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(54) **Title:** A CABLE STAYED WIND TURBINE TOWER AND A METHOD FOR TRANSPORTING THE WIND TURBINE TOWER

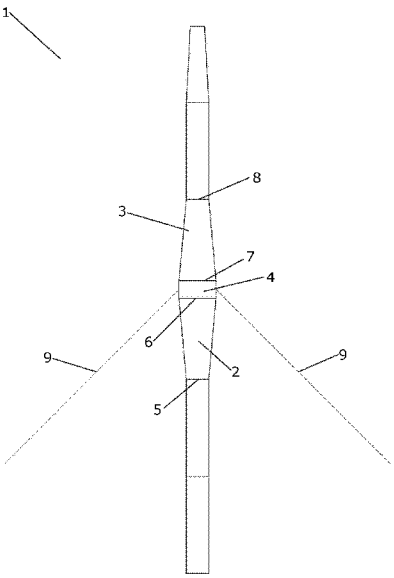


Fig. 1

(57) **Abstract:** A wind turbine tower (1) mounted on a foundation and arranged to carry at least one nacelle is disclosed. At least one stay cable (9) is connected at one end to the tower (1), at a cable mounting position, and at the other end to a stay cable foundation. The tower (1) comprises a lower transition section (2) and an upper transition section (3), the lower transition section (2) forming part of the tower (1) immediately below the cable mounting position and the upper transition section (3) forming part of the tower (1) immediately above the cable mounting position. The diameter of the lower transition section (2) increases along an upwards direction, and the diameter of the upper transition section (3) decreases along an upwards direction. The tower (1) fulfils size constraints for rail transport and a large tower diameter at the cable mounting position can be obtained.

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A CABLE STAYED WIND TURBINE TOWER AND A METHOD FOR TRANSPORTING THE WIND TURBINE TOWER

FIELD OF THE INVENTION

The present invention relates to a wind turbine tower having at least one stay cable connected at a cable mounting position thereof. The invention further provides a method for transporting the wind turbine tower.

BACKGROUND OF THE INVENTION

It is sometimes desirable to provide wind turbine towers with stay cables in order to provide sufficient stability to the wind turbine towers without having to provide the wind turbine tower with excessively thick walls. This is in particular relevant for high wind turbine towers.

The position along the tower where the stay cables are mounted should preferably have a large diameter, e.g. in order to provide sufficient strength to the wind turbine tower at this position and/or in order to allow sufficient space inside the tower for accommodating equipment for tightening the stay cables.

In some cases the easiest and/or most cost efficient way of transporting wind turbines over large distances is transport by rail. For rail transport, certain size constraints must be met in order to accommodate the wind turbine parts on the rail cars and in order to allow the rail cars to follow the curves of the rail tracks. The size constraints are stricter at the centre of a rail car than at the ends of the rail car, due to the ability of the rail car to follow the curves of the rail tracks.

US 2010/0132269 A1 discloses a rail-transportable wind turbine tower having a plurality of axial substantially tubular sections with an outer

diameter no greater than a designated maximum diameter. At least one of the sections includes at least one reverse taper portion located near a base of the tower.

EP 1 234 978 B1 discloses an off-shore wind power plant with a rotor disposed on a tower, with a base made from a single, hollow steel column. At least three stays are arranged beneath the rotor in a node being arranged between the tower and the column.

DESCRIPTION OF THE INVENTION

It is an object of embodiments of the invention to provide a cable stayed wind turbine tower with sufficient strength at a mounting position of the stay cables, the wind turbine tower being transportable by means of rail transport.

It is a further object of embodiments of the invention to provide a method for transporting a cable stayed wind turbine tower with a sufficient strength at a mounting position of the stay cables, by means of rail transport.

According to a first aspect the invention provides a wind turbine tower mounted on a foundation and arranged to carry at least one nacelle, wherein at least one stay cable is connected at one end to the tower, at a cable mounting position, and at the other end to a stay cable foundation, wherein the tower has a first tower diameter at the cable mounting position, and wherein the tower comprises a lower transition section and an upper transition section, the lower transition section forming part of the tower immediately below the cable mounting position and the upper transition section forming part of the tower immediately above the cable mounting position, and wherein the diameter of the lower transition

section increases along an upwards direction, and the diameter of the upper transition section decreases along an upwards direction.

Thus, according to the first aspect, the present invention provides a wind turbine tower, i.e. a tower being arranged to carry at least one nacelle of a wind turbine. The wind turbine tower is mounted on a foundation, which may be either an onshore foundation or an offshore foundation.

At least one stay cable is connected at one end to the tower, at a cable mounting position, and at the other end to a stay cable foundation. In the present context the term 'stay cable' should be interpreted to mean a cable which provides support for the tower, in particular with respect to bending moments on the tower. Thus, the wind turbine tower according to the first aspect of the invention is a so-called cable stayed tower.

