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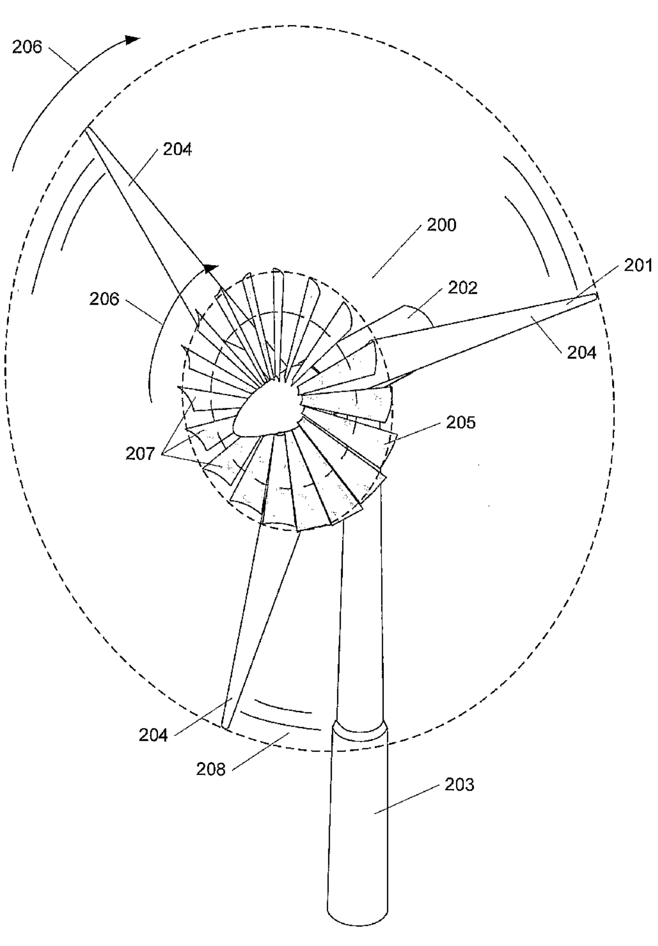
(54) Title: A WIND POWER PLANT WITH EXTRA SET OF BLADES



(57) Abstract: The present invention relates to a wind power plant with a first set with at least one blade mounted on a shaft and at least one second set with at least one blade mounted on the same shaft and mounted such that the blade sets will have the same direction of revolution and the same number of revolutions. The second set of blades has a length which is smaller than that of the first set of blades and has another optimal tip speed ratio than the first set of blades, whereby the two sets of blades are optimised with regard to power output at the same number of revolutions. The ratio between the lengths of the two sets of blades can be determined approximately by the ratio between the optimal tip speed ratios of the two sets of blades. Alternatively the second set of blades can be constructed to have an optimal tip speed ratio, which is determined on the basis of the ratio between the length of the two sets of blades and the optimal tip speed ratio for the one set of blades. The two or more sets of blades can be placed either right behind each other or in the same rotor plane and, according to the invention, the two sets of blades can be constituted by a small wind rose and a larger fast-runner. The invention further relates to use of such wind power plant.

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A wind power plant with extra set of blades

The invention relates to a wind power plant with a first set of blades mounted on a shaft and at least one extra set of blades of a smaller length than the first set of blades. The at least two sets of blades are mounted on the same shaft and with the same direction of revolution.

Background

Wind is to an increasing extent exploited as source of energy and consequently more and increasingly bigger wind power plants are placed in various places. In order to achieve a higher power output, the wind power plants are, on the one hand, made more efficient by optimisation of the individual components of the plant and, on the other, made larger with increasingly longer blades.

By a wind power plant with three-bladed rotor on horizontal axis, the blade are relatively narrow at their innermost portions, towards the hub, and in that part of the rotor a large amount of the wind passes through without being exploited or it is exploited only to a limited degree. If also this part of the wind could be used optimally, the power output of the turbine could be increased considerably.

One method of capturing and exploiting this energy is by making the blades very wide at the innermost portion, at the root. However, this entails very high loads on the blades – in particular in case of high wind speeds and gusts of wind, where the rotor must consequently be stopped or turned out of the wind earlier (at lower wind speeds) than would otherwise be the case with conventionally configured blades. Moreover the very wide blades give rise to problems, on the one hand during the production and, on the other, not in the least when the finished blades are transported to the site of deployment.

It is also known, ia from DE 10152449, to configure the blades such that their innermost part, towards the root, consists of foldable cloths or shells to the effect that the blade surface can be changed as a function of eg the wind speed. However, such blades involve a considerable increase in complexity of the manufacturing process, thereby adding considerably to the cost thereof. Moreover the technique involves the use of sophisticated control mechanisms for regulating and implementing the modification of the surface area of the blade.

Furthermore, wind power plants are known from EP 1255931, where the ‘hole’ centrally in the rotor is covered by a similar extra, but small, rotor which rotates in the same direction, arranged in front of the first one. The smaller rotor must then turn faster than the large rotor in order for the two rotors to operate with equal efficiency. Therefore, this design with an extra rotor requires either gear exchange between the rotors or two shafts whose outputs are then to be coupled in some way. This adds considerably to the costs of construction of the turbine and makes it considerably more complex. Likewise, it may be necessary to allow the blades of the small rotor to be configured with pitch bearings in order for the shorter blades to cope with the large differences in angles of incidence.

Object and description of the invention

It is the object of the invention to provide a wind power plant which is able to optimally or approximately optimally exploit all the wind within the rotor plane and at all wind speeds, whereby the above problems of, on the one hand, storm loads and, on the other, complex and expensive gear exchange are obviated.

The present invention thus relates to a wind power plant with a first set with at least one blade mounted on a shaft and at least on second set with at least one blade mounted on the same shaft. The at least two sets are mounted such that the sets of blades have the same direction of revolution and the same number of revolutions, and the second set of blades has a length which is smaller than that of the first set of blades. The second set of blades further has a second optimal tip speed ratio than the first set of blades, whereby the two sets of blades are optimised with regard to power output at the same number of revolutions.

