed and separated by a regular distance, which, for sake of simplicity, we pose equal to *D*. On a vertical plane, the flow lines within each conduit enter the rotor space with a constant slope *φ* = 19° 28' 16" upwards.

Fig. 7 is a side view of the complete stator with the upper base 6, similar in size and shape to the lower base, coaxial with the inferior conical sections and separated from the lower base by a distance equal to 4*D*. Two guides identical to those of the lower base are mounted on the upper base to allow the mobile collector to swing longitudinally around the central fixed part of the stator, positioning itself leeward to the stator.

As shown in Fig. 2, the swivelling collector, by virtue of its shape and constraints, produces air streams via the leeward flow conduits similar to those produced via the windward conduits of the stator (white arrows). This contributes to sustain the cyclonic circulation of air in the rotor space, enhancing its cylindrical symmetry and concentricity with the rotor shaft (dotted arrows), and eliminates any braking action on the blades travelling through the leeward sectors.

Numerical models have confirmed the theoretical result according to which, for a wide wind speed range and, therefore, even for high Reynolds numbers, this geometry promotes a steady laminar flow through the flow conduits of the stator and, exiting from the conduits, for a travel distance *l* inside the rotor space equal to:

(7) $$l = R \cdot \cos\frac{\pi}{12}\sin\varphi \approx 0.622 \cdot D$$

greater than the boundary layer thickness. In this peripheral region, in correspondence of each sector, the flow lines converge in the horizontal plane causing a slight compression of the air, highlighted by the CFD analysis, which positively affects the intrinsic efficiency of the turbine. The surface perpendicular to the flow lines within this *primary* injection flow, which describes the ideal shape of the blade in the horizontal plane, is expressed by the parametric equation:

(8) $$y = r(\theta - 1)\tan\theta \qquad x = r(1-\theta),$$

with $0 \le \theta \le 0.20$. Contrarily to traditional VAWTs, in the novel turbine the air thrust, corresponding to the primary flow, acts on the convex side of the blade rather than on the concave side. The reason for this lies on the fact that, while in the generators of the prior-art the intent is to reduce the resistance that the blades have to face in the windward travel, in the new turbine the passive phase is practically absent during the entire rotation and one can focus on optimizing the energy transfer from the flow to the rotor.

The condition of perpendicularity of the flow onto the blades imposes that they do not extend straight and parallel to the axis of rotation but have a torsion angle of $90° - \varphi$ = 70° 31' 44". As shown in Fig. 8, each blade consists of a helix that winds in an arc of length $D\sqrt{2}$ around the axis of rotation, about 1/5 of a full turn, and a minimum of three blades evenly distributes the torque along the rotor shaft.

Being the number of blades that composes the rotor lower than the number of flow conduits, the air injected from the latter that does not strike any blade constitutes the *secondary* flow, whose energy feeds the vortex and ensures that the entire surface of the blades is constantly subject to the lift generated by the concurrent movement of the air that precedes the blades during a complete rotation.

Anyway, since this is a real-world system, not all the energy corresponding to the horizontal component of the injection velocity is transferred to the blade: a fraction of it is transferred by viscous friction to the air mass in rotation at the center of the stator, the so-called *tertiary* flow, which acts on the inner, concave section of the blades, constituted by an analytic (tangent) continuation of the surface of the blades with a curve of opposite concavity, whose radial extension varies with altitude. Fig. 8d shows, in a sectional view, the two surfaces, convex 7 and concave 8, that compose the helical blades, fixed to a right-cone 9 at the bottom, which completes the truncated cone of the lower base of the stator, and, at the top, to a guide free to slide along a circular rail integral with the upper base of the stator. It should be noted, finally, that the rotor is devoid of a central shaft in such a way not to hinder the formation of the core of the vortex. In this innermost region of the tertiary flow, in fact, the air reaches very high speeds and consequently a very low pressure ensuring the confinement of the flux tube during the rising towards the discharge area.

* * *

For sake of completeness let’s verify with a direct calculation that, for the particular geometry of the new stator, the efficiency of this kind of turbine approaches the maximum allowed.

Being *D* the height of each flow sector, considering four superimposed sectors orders, the overall effective area of external air interception from the stator is:

(9) $$A_e = 4R \cdot 4D = 8\left(\sqrt{6}+\sqrt{2}\right) \cdot D^2 .$$

Indicating with v_e the external, or entering, wind speed, and with ρ = 1.16 *Kg/m*^{3} the air density, the total available power $P_e^{\max}$ is expressed by:

(10) $$P_e^{\max} = \frac{1}{2}\rho A_e v_e^3 = 4\left(\sqrt{6}+\sqrt{2}\right)\rho D^2 v_e^3 .$$

Numerically, for a wind speed v_e of 10 *m/s* and *D* = 1.2 *m*, $P_e^{\max}$ = 25.8 *kW*.

The portion of the impinged blade or, in other words, the internal surface of incidence A_i for each flow conduit is:

(11) $$A_i = D^2 \cos\frac{\pi}{4} \cdot \frac{1}{\cos\varphi} = \frac{3}{4} D^2 .$$

In a conduit where the vertical side walls of which are two identical cycloid arcs, converging with an angle of 30° (360°/12), the intake air is subjected to an acceleration by the tunnel effect inversely proportional to the narrowing of the cross-section area. Indicating with v_i the internal, or injection, air speed, assuming a laminar flow and smooth surfaces, and being D^2 the intake section of each sector, we obtain that the injection air speed is greater than the external wind velocity by a factor:

(12) $$v_i = \frac{D^2}{A_i} v_e = \frac{4}{3} \cdot v_e .$$

The sectors contribute to the total power in a different extent according to the orientation of their inlet section relative to the incident wind direction; without loss of generality, for all the conduits that surround the rotor, we can consider the ensuing three possible angulations: 75°, 45° e 15° (or 90°, 60°, 30° and 0° for the other limit position). Because the leeward sectors receive a quantity of air equal to the windward sectors by virtue of the collector geometry, the flow intercepted by the two front sectors, placed at 75° with respect to the wind direction, proportional to $\sin 75°$, is equal to that of the two diametrically opposite sectors, in correspondence of the cusp of the collector; four sectors intercept a flow proportional to $\sin 45°$, the remaining four sectors to $\sin 15°$. By summing all the contributions of the conduits of the stator, the total power within the rotor space is:

(13) $$P_i^{\max} = 4 \cdot \frac{1}{2} \rho A_i \cos\frac{\pi}{12} \cdot 4 \left[\sin\frac{5\pi}{12}\left(v_i \sin\frac{5\pi}{12}\right)^3 + \sin\frac{\pi}{4}\left(v_i \sin\frac{\pi}{4}\right)^3 + \sin\frac{\pi}{12}\left(v_i \sin\frac{\pi}{12}\right)^3 \right] = 9 \rho A_i v_i^3 \cos\frac{\pi}{12}$$

By substituting the values of A_i and v_i given by (11) and (12), and taking into account the result expressed by (10), we get:

(14) $$P_i^{\max} = 9 \rho A_i v_i^3 \cos\frac{\pi}{12} = 9 \rho \cdot \frac{3}{4} D^2 \cdot \left(\frac{4}{3} v_e\right)^3 \frac{\sqrt{6}+\sqrt{2}}{4} = 4\left(\sqrt{6}+\sqrt{2}\right) \rho D^2 v_e^3 = P_e^{\max} \quad \square$$

The available power within the rotor space is equal to that intercepted by the stator, in the assumption of laminar flow. The load losses due to the viscosity of the air are partially compensated by the density increase of the fluid, here supposed unchanged.

