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(54) TURBINE ROTOR

(71) I ALBERTO KLING, a Citizen of Colombia, of Seestrasse 38, D-8131 Berg, Western Germany do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:

This invention relates to turbine rotors.

For augmenting the flow volume intake of a wind turbine rotor of a given cross section for conversion thereof into another form of energy, such as electric energy, it is known to employ stationary diffusors, by means of which the energy output of the wind turbine may be increased by a factor of about 3, as compared to unshrouded turbines under equally free wind flow conditions. These stationary diffusors, which surround the rotor rotating therein in the manner of a channel duct, are employed for augmenting the wind energy intake of a wind turbine by increasing the volumetric flow rate at the turbine, i.e. by increasing the wind flow velocity as well as the pressure drop across the turbine. This, in turn, increases the amount of kinetic energy that can be extracted from the wind by a turbine of a given diameter.

Such stationary diffusor shrouds are therefore employed to decrease the size of a wind turbine required for a given power output and to increase the rotational speed of the turbine. This type of augmenting diffusor shroud has proved to be uneconomical, since the ratio of the diffusor shroud's total length to its throat diameter is of the order of 7 to 1 to 3 to 1, with the main contribution to the shroud length being the diffusor proper. Such large sized stationary shrouds are not only expensive as regards their constructions, but also require expensive structures for their support.

According to this invention a turbine rotor for operation without the influence of flow-guiding stationary housings or channels in a flow medium contained in a space of unlimited dimensions as compared to the dimensions of the rotor comprising a shroud attached to the rotor blades adjacent the outer periphery of said rotor and formed as an axially symmetrical outer annular shroud rotating in unison with the rotor, and an inner annular shroud affixed to the inner ends of the rotor blades, in which the outer annular shroud in radial section has a profile adapted to produce a lift force under onflow conditions and oriented in the annular shroud such that its suction side forms the interior surface of said annular shroud facing a passage delimited by said annular shroud, and that the effective angle of attack of said profile with respect to a direction parallel to the central axis of said passage has a value giving rise to a circulation flow about said profile and is smaller than the critical (stalling) angle of said profile, the inner shroud defining an inner limit of said passage, said inner shroud in radial section having a profile adapted to produce a lift force under onflow conditions and being oriented such that its suction side forms the exterior surface of said inner annular shroud facing said passage, and the angle of attack of the inner shroud relative to a direction extending parallel to the centre axis of said annular passage is smaller than the critical (stalling) angle of said profile.

The configuration of the rotor according to the invention offers substantial advantages over the prior art. Since the angle of attack of the annular shroud's profile does not exceed the critical stalling angle thereof, the profile of the annular shroud under onflow of the wind stream acts as an airfoil producing a lift. In this case this lift acts radially inwards, tending to contract the outer annular shroud concentrically about the center axis thereof. This aerodynamic force acting on the annular shroud is combined with a circulation about the annular shroud. (This type of circulation is also present in the conventional airfoil flow pattern).

Since the annular shroud is axially symmetrical, there forms a vortex toroid lying the the main rotor plane and remaining restricted to an area in the immediate vicinity of the rotor plane. This means that a net circulation is established in such a sense that an augmentation of the flow volume is established without a physical diffusor being present adjacent the rotor. Due to the presence alone of the vortex toroid, the onflowing air attains an increased velocity in the rotor passage, whereby the volumetric flow rate as well as the downstream flow cross section are increased correspondingly. This results in an increase of the power output of the turbine.

A particularly advantageous embodiment of the rotor according to the invention is further obtained by the profile of the respective annular shroud being designed as a curved aerodynamically shaped profile having an upstream entry nose and a downstream edge. By selecting the profile, for instance among the numerous wing profiles described in the literature (such as NACA profiles, CLARK, or LIEBECK profiles), it is possible to coordinate the drag values, lift values and values of the critical angle of attack such that the optimum effect of the annular shroud is achieved under any desired conditions.

In a particularly advantageous embodiment the invention provides that the upstream edges of the rotor blades extend in a common plane with the upstream edges of the annular shrouds. This arrangement results in the rotor blades being disposed at that portion of the annular shrouds, at which the flow through the annular passage, in which the rotor blades are disposed, has its highest velocity under the influence of the circulation about the annular shrouds. In this manner, it is possible to achieve an optimum efficiency with a rotor of smallest dimensions.