Here and in the following the tip speed ratio is defined as the ratio between the blade tip speed and the wind speed. “Optimised with respect of power output” is intended to designate that each set of blades is optimised to exhibit approximately maximal power coefficient for the relevant rotor type and hence exploit the wind energy optimally.

By a wind power plant in accordance with the above, the advantageous aspect is obtained that the power output of the wind power plant is increased considerably, as the wind is also exploited centrally at the rotor where, otherwise, in conventional wind turbines, it escapes between the rotor blades. Simultaneously a synergy effect is accomplished in that the total wind energy obtained by the wind power plant according to the invention is larger than what can be obtained for each of the two sets of blades combined. This is accomplished in that the wind near the centre of the rotor is not only utilised by the smaller set of blades, but is also to a certain extent directed and transmitted to the large blades where they exploit the wind optimally. Moreover, the present invention is advantageous in that the two sets of blades are mounted on the same shaft, whereby the need for more than one shaft is eliminated, and likewise it is not necessary to have to use gear exchange between the two sets of blades since they rotate with the same number of revolutions.

According to one embodiment, the ratio between the lengths of the two sets of blades is determined approximately by the ratio between the optimal tip speed ratios of the two sets of blades. Hereby it is accomplished that both sets of blades are constructed to run optimally at the same number of revolutions with ensuing highest possible power output.

This is also accomplished in accordance with yet an embodiment of the invention, where the second set of blades is constructed for an optimal tip speed ratio determined on the basis of the ratio between the lengths of the two sets of blades and the optimal tip speed ratio for the one set of blades.

The invention further relates to a wind power plant in accordance with the above, wherein the at least two sets of blades are arranged right after each other on their common shaft or wherein the at least two sets of blades constitute a shared rotor plane. Hereby it is accomplished that each set of blades is able to utilise the energy of the wind optimally without significantly disturbing the flow field of the second set of blades. Arrangement of the two sets of blades right in front of each other also prevents an aerodynamic gap between the two or more sets of blades. Also, the embodiment is advantageous in that the extra set(s) of blades are easily and readily mounted on the wind power plant and correspondingly easily replaced or maybe removed altogether again if needed.

One embodiment of the invention describes a wind power plant, where the second set of blades constitutes a wind rose, and the first set of blades constitutes a fast-runner. This embodiment is advantageous in that a wind rose is simple and relatively inexpensive to manufacture. Additionally, the wind rose is efficient, at fixed number of revolutions, across a relatively wide interval of wind speeds.

According to yet an embodiment of the invention the second set of blades is hingedly mounted to the effect that they can be turned about their longitudinal axis. Hereby the loads on these blades can be reduced considerably, which may be an advantage in case of high wind speeds which are not so high that the entire rotor has to be stopped or turned out of the wind. The one set of blades can thus be turned out of the wind independently of the second set of blades.

According to yet an embodiment of the invention the second set of blades is mounted such that they can be braked independently of the first set of blades or may be assembled radially in one or more groups. Both embodiments are advantageous in that the storm loads can be reduced on the second set of blades, while the first set of blades can continue to operate unaffected thereby.

The present invention also relates to use of a wind power plant as described by one or more of the above-mentioned elements. The advantages thereof are as mentioned above.

Brief description of drawing

In the following the invention is described with reference to the figures, wherein:

Figure 1 shows schematic curves of the power coefficients of various wind rotors as a function of their tip speed ratios;

Figures 2-3 show a wind power plant according to the invention with two sets of blades arranged right behind each other, seen in an inclined view from the front and from the side;

Figures 4-5 show a further embodiment according to the invention of a wind power plant with two sets of blades arranged in the same rotor plane, seen in an inclined view from the front and from the side;

Figure 6 shows a wind power plant according to the invention, where the second set of blades is hingedly mounted;

Figure 7 shows a wind power plant according to the invention, wherein the second set of blades can be brought together in groups; and

Figures 8-11 show different embodiments of the second set of blades.

Description of embodiments

Figure 1 shows the power factors or power coefficients Cp, 102 of various kinds of wind rotors outlined as a function of their tip speed ratios X, 101. The tip speed ratio X is given as the ratio between the blade tip speed and the wind speed and thus varies proportionally with the length of the blade and inversely proportionally with the time of revolution of the blade (the time it takes to perform a full revolution). Based on the curves from Figure 1, it can be read at which tip speed ratio 101 a rotor of a specific type will operate optimally (have maximal effect factor). The curve 103 is for an ideal propeller rotor, which will always be above the realisable, ia due to the friction in actual rotors. The curve 104 shows the power coefficient for a fast-runner, which is the designation for a rotor whose tip speeds are several times higher than the wind speed. Modern wind power plants with three blades are fast-runners. A multi-bladed slow-runner, such as a wind rose, has characteristics as shown by curve 105. The power coefficient curve of an old-fashioned wind mill is given by 108, and the curves 106 and 107 apply to a Savonius and a Darrieus tubine, respectively, which are both turbines with vertical axes of revolution. In order to achieve the maximal power output from a rotor, its time of revolution is to be adjusted to the rotor diameter, to the effect that a larger rotor should rotate more slowly than a small one. These power coefficient curves are used to advantage in the following to design a wind power plant with optimal exploitation of the wind.

Figure 2 shows a wind power plant 200 according to the invention, where the wind turbine comprises a rotor 201 and a nacelle 202 on a tower 103, as is usual. Here the rotor 201 is a fast-runner with three blades or wings 204. Immediately in front of the primary rotor a further, small rotor 205 is mounted that has a far smaller diameter covering the innermost part of the large rotor 201. Hereby all the wind within the large rotor area 208 is used optimally, the wind at the innermost part of the blades 204 being, on the one hand, exploited by the additional rotor 205 instead of proceeding directly through the hole in the rotor and, on the other, is to a certain extent directed out onto the widest part of the large blades 204 where the wind is exploited optimally.