To calculate the absorbable power by the rotor, we decompose the injection speed v_i in its horizontal component, $v_i^{(h)}$, and its vertical component, $v_i^{(v)}$, which are given, respectively, by:

(15) $$v_i^{(h)} = \cos\varphi \cdot v_i = \frac{2\sqrt{2}}{3} \cdot \left(\frac{4}{3} v_e\right) \qquad v_i^{(v)} = \sin\varphi \cdot v_i = \frac{1}{3} \cdot \left(\frac{4}{3} v_e\right).$$

The work orthogonal to the axis of rotation done on blades is due only to the horizontal component $v_i^{(h)}$. Substituting this into equation (13) and considering the perpendicular projection of the inner surface with respect to the axis, $A_i \cos\frac{\pi}{4}$, the potentially absorbable power is:

(16) $$P_i = 9\rho\left(A_i \cos\frac{\pi}{4}\right)(\cos\varphi \cdot v_i)^3 \cos\frac{\pi}{12} = \cos\frac{\pi}{4} \cos^3\varphi \cdot P_i^{\max} = \frac{\sqrt{2}}{2}\left(\frac{2\sqrt{2}}{3}\right)^3 \cdot P_i^{\max} = \frac{16}{27} \cdot P_i^{\max}$$

Hence:

(17) $$C_P \equiv \frac{P_i}{P_i^{\max}} = 59.26\%.$$

In the event that the power corresponding to the horizontal component of the injected air is entirely absorbed, the theoretical efficiency of the generator coincides with the Betz’s limit. The CFD simulation of a real-world prototype has provided a coefficient C_P = 0.548 ± 0.027 for a wind speed of 8 *m/s*.

It should be stressed the fact that this remarkable result is only possible with the particular choice of the angle φ of 19° 28' 16" for the inclination of the conical surfaces. Any other angle φ' such that $\sin\varphi' \neq \frac{1}{3}$ would lead to a theoretical value of C_P less than 59.3%, just like the case of the actuator disk of Betz’s theory when it is not met the condition of Betz

$$\frac{v_{out}}{v_{in}} = \frac{1}{3}.$$

The results (14) and (16) relating to the available total power and to the absorbable power assume that the rotor is composed of a number of blades (twelve) equal to the number of baffle walls that delimit the rotor space. We shall now verify how the lift force acting on the blades along their entire path, or the absence of a resistant phase, allows the use of a rotor with a lower number of blades. Tests on model clearly show that even a single vertical shovel allows regular rotation in any wind condition, an unattainable result at the state of prior art.

In absence of the rotor, the air injected from each sector, not impinging on any blade, moves straight ahead as far as it intersects the stream exiting the next flow conduit according to a constant angle and the respective velocities are summed vectorially. Each sector contributes to increase the tangential velocity of the vortex proportionally to the sine of the relative angle formed with respect to the wind direction by its own inlet section. Since the ratio of the tangential velocity to the axial velocity of the vortex is constant at each point, it is always possible to select the height of the stator in such a way that the air entering the base of stator exits from the top of the rotor space after completing a full round. Within this assumption, considering the possible angulations 15°, 45° and 75°, the average injection velocity results:

$$\bar{v} = \frac{\sin\frac{\pi}{12}\sin\frac{\pi}{12} + \sin\frac{\pi}{4}\sin\frac{\pi}{4} + \sin\frac{5\pi}{12}\sin\frac{5\pi}{12}}{\sin\frac{\pi}{12} + \sin\frac{\pi}{4} + \sin\frac{5\pi}{12}} v_i = \left(\sqrt{6} - \sqrt{2}\right) v_e$$

Starting from the base of the stator and proceeding in the direction of the counterclockwise rotation, from simple geometric considerations, we have for the tangential velocities of the vortex:

$$\begin{array}{llll}
v_1^2 = \bar{v}^2 & v_1 = 0.78 \cdot v_i & v_7^2 = \frac{9}{4}\left(\frac{7}{2} - \sqrt{3}\right) v_i^2 & v_7 = 1.99 \cdot v_i \\
v_2^2 = \frac{9}{8}\left(3 - \sqrt{3}\right) v_i^2 & v_2 = 1.19 \cdot v_i & v_8^2 = \frac{9}{16}\left(10 - \sqrt{3}\right) v_i^2 & v_8 = 2.16 \cdot v_i \\
v_3^2 = \frac{9}{4} v_i^2 & v_3 = 1.50 \cdot v_i & v_9^2 = \frac{45}{8} v_i^2 & v_9 = 2.37 \cdot v_i \\
v_4^2 = \frac{45}{16} v_i^2 & v_4 = 1.68 \cdot v_i & v_{10}^2 = \frac{99}{16} v_i^2 & v_{10} = 2.49 \cdot v_i \\
v_5^2 = \frac{9}{8}\left(\frac{9}{2} - \sqrt{3}\right) v_i^2 & v_5 = 1.76 \cdot v_i & v_{11}^2 = \frac{9}{16}\left(13 - \sqrt{3}\right) v_i^2 & v_{11} = 2.51 \cdot v_i \\
v_6^2 = \frac{9}{4}\left(\frac{13}{4} - \sqrt{3}\right) v_i^2 & v_6 = 1.85 \cdot v_i & v_{12}^2 = \frac{9}{4}\left(\frac{19}{4} - \sqrt{3}\right) v_i^2 & v_{12} = 2.61 \cdot v_i
\end{array}$$

In the absence of the blades, therefore, the velocity increases gradually, moving from one sector to the next.

Said v_b the air velocity before the blade and v_a the air velocity after the blade, with $v_a > v_b$, and being A_l the area subject to the pressure gradient, the power due to the lift effect that results is expressed by the formula:

(18) $$P_l = \frac{1}{2} \rho A_l \bar{v} \left(v_a^2 - v_b^2\right).$$

The area A_l, perpendicular to the flow, considering equation (7) will be:

(19) $$A_l = l \cdot D = R \cdot \cos\frac{\pi}{12} \sin\varphi \cdot D = \frac{1}{6}\left(2 + \sqrt{3}\right) \cdot D^2 \approx 0.622 \cdot D^2.$$

The surface A_l on which acts the pressure gradient is less than the area of incidence A_i previously considered since only a fraction of the air that comes out from each sector spreads out in the area of influence of the adjacent sector, producing an accelerated air stream. In particular, the edge of the blade does not experience any pressure gradient (same tangential air speed on leading surface and on trailing surface), which qualitatively explains why $A_l < A_i$.