The invention may be performed in various ways and some specific embodiments will now be described by way of example with reference to the accompanying drawings, in which:-

Figure 1 is a perspective view of one half of a rotor according to the invention;

Figure 2 shows a radial section of the rotor of Figure 1; and

Figure 3 shows five exemplary embodiments a to e of profile sections of the annular shroud of the rotor according to Figures 1 and 2.

Figures 1 and 2 show an exemplary embodiment of the rotor. The rotor is for operation without the influence of flow-guiding stationary housings or channels in a flow medium contained in a space of unlimited dimensions as compared to the dimensions of the rotor, particularly a wind turbine rotor, comprising a shroud attached to the rotor blades adjacent the outer periphery of said rotor and formed as an axially symmetrical outer annular shroud rotating in unison with the rotor and an inner annular shroud affixed to the inner ends of the rotor blades. The rotor shown in these figures has a plurality of rotor blades 9 uniformly spaced about its circumference and having affixed to their outer ends an outer annular shroud 10, and to their inner ends an inner annular shroud 11. The inner annular shroud 11 is connected through spokes 12 to a central hub 13 non-relatively rotatably supported by a shaft 14. The shaft 14 may be rotatably supported in a carrier structure and coupled to an electrical current generator, the last-named parts not being shown in the drawings for the sake of simplicity. In this embodiment, the outer annular shroud 10 is arranged and profiled in the manner such that the passage 15 limited thereby, and by the annular inner shroud 11, through which the air impinging on the rotor blades flows, widens from its upstream intake opening to its downstream outlet opening. Annular shroud 10, in radial section has a profile adapted to produce a lift force under onflow conditions and oriented in the annular shroud 10 such that its suction side forms the interior surface of the annular shroud 10 facing towards passage 15, and the angle of attack of the profile relative to a direction extending parallel to the centre axis of the annular passage 15 is smaller than the critical angle of attack of the profile, at which separation of the flow from the profile would occur.

As particularly shown in Figure 2, the profile of the outer annular shroud 10 is disposed at an angle to the oncoming wind flow along the entire circumference of the shroud. This results in an aerodynamic (lift) force acting substantially radially inwards of the annular shroud 10, as generally known from the airfoil theory. In combination therewith, there develops a circulation about the profile of the annular shroud along its entire circumference as shown in Figure 2, by an elliptical line surrounding each of the section points of the annular shroud. This circulation results in an increase of the flow velocity in passage 15 over the flow velocity of the wind stream in front of the rotor, whereby the cross sectional flow area of the oncoming wind embraced by the rotor is greater than the flow area of passage 15. The flow pattern of the oncoming air stream in the area embraced by the configuration and arrangement of the annular shroud 10 as well as the flow pattern thereof after passing through the rotor are substantially shown by phantom lines in Figure 2. The arrangement and the profiled shape of the annular shroud 10 result in an aerodynamic effect on the rotor, due to which the oncoming air stream is embraced, directed through passage 15 of the rotor, and exhausted backwards under enlargement of its cross section, in an area substantially larger than that of the rotor surface area. The inner annular shroud 11 also has, in radial section, a profile adapted to produce a lift force under onflow conditions, and oriented in the anner annular shroud such that its suction side forms the outer surface thereof facing passage 15. Passage 15 is outwardly defined by the outer annular shroud 10, and inwardly, by inner annular shroud 11, thus forming an annular passage in which the rotor blades 9 are disposed and through which passes the flow impinging on rotor blades 9. The angle of attack of the profile of the inner annular shroud 11 relative to a direction extending parallel to the centre axis of annular channel 15 is smaller than the critical angle of attack of the profile, at which separation of the flow would occur. The profile may for example be one of the conventional airfoil profiles 4*a*, 4*b*, 4*c*, 4*d*, or 4*e* shown in Figures 3a to 3e and discussed below with reference to these Figures.

The arrangement of the annular shrouds with their profiled shapes thus results in an aerodynamic flow augmentation effect otherwise obtainable only with the aid of stationary diffusor structures disposed about a revolving rotor and having a diffusor proper extending backwards far beyond the rotor. An elongate physical diffusor of this kind is not required for the rotor according to Figures 1 and 2. Due to the flow augmentation effect of the rotor according to Figures 1 and 2, the efficiency thereof is considerably improved over that of a conventional rotor of the same diameter.