The two rotors 201, 205 are mounted on the same shaft and rotate in the same direction, as illustrated by arrows 206. Owing to the different lengths of the blades 204, 207 of the two rotors, their blade tip speeds and hence also their tip speed ratios are correspondingly different if the rotors turn equally fast with same time of revolution. If the 'hole' in a primary rotor is filled with yet a similar rotor of the same type, but merely with a smaller diameter, the result will thus be that the one of the rotors is not able to run as efficiently as possible, or alternatively that the two rotors are unable to rotate equally fast, and a gear exchange becomes necessary. This problem is solved by the present invention by selecting the smaller, secondary rotor 205 to be of another type or according to a different principle with another optimal tip speed ratio than that of the primary rotor 201. Hereby both rotors may operate with the same time of revolution and at their respective, optimal tip speed ratios with best power output as the result. Simultaneously the rotors may sit on the same shaft, and gear for the smaller rotor is rendered superfluous. This is shown in Figure 2, where the primary, larger rotor 201 is a three-bladed fast-runner, whereas the smaller, secondary rotor 205 is a wind rose, which type of wind rotor is a slow-runner with a far smaller tip speed ratio, see Figure 1. By designing and constructing the two rotors in relation to each other in this manner, it is thus accomplished that both rotors will provide maximum power output at the same time of revolution. Simultaneously the synergy effect of the wind being used better than merely by adding the sums of the two rotors is accomplished, the wind being, at the smaller rotor 205, not just captured and utilised, but also to a certain degree conveyed and transmitted to the blades 204 of the primary rotor where they are the widest and most efficient.

According to one embodiment of the invention, the ratio between the lengths of the two sets of blades 204, 207 is determined as approximately the ratio between the optimal tip speed ratios of the two sets of blades. This means that, if the two rotor types – and hence their optimal tip speed ratios - are selected, their ratio of sizes is dimensioned based thereon. Correspondingly, the type of the secondary (primary) rotor can be determined directly based on the type of the primary (secondary) rotor and the ratio between the blade lengths of each rotor. This can be illustrated by the following examples:

<u>Example 1</u>:

As wind speed, a mean value applying to both rotors is used.

Primary rotor: Three-bladed fast-runner with maximal C_p at

$$X_{large} = \frac{V_{tip,large}}{V_{wind}} = 7.$$

Rotor diameter $D_{large} = 100m.$

Secondary rotor selected with diameter $D_{small} = 20m$.

$$X_{small} = \frac{V_{tip,small}}{V_{wind}} = V_{tip,small} \cdot \frac{X_{large}}{V_{tip,large}} = \frac{\pi D_{small} \cdot T_{large}}{\pi D_{large} \cdot T_{small}} \cdot X_{large} = \frac{D_{small}}{D_{large}} \cdot X_{large} = \frac{20m}{100m} \cdot 7 = \underline{\underline{1,4}}$$

wherein T is the time of revolution.

In accordance with the invention, a rotor with optimal tip speed ratio X_{small} of about 1.4 is thus selected or constructed as secondary rotor

<u>Example 2</u>:
Primary rotor like in example 1.
As secondary rotor some kind of wind rose is selected with $X_{small} = 1$.

$$X_{small} = \frac{D_{small}}{D_{large}} \cdot X_{large} \text{ (same calculations as in example 1).}$$

$$\Updownarrow$$

$$D_{small} = \frac{X_{small}}{X_{large}} \cdot D_{large} = \frac{1}{7} \cdot 100m \approx \underline{\underline{14,3m.}}$$

Thus the diameter of the secondary rotor is selected to be about 14.3 m.

Besides, the wind power plant according to the invention is advantageous in that the wind rose is efficient across a larger interval of wind speeds, and therefore the wind rose is not as sensitive to deviations in wind speeds. This is a major advantage over eg a small three-bladed fast-runner which, in order to operate properly at the low tip speeds, would have to operate across a large interval of angles of incidence, which would presuppose pitch regulation of each blade.

The two rotors 201, 205 are mounted immediately after each other, as will also appear from Figure 3, where the wind power plant 200 is shown seen from the side. By the rotors 201, 205 being mounted in immediate succession it is avoided that an aerodynamic gap is formed between the two rotors, whereby the flow field remains optimal and all the wind through the rotor plane will be exploited. Here the secondary, smaller rotor 205 can also be mounted on the main shaft in such a manner that it can be uncoupled and stopped independently of the revolution of the primary rotor. This is advantageous in case of high wind speeds, where the storm loads can thus be reduced considerably.

Likewise, according to an alternative embodiment, the secondary, smaller rotor 205 can be arranged immediately behind the primary, large rotor 201.

Figure 4 shows yet an embodiment of a wind power plant according to the invention, where the one set of blades 204 from the larger, primary rotor 201 is mounted in the same plane as the extra set of shorter blades 207 from the second rotor 205 and thus constitutes a combined rotor with shorter blades 207 arranged in between the larger blades 204. In the outlined embodiment the assembled rotor is here constituted by a wind rose and a three-bladed fast-runner. This is also shown in Figure 5, seen in a side view.

In case of high wind speeds, it may be necessary to limit the loads on the blades. The loads on a wind rose become critical in case of lower wind speeds compared to a fast-runner, and therefore it may be advantageous to be able to reduce the area of the wind rose against the wind without changing the setting of the fast-runner. One way of doing so is by mounting the blades 207 on the smaller, secondary rotor in hinges or turnable joints 601, as outlined in Figure 6, where only a part of the rotor is shown. Hereby the blades 207 can be turned out of the wind direction 602, and the storm loads are reduced drastically. In case of very short blades, shorter than the distance from the rotor plane to the tower, the blades 207 can likewise be hinged in such manner that they can, in case of critical wind speeds, be laid down entirely or partially in the wind direction along the nacelle.

Another method of reducing the loads on the blades 207 of the secondary rotor in case of high wind speeds is outlined in Figure 7. Here the blades are also hingedly mounted 701; however, in this embodiment is such a manner that the blades 207 can be assembled in groups 702 by sliding or being taken together and partially or to a certain extent across each other radially. The suggestions outlined in figures 6 and 7 for limiting storm loads on the second set of shorter blades 207 can also be used on several types of rotors other than the shown wind rose.