We apply the expression (18) to calculate the total power due to the pure lift effect, by setting $v_a = v_{n+1}$, $v_b = v_n$ $\left(v_0^2 \equiv v_1^2 - v_e^2\right)$:

(20) $$P_l^{\max} = \frac{1}{2} \rho A_l \cdot \bar{v} \cdot \left[4 \cdot \sum_{n=0}^{11} \left(v_{n+1}^2 - v_n^2\right)\right].$$

Replacing the value of A_l and the average speed $\bar{v}$, and developing the summation

$$\sum_{n=0}^{11}\left(v_{n+1}^2 - v_n^2\right) = 3\left(2+\sqrt{3}\right)\cdot\overline{v}^2 = \frac{27}{4}v_i^2 = 12\cdot v_e^2\ ,$$

we get:

(21) $$P_l^{\max} = \frac{1}{2}\rho D^2 v_e^3 \cdot \frac{2+\sqrt{3}}{6}\cdot\left(\sqrt{6}-\sqrt{2}\right)\cdot 48 = \rho D^2 v_e^3 \cdot 4\left(\sqrt{6}+\sqrt{2}\right) = P_i^{\max} = P_e^{\max} \quad \square$$

The result obtained according to aerodynamic lift considerations perfectly matches the value of the total available power previously calculated and rests on the assumption of the absence of the rotor. The presence of the blades causes the injected air to be arrested before reaching the flux of air injected through the next flow sector; consequently, the diffusion and merging of stream lines involve a number of adjacent sectors gradually smaller with the increase of the number of blades that compose the rotor, up to vanish completely when the number of the blades is equal to 12. On the other side, the internal available power, $P_i^{\max}$, calculated according to standard considerations, on the contrary assumes that the rotor is composed of 12 blades, equal to the number of radial sectors; a lower number of blades means that one or more of the terms of equation (13) is zero, and, consequently, that the total available power progressively reduces until it vanishes in the absence of blades. A direct calculation shows that for an intermediate number of blades between 0 and 12 – provided they are arranged at regular angular distances – the “thrust” contribution to the power on the blade that is missed is compensated in equal measure by the contribution of the augmented aerodynamic “lift” on the first available blade immediately preceding.

To conclude, let’s suitably choose the height of the stator, as in the procedure seen above for the calculation of the velocities within the vortex, in such a way that, in the time the injected air takes to cross the rotor for its entire height, it executes a full revolution around the axis. We can thus consider for the exhaust speed the value $v_o = v_{12} \approx 2.61\cdot v_i \approx 3.48\cdot v_e$. Therefore, be $A_e = D^2\cdot 2\left(\sqrt{6}+\sqrt{2}\right)/\tan\varphi$ the external total area of interception and $A_o = \pi r^2/\cos\varphi$ the cross-section area of the exhaust. Indicating with ρ_e the entering air density, the flow rate intercepted by the stator, expressed by $Q_e = A_e\rho_e v_e$, will be equal to the outgoing flow rate, $Q_o = A_o \rho_o v_o$, only if we admit a slight increase in the exhaust air density, ρ_o.

By setting $Q_e = Q_o$, one obtains:

$$\frac{\rho_o}{\rho_e} = 1.16 ,$$

that is, an increase of air density of about 10÷20%, in agreement with what has been shown by numerical simulation models, which in a real generator partially compensates for friction and turbulence losses, thus keeping constant the efficiency for a wide range of wind speed.

CLAIMS

1. Cyclonic-flow wind turbine with statoric and rotoric elements, comprising:
   a) two annular surfaces, coaxially placed and separated by a given distance, which two annular surfaces constitute the *top and bottom bases* of the fixed structure of the stator, whose purpose is to prepare the fluid to rise along the axis and facilitate the outflow;
   b) a set of *vertical walls*, delimited by said top and bottom bases and integral to them, whose curved horizontal section represents an arc of cycloid, radially arranged at regular angular distances around the inner edge of the bases and which extend up to a given distance from the axis of symmetry of the stator, able to impose to the fluid a rotational motion around the axis which is laminar in a region of pre-determined extent inside the rotor space;
   c) a series of stacked annular surfaces, spaced apart and arranged in a coaxial manner with the structure, rigidly attached to said vertical walls in such a way to define a plurality of *flow conduits*, which establish the ratio between the tangential velocity and the axial velocity of the vortex inside the rotor space, delimited by them, and which represent the cylindrical, central, fixed part of the stator;
   d) a mobile element named *collector*, enclosed between the top and bottom bases, constrained and free to oscillate longitudinally around said cylindrical central part, delimited by an outer vertical surface, of semicircular horizontal section and by an inner vertical surface, that is, facing the center of the stator, the purpose of which is to exactly replicate the action of the wind on the central body of the stator also downwind;
   e) a *hollow rotor*, devoid of a central axis of rotation, to keep free the area which will be occupied by the low pressure core of the vortex, composed of thin helical blades, whose inner region is occluded at the bottom by a cone, integral with the blades and with the underlying electric generator, or other energy converter, that completes the truncated-cone surface of the lower base of the stator, while the upper part constitutes the air exhaust opening.

2. Turbine according to claim 1, wherein the top base and the bottom base are constituted by two identical annular surfaces, each annular surface presenting a connection surface between the inner edge and the outer edge, which connection surface presents a given slope in respect of the horizontal plane.

3. Turbine according to claim 2, wherein each annular surface belonging to said series of annular surfaces presents a connection surface between the inner edge and the outer edge, which connection surface presents the same slope of the connection surface of the bottom base and/or the top base.

4. Turbine according to claim 3, wherein each annular surface belonging to said series of annular surfaces presents an inner radius equal to the inner radius of the top and/or of the bottom base and an outer radius equal to not less than the half of the outer radius of the top base and/or the bottom base and less than the outer radius of the top base and/or the bottom base.

5. Turbine according to claim 1, wherein the annular surfaces belonging to said series of annular surfaces are disposed equidistant to each other.

6. Turbine according to claim 1, wherein the annular surfaces belonging to said series of annular surfaces are spaced apart with decreasing distances towards said top base.

7. Turbine according to claim 1, wherein the inner vertical surface of said collector presents a horizontal section formed by two specular arcs of cardioid.

8. Turbine according to one or more of the preceding claims, wherein the angle of radial deflection, that is, the angle formed in the horizontal plane by the respective tangent lines in the two extreme points of the arc of cycloid that represents the profile of said vertical walls, which laterally delimit the radial flow conduits, is equal to 45°, i.e. such that the velocity of the flow injected into the rotor space is constantly oriented to the right, or to the left, of 45° in the horizontal plane.