Figure 3 shows five exemplary embodiments of the profiles of the annular shroud 10,11. These profiles are examples of a great number of airfoil or wing profiles already tested and analysed by research establishments. The relevant data of these profiles, e.g. drag, lift, critical angle of attack are recorded in textbooks and therefore readily accessible for designing the annular shroud. Figure 3a to 3d show curved profils having a rounded entry nose and a sharp downstream edge (Figure 3a CLARK profile, Figure 3b curved profile, Figure 3c LIEBECK profile, Figure 3d NACA profile). The employ of profiles of this type in the annular shrouds 10,11 results in particularly favourable flow patterns. In principle, however, it is also possible to employ a simple plate for the profile, as shown in Figure 3e. While the aerodynamic properties of a plate profile of this kind are less favourable than those of specifically shaped aerodynamic profiles, the flow augmentation effect achieved with annular shrouds, of this configuration in the rotor according to Figures 1 and 2 is still quite considerable.

In the case of the rotor shown in Figures 1 and 2, the central area inwardly of the inner ends of rotor blades 9 is formed as an open section through which the air stream may pass freely. The spokes 12 connecting the rotor to its hub 13 and disposed in this open section constitute a negligible restriction of the open section. Due to the fact that the central area of the rotor in the embodiment of Figures 1 and 2 is pervious to flow, a circulation may also be formed about the profile of the inner annular shroud under onflow conditions, as shown in phantom lines in Figure 2. This circulation is to be considered, of course, to extend along the entire circumference of the annular shroud. Thus the circulations about the inner annular shroud 11 and the outer annular shroud 10 each form a respective vortex toroid. Due to this circulation, the oncoming flow attains an increased valocity adjacent passage 15 of the rotor, and in addition, a greater amount of air is introduced into said passage than the amount of air corresponding to the sectional area of said passage in the case of a non-shrouded rotor of the same diameter. Thus there is likewise established an aerodynamic diffusor effect without there having to be provided an elongate, stationary diffusor surrounding the rotor. In this embodiment, the rotor may thus also be designed in a very short and compact form, and its efficiency is greater than that of conventional rotors of the same diameter.

As shown particularly in Figures 2 ,the upstream edges of the rotor blades 9 lie in a common plane with the forward edges of the annular shrouds 10, 11.

The axial length of the annular shrouds amounts only to a fraction of the outer diameter of the rotor.

In the rotor the flow passage, through which the stream to be converted by the tubine flows, is defined not only by the outer annular shroud, but also by the inner annular shroud, which due to the configuration of its cross section as a slanting profile acts in an analogous manner as already described in detail with respect to the effect of the outer annular shroud. In this manner, the inner wall of the annular passage as well as the outer wall thereof are employed for generating a circulation, itself acting in the manner of a physical diffusor, so that the sectional area of the oncoming flow embraced and conducted into the rotor is considerably larger than the flow area determined by the cross section of the rotor's annular passage. Thus this also results in a greatly increased utilization of the onflowing medium's energy as compared to conventional rotors and a more space-saving construction that in the case of rotors surrounded by elongate diffusors. In the rotor, the axially interior space inside of the rotor blades is not occupied by a fairing projecting upstream of the rotor plane, but forms an unobstructed opening, through which only the struts supporting the rotor on its shaft extend, so as to permit flowthrough of such opening and thus the establishment of a circulation about the profile of the inner annular shroud. Thus, the configuration and the profile design of the annular shrouds of the rotor combine to result in a control of flow conditions about the rotor, so as to produce by aerodynamic means an effect corresponding to that of a physical diffusor means disposed about the rotor, which would require a considerable axial length, and thus a large space. Due to the absence of a bulky diffusor means of considerable length particularly in the axial direction, the rotor can be designed very compactly and to save space, while nevertheless permitting to achieve a considerable increase of the converted energy, based on the rotor flowthrough area, as compared to known rotors. The rotor may be of a very lightweight and therefore low cost construction, since the outwardly directed centrifugal forces acting on the annular shroud on rotation of the rotor are to a large extent compensated by the radially inwardly directed "lift" produced under onflow conditions by the profile of the outer annular shroud. In view of the small forces to be absorbed by the structure, it is therefore also possible to prefabricate the annular shrouds in individual sections having a suitable size for transport, and to assemble these sections at the installation site of the turbine. This is of particular importance in the contruction of wind turbines having a large diameter. Seen as a whole, the rotor is of simple and space-saving contruction and has a very high degree of efficiency as well as of economy and reliability in operation.