Figures 8-11 show various other embodiments of the smaller, secondary rotor 205. Figure 8 illustrates a rotor 205 of a type, where the blades or wings 207 are configured as vanes like on a ventilator.

The rotor 205 outlined in Figure 9 also has vane-like and a relatively large number of closely arranged blades 207. Owing to the vane-shape of the blades, the rotor is not as sensitive to small tips speeds and with be approximately equally efficient across a relatively large wind speed interval. The blades on the rotor shown in Figure 9 can be manufactured eg by folding of thin plates.

Figure 10 outlines a rotor 205, whose blades are manufactured in accordance with the same principle as the previous Figure, but featuring only quite few blades 207 (here four blades), meaning that the optimal tip speed ratios of the two rotors will be different.

Finally, Figure 11 shows yet a rotor principle 205 for use as secondary rotor on a wind power plant according to the invention. Here the individual blades 207 are formed of stretch-mounted canvas or thin plates.

The blades of the various rotor principles shown in the preceding figures 8-11 can also be arranged in the same rotor plane as the larger, primary rotor 201 between the longer blades and in this manner fill the centre of the rotor and utilise the wind optimally.

It will be understood that the invention as disclosed in the present description and figures can be modified or changed while continuing to be comprised by the protective scope conferred by the following claims.

Claims

1. A wind power plant with a first set of at least one blade mounted on a shaft and at least one second set with at least one blade mounted on the same shaft and mounted such that the blade sets will have the same direction of revolution and the same number of revolutions, which second set of blades has a length which is smaller than that of the first set of blades, and which second set of blades has another optimal tip speed ratio than the first set of blades, whereby the two sets of blades are optimised with regard to power output at the same number of revolutions.

2. A wind power plant according to claim 1, **characterised in** that the ratio between the lengths of the two sets of blades is approximately determined by the ratio between the optimal tip speed ratios of the two sets of blades.

3. A wind power plant according to claim 1, **characterised in** that the second set of blades is constructed for an optimal tip speed ratio determined on the basis of the ratio between the lengths of the two sets of blades and the optimal tip speed ratio for the one set of blades.

4. A wind power plant according to one or more of claims 1-3, **characterised in** that the at least two sets of blades are arranged right after each other on their common shaft.

5. A wind power plant according to one or more of claims 1-5, **characterised in** that the at least two sets of blades constitute a common rotor plane.

6. A wind power plant according to one or more of claims 1-5, **characterised in** that the second set of blades constitutes a wind rose and the first set of blades constitutes a fast-runner.

7. A wind power plant according to one or more of claims 1-6, **characterised in** that the second set of blades is hingedly mounted to the effect that they can be rotated about their longitudinal axis.

8. A wind power plant according to one or more of claims 1-7, **characterised in** that the second set of blades is mounted such that they can be braked independently of the first set of blades.

9. A wind power plant according to one or more of claims 1-8, **characterised in** that the second set of blades is mounted such that they can be brought together radially in one or more groups.