The cable mounting position is a position along the tower, between the foundation and the nacelle, where the stay cables are connected to the tower. In order to allow the stay cables to provide the required support for the tower, the cable mounting position should be arranged at a certain distance from the foundation, and thereby from the ground. Furthermore, the cable mounting position may advantageously be arranged below the rotor of the wind turbine, i.e. below the lowest point that the tips of the wind turbine blades pass, in order to ensure that no collisions occur between the wind turbine blades and the stay cables.

The tower has a first tower diameter at the cable mounting position. The first tower diameter should be sufficiently large to provide a required strength to the tower at the cable mounting position, allowing the tower to handle the loads applied to the tower by pulling forces in the stay cables. Furthermore, the first tower diameter should be sufficiently large to accommodate tensioning equipment for tensioning the stay cables

inside the tower at the cable mounting position. It may therefore be desirable that the first tower diameter is larger than the diameter of the tower at other positions along the length of the tower.

The tower comprises a lower transition section and an upper transition section. Thus, the tower is of a kind comprising multiple tower sections, which are assembled to form the final tower.

The lower transition section forms part of the tower immediately below the cable mounting position and the upper transition section forms part of the tower immediately above the cable mounting position. Accordingly, the lower and upper transition sections are arranged in or immediately adjacent to a region of the tower where the cable mounting position is located.

The diameter of the lower transition section increases along an upwards direction, and the diameter of the upper transition section decreases along an upwards direction. Thus, tower diameter of the tower is smaller than the first tower diameter in a region immediately below the cable mounting position as well as in a region immediately above the cable mounting position. Thereby the cable mounting position defines at least a local maximum of the tower diameter.

Furthermore, the lower transition section as well as the upper transition section has a varying diameter, in such a manner that the largest diameter of the lower/upper transition section is at one end of the lower/upper transition section. This largest diameter is the first tower diameter. This allows each of the lower transition section and the upper transition section to be arranged on a rail car with the end having the largest diameter arranged at or near an end portion of the rail car, and

the end having a smaller diameter arranged at or near a centre portion of the rail car.

As described above, the size constraints on goods being transported via rail transport are stricter at the centre portion of the rail car than at the end portions of the rail car, in order to allow the rail car to follow the curves of the rail tracks. Accordingly, by arranging the lower transition section and the upper transition section on rail cars in the manner described above, the tower can be transported via rail transport, even though the first tower diameter exceeds the size constraints in the centre portion of the rail car. Accordingly, the wind turbine tower according to the first aspect of the invention provides a sufficient diameter of the tower at the cable mounting position, and it is possible to transport the wind turbine tower via rail transport.

The wind turbine tower may further comprise a cable mounting section arranged between the lower transition section and the upper transition section, the cable mounting section including the cable mounting position.

According to this embodiment, the stay cables are connected to a separate section of the tower, i.e. the cable mounting section, which is arranged between the lower transition section and the upper transition section.

The cable mounting section may be substantially cylindrical with a cylinder diameter being equal to the first tower diameter. Furthermore, the cable mounting section may have a height which is significantly smaller than the height of each of the lower transition section and the upper transition section. For example, it may have a height corresponding to the maximum allowable load width of a rail car. Such a small height of the cable mounting section allows it to be accommodated on a rail car

with its axial direction perpendicular to the longitudinal direction of the rail car. Accordingly, it will be possible to transport the cable mounting section via rail transport. The height of the cable mounting section could, e.g., be less than 4 meters, preferably less than 3.9 meters or less than 3.68 meters.

As an alternative, the cable mounting position may form part of the lower transition section or the upper transition section. According to this embodiment the lower transition section and the upper transition section are attached directly to each other, and the stay cables are connected to the tower via either the lower transition section or the upper transition section, rather than via a separate cable mounting section.

The first tower diameter may define a maximum tower diameter of the tower. According to this embodiment, none of the tower sections of the wind turbine tower has a diameter which exceeds the first tower diameter. Thereby all of the tower sections can be transported via rail transport.

At least three stay cables may be connected to the tower at the cable mounting position. The stay cables may advantageously be arranged substantially equidistantly along the circumference of the wind turbine tower. For instance, when three stay cables are connected to the tower, the stay cables may be arranged with a mutual angle of 120° there between. By providing the wind turbine tower with at least three stay cables it is ensured that the tower is supported with respect to loads, such as bending moments, on the tower in all directions.

The first tower diameter may be smaller than or equal to 4.0 m. Standard rail cars are able to accommodate goods with a diameter of up to approximately 4 m at their ends. Thus, when the first tower diameter is

smaller than or equal to 4.0 m it is ensured that the end of the lower/upper transition section having the largest diameter can be accommodated at or near an end portion of a standard rail car.

The lower transition section and/or the upper transition section may have a tapered shape, and the diameter of the transition section may vary between a maximum diameter at a first end, the maximum diameter being equal to the first tower diameter, and a minimum diameter at a second end arranged opposite to the first end.

According to this embodiment, the lower transition section and/or the upper transition section has a diameter which varies continuously along the entire height of the transition section. This makes the lower transition section and/or the upper transition section very suitable for being positioned on a rail car with the second end, i.e. the end with the minimum diameter, arranged at a centre region of the rail car, and the first end, i.e. the end with the maximum diameter, arranged at an end part of the rail car.