The construction of the outer and inner annular shrouds and thus of the rotor is directly related to the profiles selected for the annular shrouds. Thus the rotor may be constructed with the profiles of the outer and the inner annular shrouds being formed and disposed such that their profile chords with respect to the central axis of the passage surrounded by the annular shroud diverge towards the downstream outlet opening thereof. Also, the rotor may be constructed with the annular shrouds being formed such that the width of the passage enclosed thereby increased from the upstream inlet opening towards the downstream outlet opening thereof.

Advantageously the rotor is designed such that the axial length of each annular shroud is a fraction of the outer diameter of the rotor. In the rotor the axial length of the annular shrouds can be very short, since the profiled configuration thereof results in the establishment of a circulation, and thus in an aerodynamic diffusor effect, without necessitating the employ of a physical diffusor extending over a considerable length downstream of the turbine. The arrangement thus provides a very compact rotor the axial length of which is substantially restricted to that of the rotor blades.

WHAT I CLAIM IS:-

1. A turbine rotor for operation without the influence of flow-guiding stationary housings or channels in a flow medium contained in a space of unlimited dimensions as compared to the dimensions of the rotor, comprising a shroud attached to the rotor blades adjacent the outer periphery of said rotor and formed as an axially symmetrical outer annular shroud rotation in unison with the rotor, and an annular shroud affixed to the inner ends of the rotor blades, in which the outer annular shroud in radial section has a profile adapted to produce a lift force under onflow conditions and oriented in the annular shroud such that its suction side forms the interior surface of said annular shroud facing a passage delimited by said annular shroud, and that the effective angle of attack of said profile with respect to a direction parallel to the central axis of said passage has a value giving rise to a circulation flow about said profile and is smaller than the critical (stalling) angle of said profile, the inner shroud defining an inner limit of said passage, said inner shroud in radial section having a profile adapted to produce a lift force under onflow conditions and being oriented such that its suction side forms the exterior surface of said inner annular shroud facing said passage, and the angle of attack of the inner shroud relative to a direction extending parallel to the centre axis of said annular passage is smaller than the critical (stalling) angle of said profile.

2. A rotor according to Claim 1, wherein the profile of each annular shroud is designed as a curved, aerodynamically shaped profile having an upstream entry nose and a downstream edge.

3. A rotor according to Claim 1 or Claim 2, wherein upstream edges of the rotor blades and upstream edge of said annular shroud are in a common plane.

4. A rotor according to any one of the preceding claims wherein the axial length of each annular shroud is a fraction of the outer diameter of the rotor.

5. A rotor according to any one of Claims 1 to 3, wherein the axial length of each annular shroud is a fraction of the outer radius of the rotor.

6. A turbine rotor substantially as hereinbefore described with reference to and as shown in Figures 1 and 2 of the accompanying drawings.

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1581305 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 1

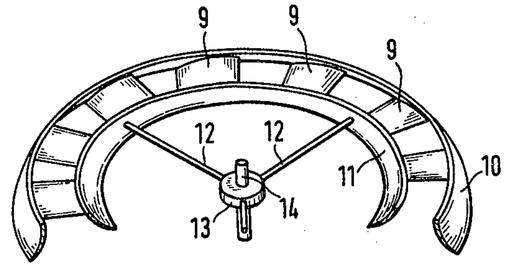

Fig. 1

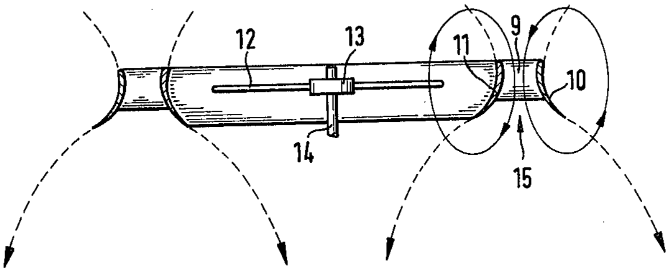

Fig. 2

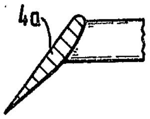

Fig.3a

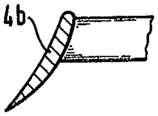

Fig.3b

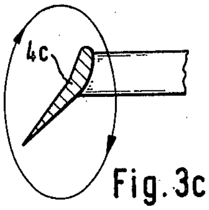

Fig.3c

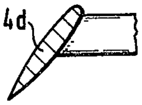

Fig.3d

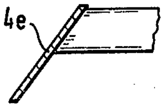

Fig.3e