9. Turbine according to one or more of the preceding claims, wherein the annular surfaces of the top base, of the bottom base and the annular surfaces belonging to the said series of annular surfaces, which inferiorly and superiorly delimit the radial flow

conduits, have a slope to the inner edge such that the velocity of the flow injected into the rotor space is constantly oriented upwards of an angle φ in the vertical plane, where $\sin\varphi = 0.333333$.

10.Turbine according to one or more of the preceding claims, wherein said inner surface of the collector is ruled with grooves, the purpose of which is to guide the laminar flow of the boundary layer to rise along the inner surface of the collector, starting from the two opposite ends toward the central cusp, of a height difference equal to that of the base between its outer edge and the innermost circle.

11.Turbine according to claim 1, wherein each blade of said hollow rotor is constituted by a helix with an angle of axial torsion equal to the complementary of said angle φ, i.e. 90°–φ, and whose section in the horizontal plane is an arc of parametric equation $y = r(\theta - 1)\tan\theta,\ x = r(1-\theta)$, where $0 \le \theta \le 0.2$, with the *convex* side facing the jets coming out from the flow conduits, analytically continued by a parabolic arc, or other conical curve, of opposite concavity, therefore with the *concave* side facing the jets, and of length variable with the height, the two curves being joined by a horizontal flex point placed at a radial distance inside the vortex where ideally terminates the laminar flow.

12.Turbine according to one or more of the preceding claims, wherein the rotor is composed of a number of blades comprised between 1 and *N*, where *N* is the number of vertical walls that delimit the rotor space.

13.Turbine according to one or more of the preceding claims, wherein the ratio between the radius *r* of the rotor, or the inner radius of the annular surfaces belonging to the series of annular surfaces, and the outer radius *R* of said surfaces, that is, the outer perimeter of the *N* vertical walls, is fixed by the following equation:

$$\frac{r}{R} = \sqrt{1 - \left(\frac{1}{2}\sin\frac{\pi}{N}\right)^2} - \left(\frac{1}{2}\sin\frac{\pi}{N}\right)\left(1 + \frac{\pi}{2}\right).$$

14.Turbine according to one or more of the preceding claims, wherein the horizontal section of the vertical walls is defined by the arc of cycloid of parametric equation:

$$x(\theta) = \frac{R}{2}(\theta + \sin\theta)\sin\frac{\pi}{N}, \quad y(\theta) = \frac{R}{2}(\cos\theta)\sin\frac{\pi}{N}, \quad 0 \le \theta \le \frac{\pi}{2}.$$

15. Method for setting in rotation inside a rotor space of cylindrical symmetry two identical streams coming from diametrically opposite directions, in such a way to generate an ascending vortex which is concentric to the axis of symmetry of the rotor space, with a constant ratio (3:1) between the tangential component and the axial component of the fluid velocity, and for transferring a significant fraction of the kinetic energy, corresponding to the component of the velocity of the fluid orthogonal to the rotation shaft, to the helical blades of a hollow rotor coaxial to the vortex, comprising the following steps:

a) defining the rotor space by radially arranging a series of short, identical and modular, flow conduits with generally rectangular or hexagonal cross-section, composed of vertical side surfaces, having a cycloidal horizontal section and converging inwardly, and of lower and upper surfaces, parallel to each other and inclined inwardly, the aim of which is that to direct the intercepted flow inside the rotor space with a velocity oriented to the right, or to the left, with respect to the radial direction of an angle of 45° in the horizontal plane, and upwards of an angle φ of 19° 28' 16'' in the vertical plane;

b) inducing an equivalent amount of flux, compared to that intercepted by the conduits exposed to the wind, to enter the rotor space through the downwind conduits by means of an appropriate vertical grooved surface, with horizontal section in the shape of a double-pitch cardioid with a central cusp, capable of self-positioning downwind to the central structure of the stator represented by said flow conduits, and delimited below and above by two surfaces having the same shape and slope of those that delimit at the bottom and at the top the flow conduits, and twice their outer radius;

designing the helical blades of the rotor in such a way that the angle of axial torsion is at most the complementary of said angle φ, and their horizontal section is composed of two curvilinear arcs, of opposite concavities and joined by a flex point, where the outermost curve, in the peripheral region of the vortex where the motion of the flow is laminar, is oriented at 45° with respect to the radial direction in the most distant point from the axis of rotation, and it exposes to the direct action of the jets its convex side, in such a way to be in every point perpendicular to the incident stream lines, while the innermost curve appears concave on the side exposed to the action of the fluid and extends toward the axis of rotation up to a depth variable with the height in a way functional to the dynamics of the central area of the vortex.