10. Use of a wind power plant as described by one or more of claims 1-9.

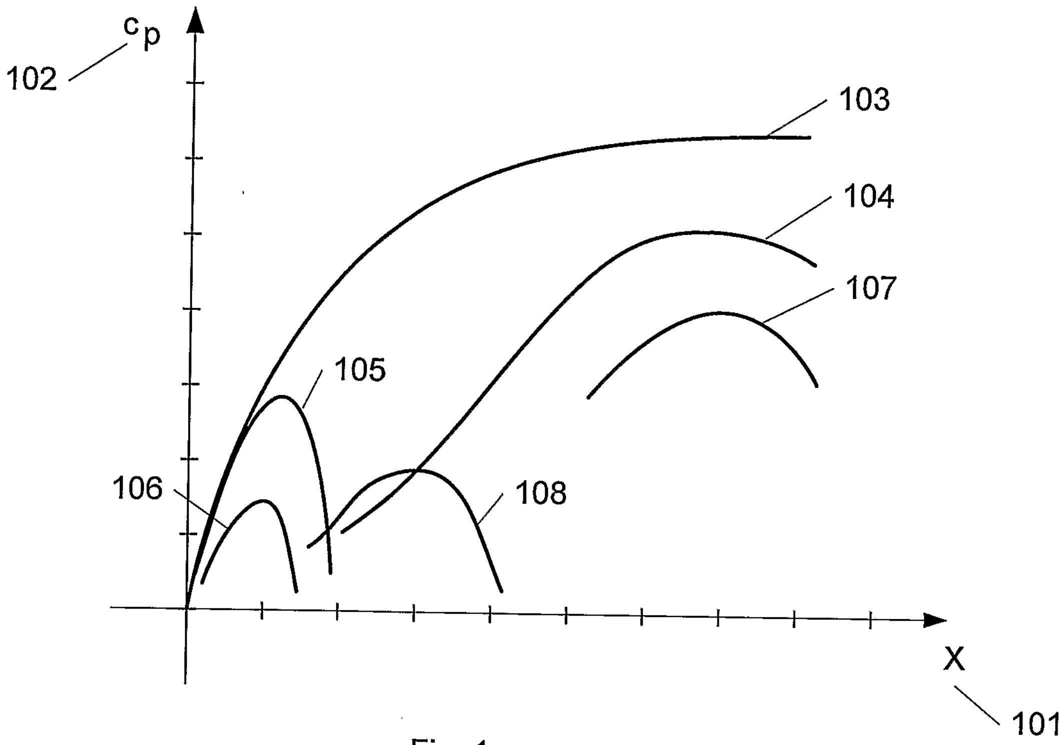

Fig. 1

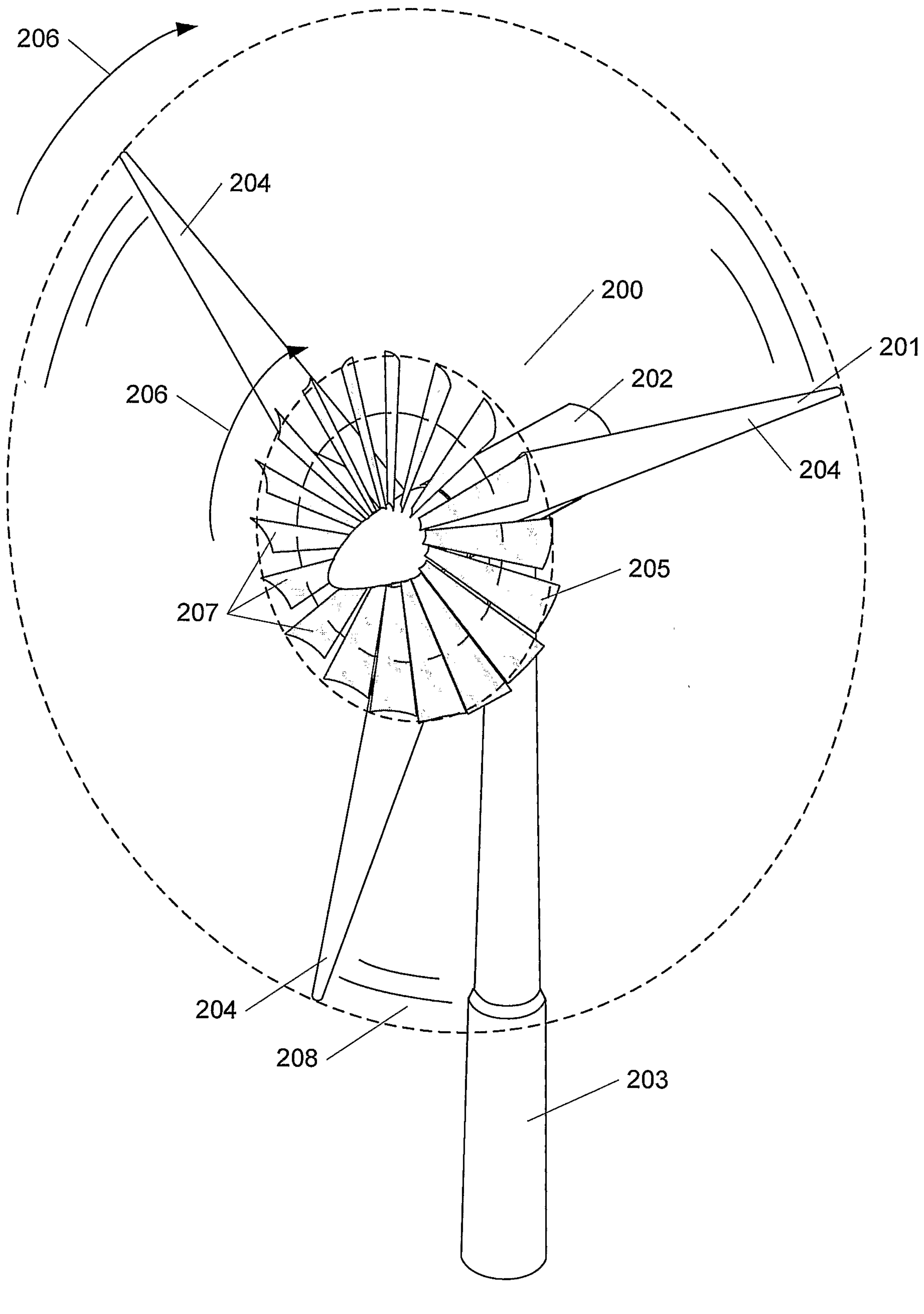

Fig. 2

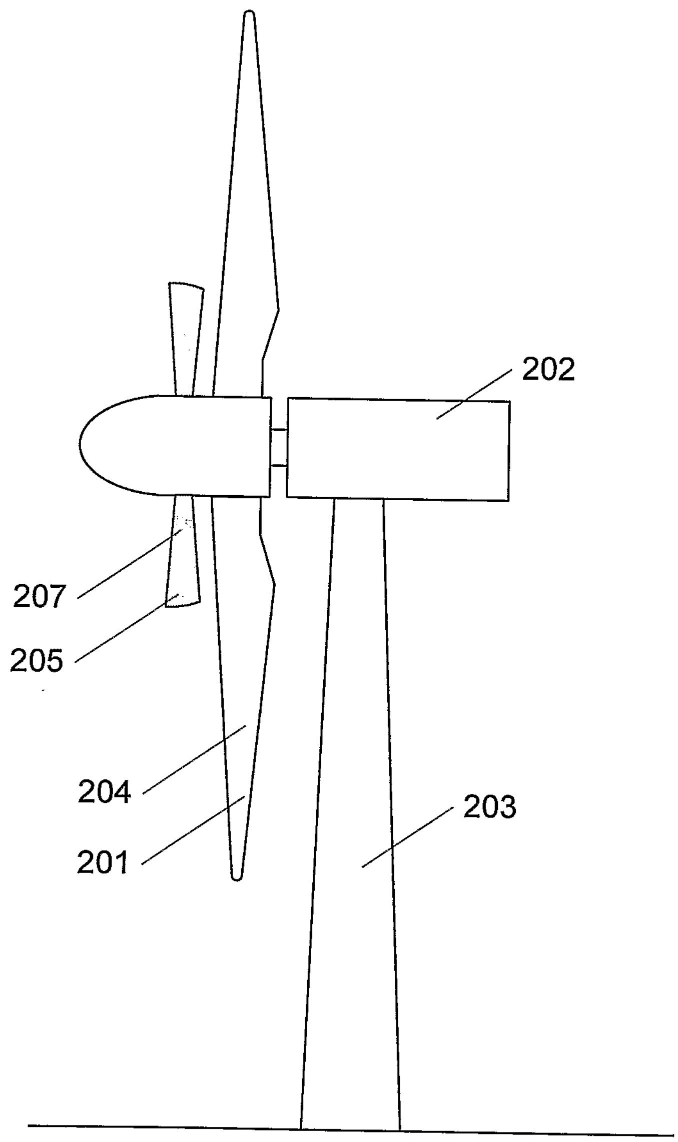

Fig. 3

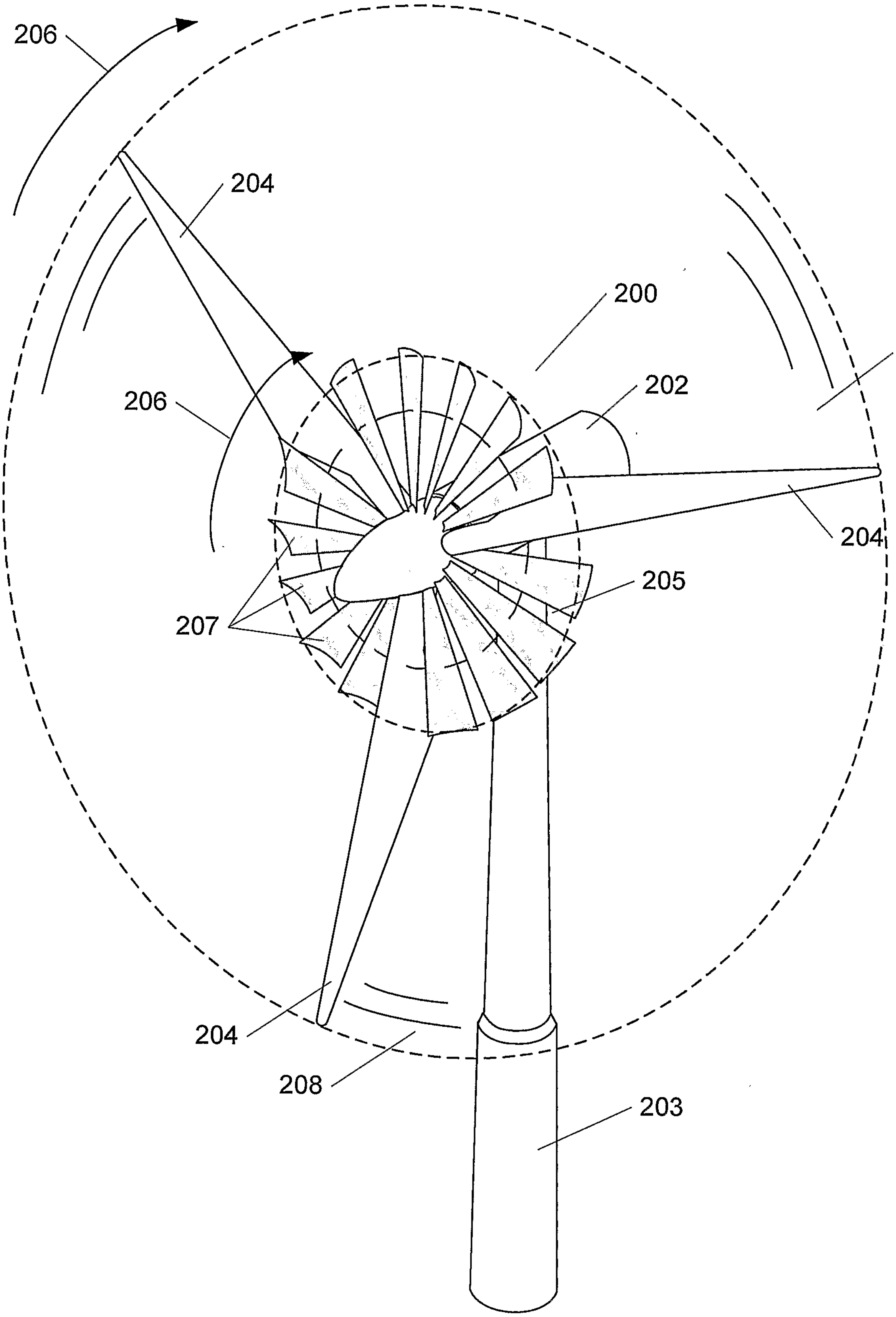

Fig. 4

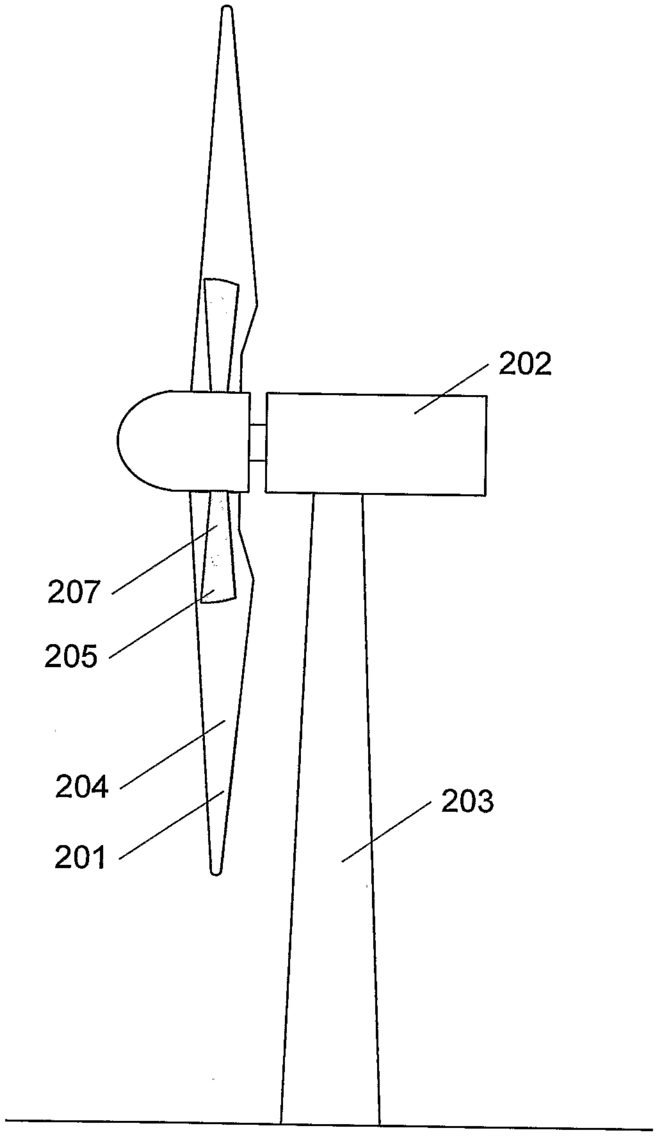

Fig. 5

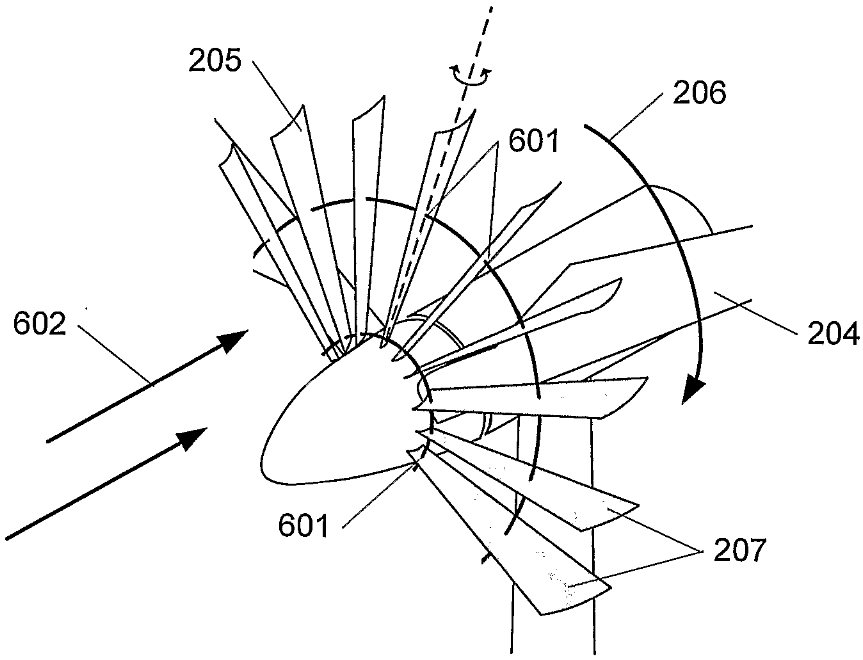

Fig. 6

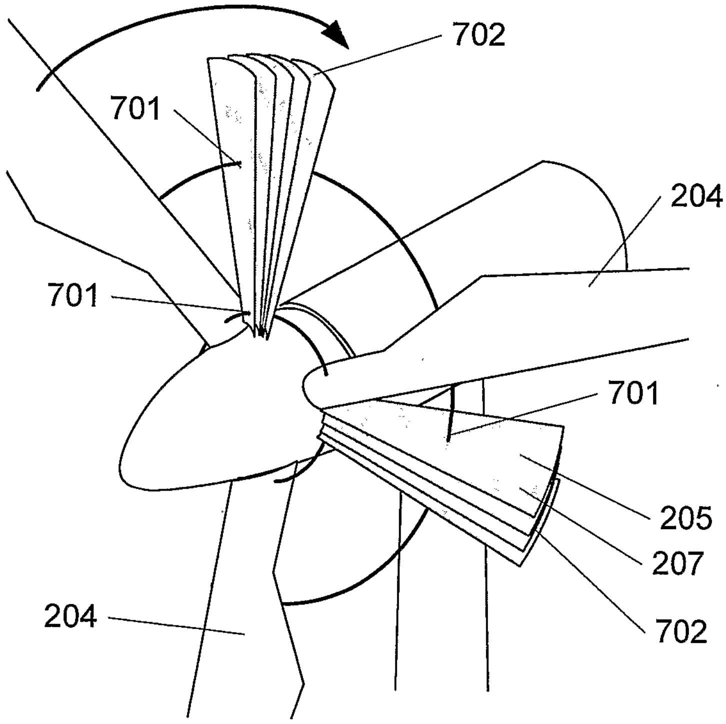

Fig. 7

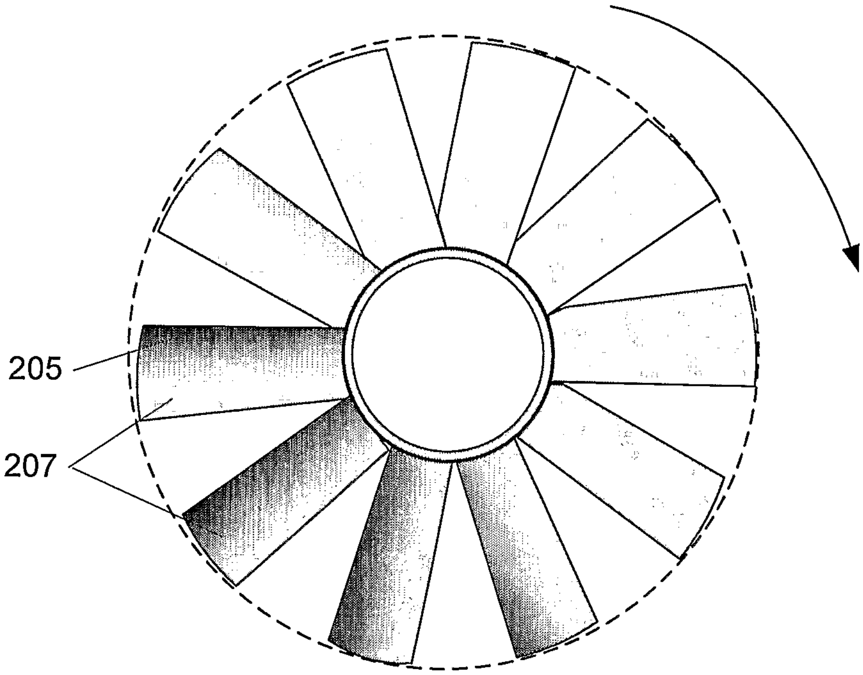

Fig. 8

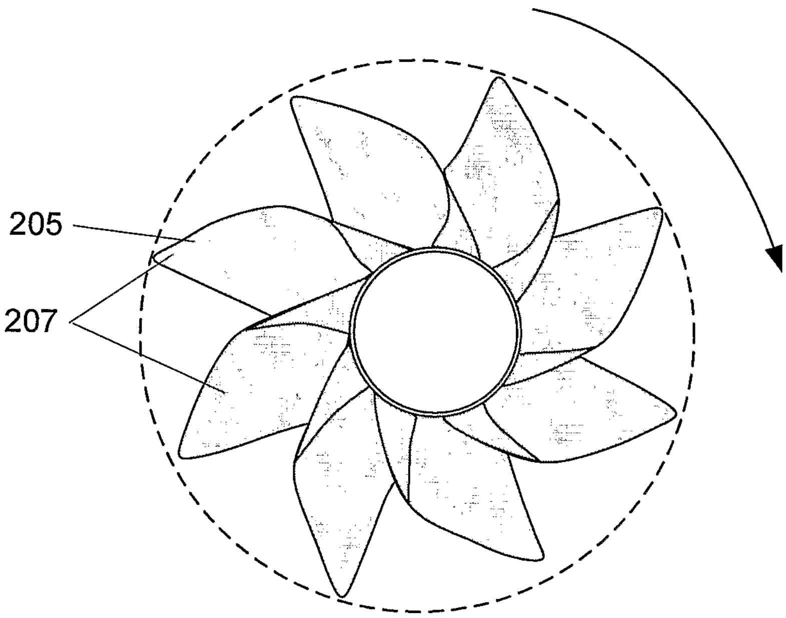

Fig. 9

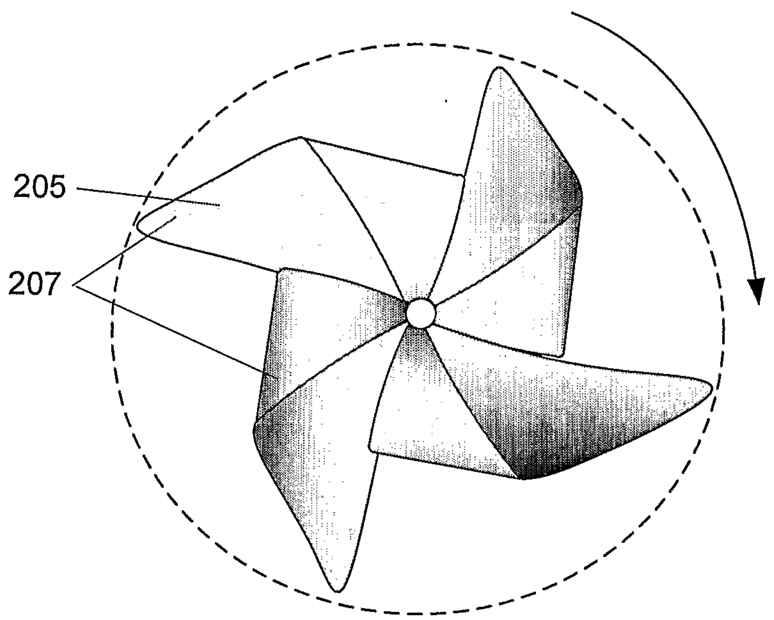

Fig. 10

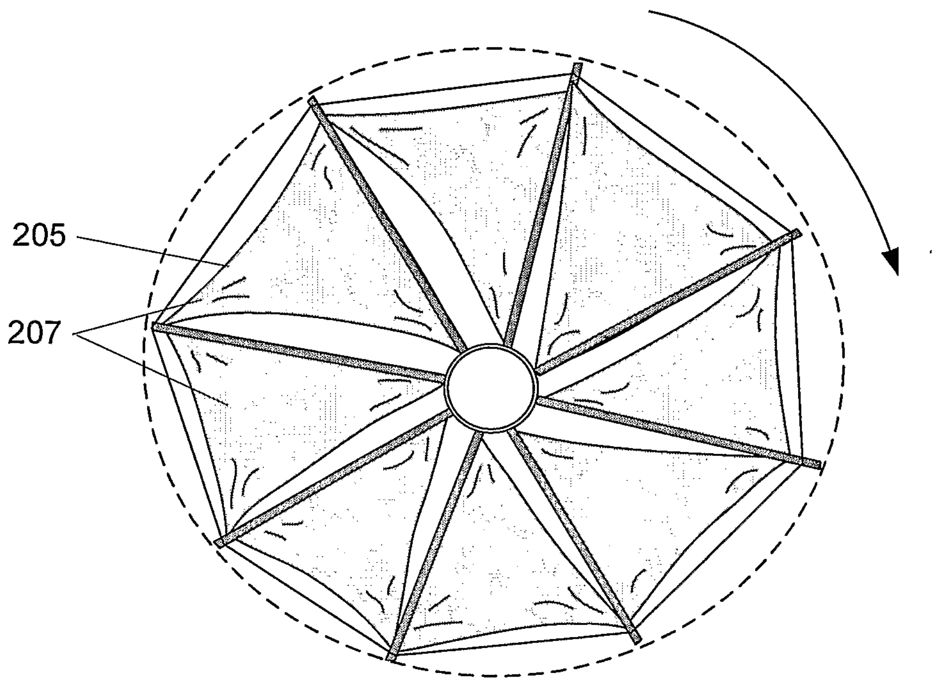

Fig. 11

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2006/000641

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D1/02 F03D1/06

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 practical, search terms used)

EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 150 301 A (BERGEY JR KARL H) 17 April 1979 (1979-04-17) column 6, line 34 - line 40 column 7, line 26 - column 8, line 8 figures 1,7	1-3,5,6, 10
Y		4,7,8
Y	JP 56 138465 A (MATSUSHITA ELECTRIC WORKS LTD) 29 October 1981 (1981-10-29) abstract; figures	4,7,8
Y	FR 627 371 A (INST VOOR AERO EN HYDRO DYNAMI) 3 October 1927 (1927-10-03) page 1, line 33 - line 36 page 1, line 50 - line 53 page 2, line 6 - line 11 figures	1-5,10

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
8 February 2007	22/02/2007

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Angelucci, Stefano

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

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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