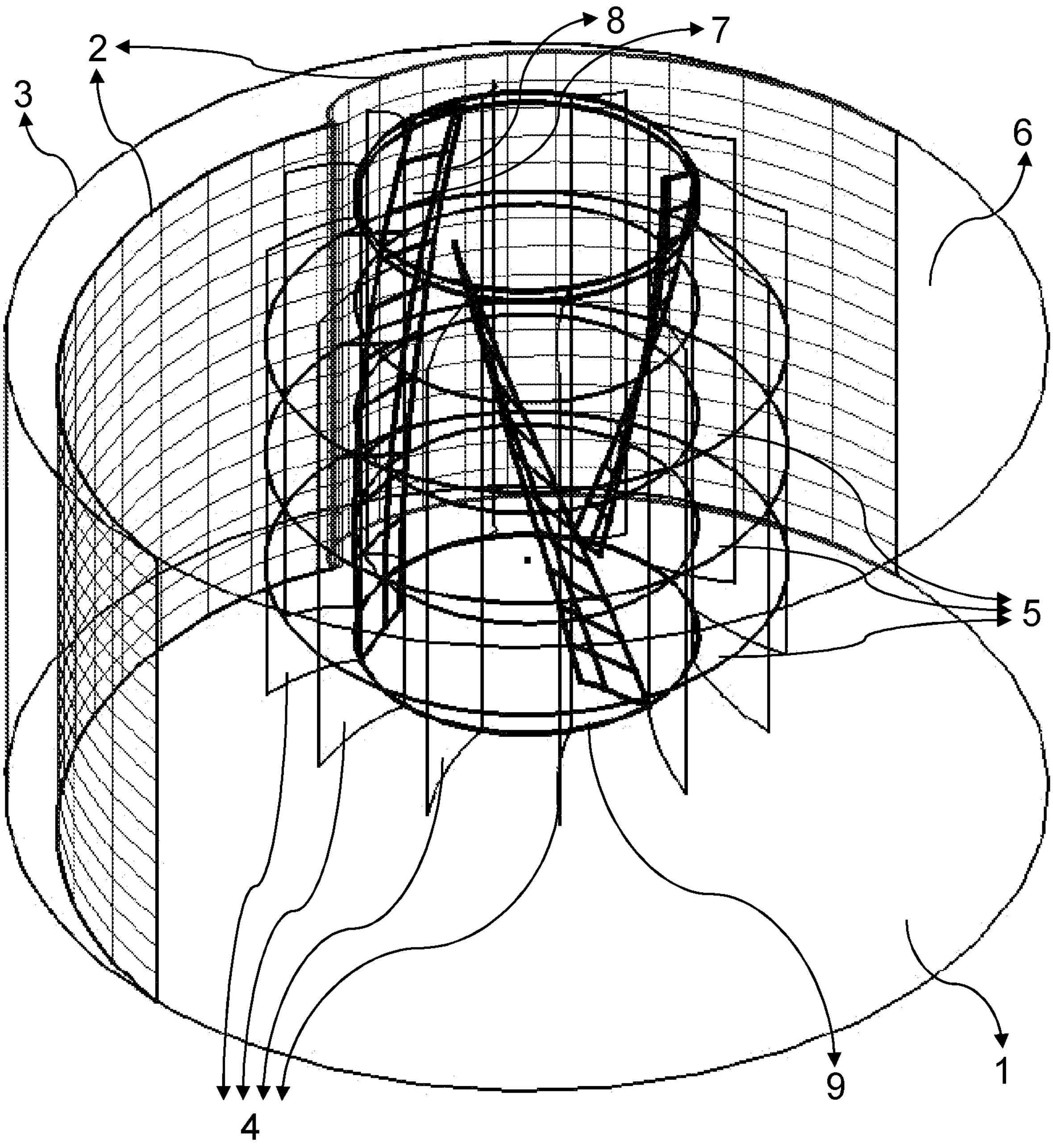

FIGURE 1

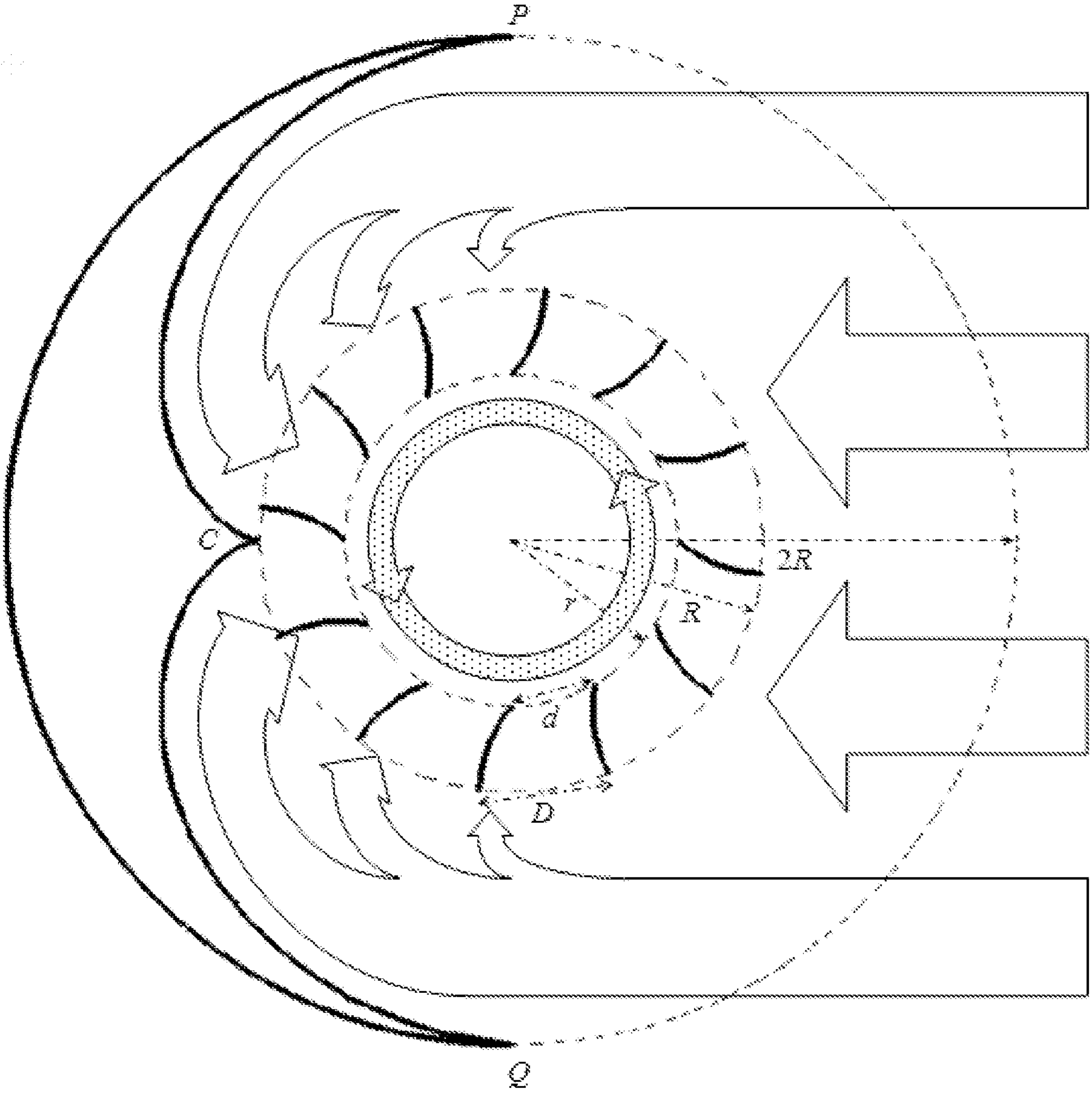

FIGURE 2

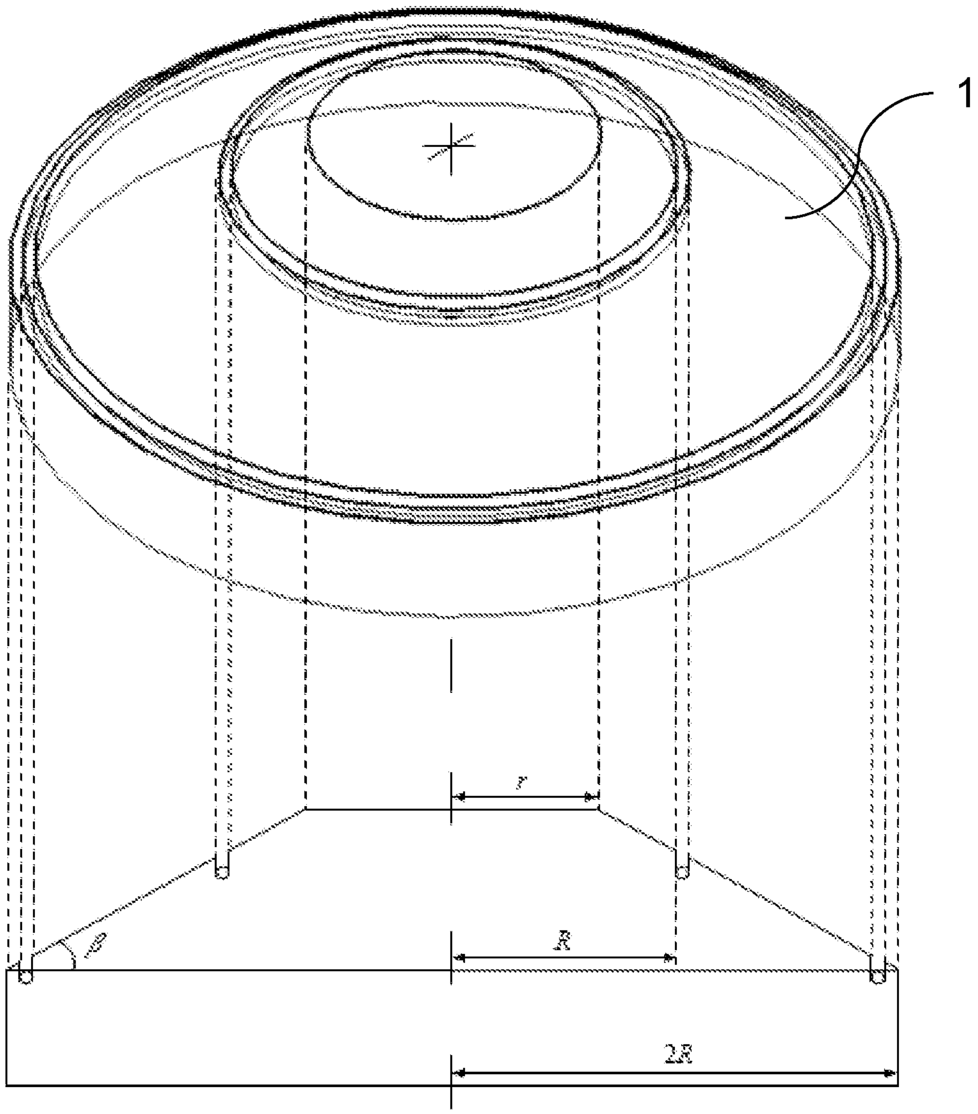

FIGURE 3

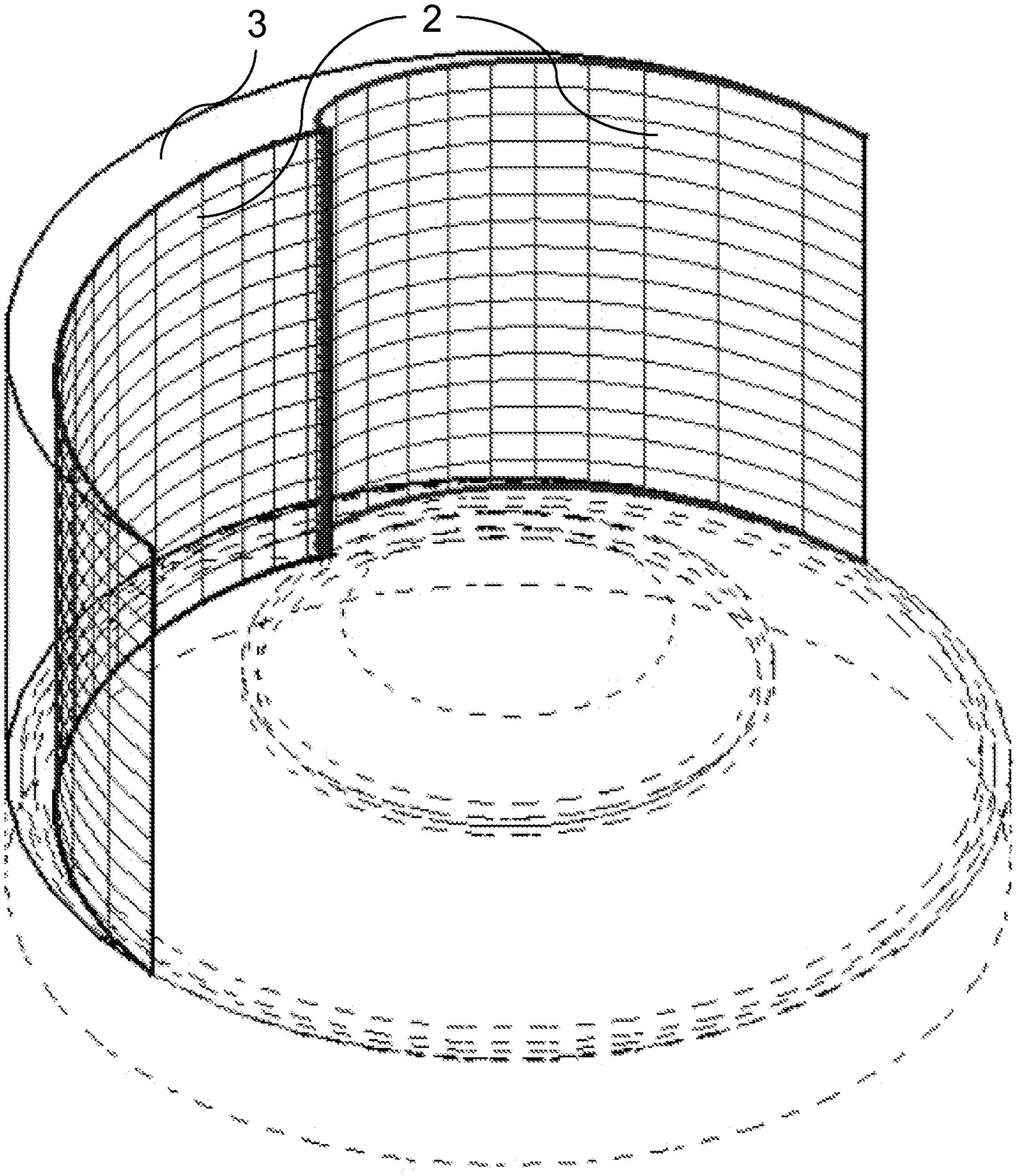

FIGURE 4

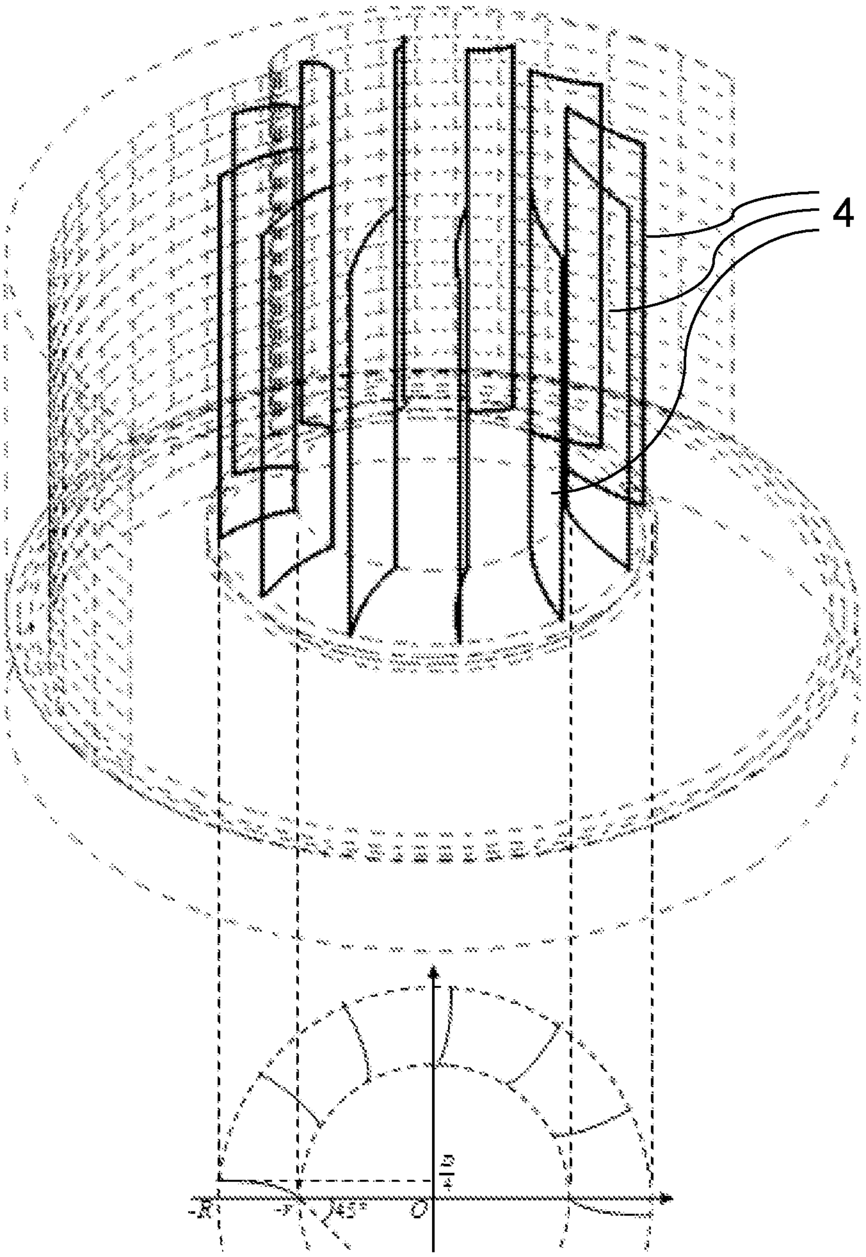

FIGURE 5

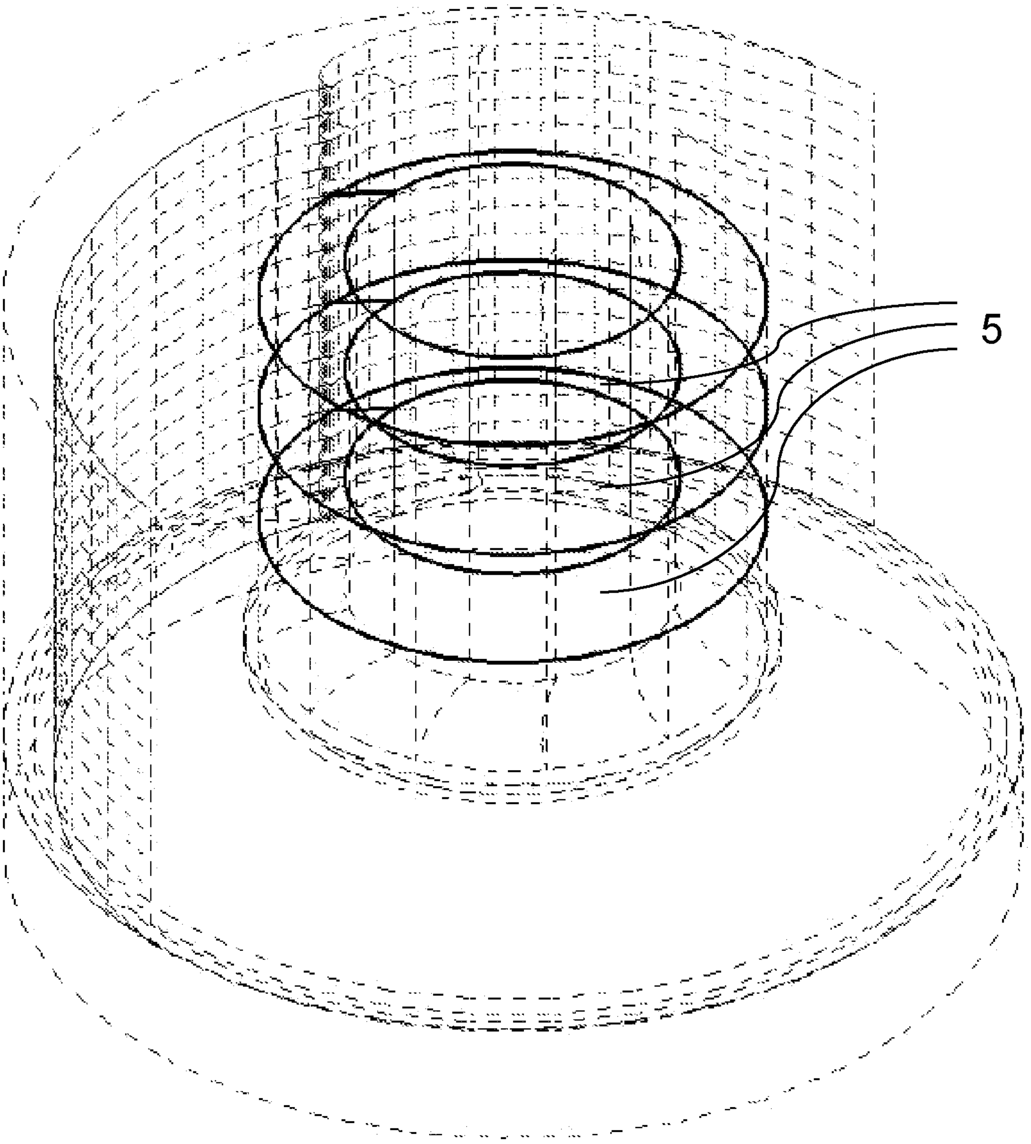

FIGURE 6

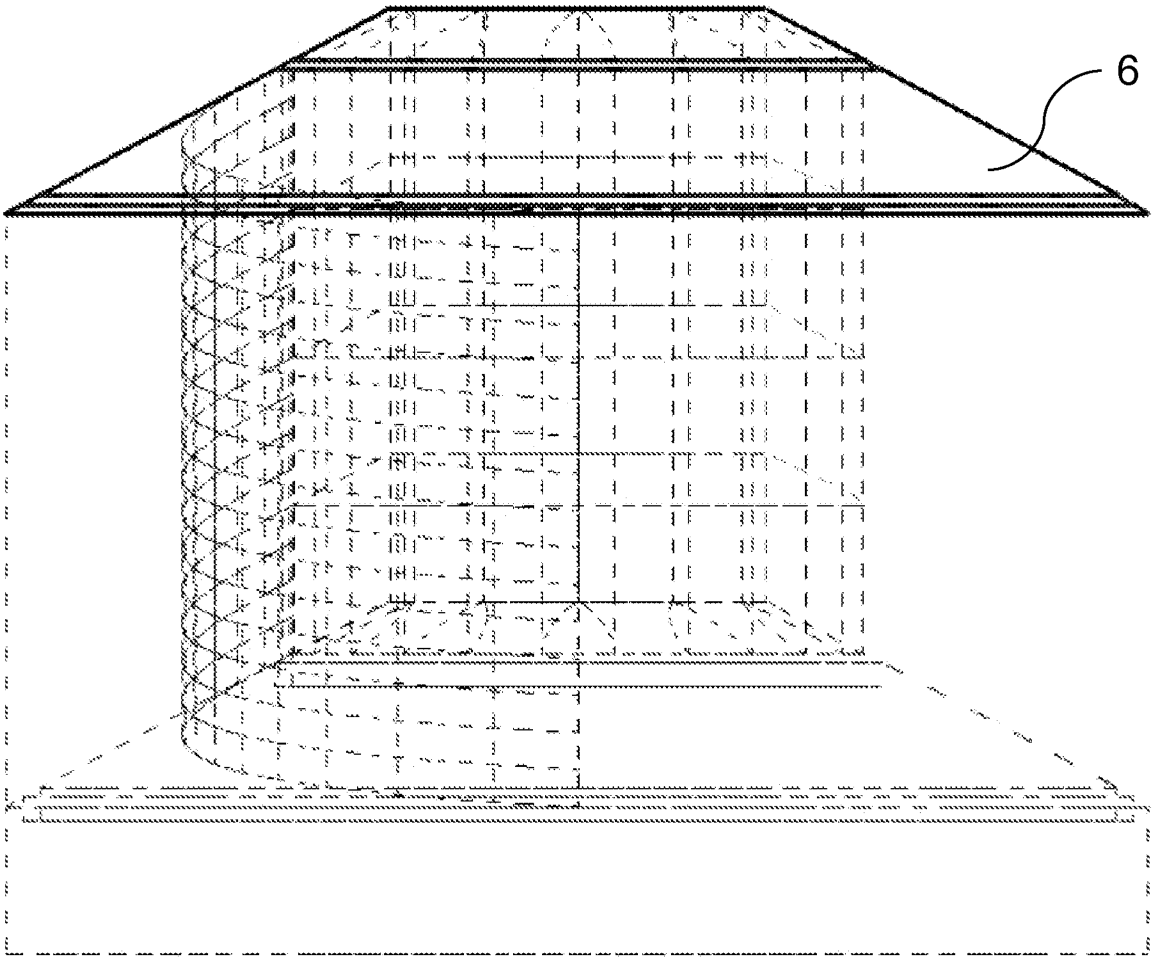

FIGURE 7

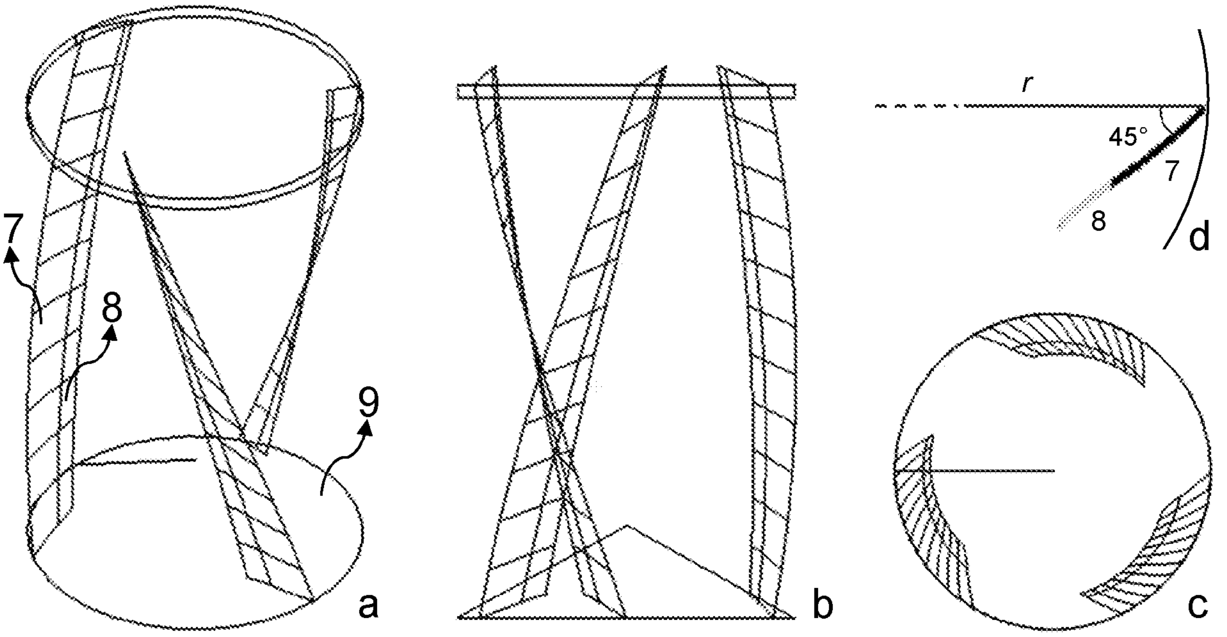

FIGURE 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/056421

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D3/04 F03D3/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F03D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	WO 2013/080192 A1 (PELLEGRI A) 6 June 2013 (2013-06-06) page 5, line 6 - page 8, line 17 page 11, line 25 - page 14, line 17 figures 1-4,9b -----	1-5, 7-10, 12-15
Y	GB 185 939 A (BUNJI HASHIMOTO; YUKITERU OZAKI) 21 September 1922 (1922-09-21) page 1, lines 12-23, 85-88 page 2, lines 17-23 figures 1,3,5 ----- -/--	1-5, 7-10, 12-15

☒ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search 14 December 2017	Date of mailing of the international search report 21/12/2017
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Pasquet, Pierre

INTERNATIONAL SEARCH REPORT

International application No
PCT/IB2017/056421

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 047 834 A (MAGOVENY GEORGE S ET AL) 13 September 1977 (1977-09-13) cited in the application column 1, lines 7-13 column 2, lines 22-34 column 3, lines 17-21 figure 2 -----	1-15
A	US 2004/012207 A1 (NAGY SANDOR [DE]) 22 January 2004 (2004-01-22) cited in the application paragraphs [0005] - [0007], [0009], [0013] figure 1 -----	1,15

2

Form PCT/ISA/210 (continuation of second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/IB2017/056421

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