As an alternative, the lower transition section and/or the upper transition section may have a tapered shape along a part of its height, and a substantially cylindrical shape along the remaining part of its height. As another alternative, the diameter of the lower transition section and/or the upper transition section may vary in a stepwise manner.

The minimum diameter of the lower transition section and/or the upper transition section may be smaller than or equal to 3.68 m. Standard rail cars are able to accommodate goods with a diameter of up to approximately 3.68 m at their centre portions. Thus, when the minimum diameter of the transition section is smaller than or equal to 3.68 m it is ensured that the end of the lower/upper transition section having the

smallest diameter can be accommodated at the centre portion of a standard rail car.

According to a second aspect the invention provides a method for transporting a wind turbine tower according to the first aspect of the invention, the method comprising the steps of:

- arranging a first transition section on a rail car with the end having the smallest diameter arranged at a centre portion of the rail car and the end having the largest diameter arranged at or near an end portion of the rail car, and

- transporting the transition section by means of the rail car.

It should be noted that a person skilled in the art would readily recognise that any feature disclosed in combination with the first aspect of the invention could also be combined with the second aspect of the invention, and vice versa. The remarks set forth above are therefore equally applicable here.

Thus, in the method according to the second aspect of the invention, a first transition section, which could be a lower transition section or an upper transition section, is positioned on a rail car. This is done in such manner that the end of the transition section having the smallest diameter is arranged at a centre portion of the rail car, where the strictest size constraints apply, and the end having the largest diameter is arranged at or near an end portion of the rail car, where the size constraints are less strict.

The transition portion is then transported by means of the rail car.

Thus, as described above with reference to the first aspect of the invention, it is possible to transport the transition section via rail transport, even though the largest diameter of the transition section exceeds the size constraints applying in the centre portion of the rail car. And accordingly the resulting wind turbine tower can be provided with a tower diameter at a cable mounting position which exceeds the size constraints applying in the centre portion of the rail car.

The method may further comprise the step of arranging a second transition section on the rail car with the end having the smallest diameter arranged at the centre portion of the rail car and the end having the largest diameter arranged at or near an end portion of the rail car opposite to the end where the largest diameter of the first transition section is arranged.

According to this embodiment, two transition sections are arranged on the same rail car. This could, e.g., be a lower transition section and an upper transition section, e.g. for the same tower. Alternatively, it could be two lower transition sections or two upper transition sections for two respective towers to be erected at a site which is supposed to accommodate two or more wind turbines.

The transition sections are arranged with the ends having the smallest diameter arranged at the centre portion of the rail car, e.g. with the ends facing each other, and with the ends having the largest diameter arranged at respective opposite end portions of the rail car. Accordingly, two transition section can be arranged on one rail car, while meeting the stricter size constraints applying at the centre portion of the rail car.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in further detail with reference to the accompanying drawings in which

Figs. 1-3 are side views of wind turbine towers according to three embodiments of the invention, and

Figs. 4 and 5 illustrate two transition sections of a wind turbine tower according to an embodiment of the invention arranged on a rail car.

DETAILED DESCRIPTION OF THE DRAWINGS

Fig. 1 is a side view of a wind turbine tower 1 according to a first embodiment of the invention. The wind turbine tower 1 comprises seven tower sections assembled to form the tower 1, including a lower transition section 2, an upper transition section 3 and a cable mounting section 4. The cable mounting section 4 is arranged between the lower transition section 2 and the upper transition section 3.

The lower transition section 2 has a tapered shape. Thereby the diameter of the lower transition section 2 increases along an upwards direction from a minimum diameter at its lower end 5 to a maximum diameter at its upper end 6, where it is attached to the cable mounting section 4.

The upper transition section 3 also has a tapered shape. Thereby the diameter of the upper transition section 3 decreases along an upwards direction from a maximum diameter at its lower end 7, where it is attached to the cable mounting section 4, to a minimum diameter at its upper end 8.

The cable mounting section 4 has a substantially cylindrical shape with a diameter being equal to the maximum diameter of the lower transition section 2 and to the maximum diameter of the upper transition section 3. This diameter also defines a maximum diameter of the wind turbine tower 1.

A number of stay cables 9, two of which are shown, are connected at one end to the tower 1 at a cable mounting position on the cable mounting section 4, and at the other end to respective stay cable foundations (not shown). The stay cables 9 provide support for the tower 1 in a manner which is known per se.

Since the stay cables 9 are connected to the tower 1 via the cable mounting section 4, they are connected to the tower 1 at a position of the tower 1 having the maximum diameter of the tower 1. This large diameter ensures that the tower 1 has sufficient strength to handle the loads introduced by pulling forces from the stay cables 9. Furthermore, it is ensured that sufficient space is available inside the tower 1 for accommodating tightening equipment required for tightening the stay cables 9.

The tower 1 is suitable for being transported by means of rail transport because the lower transition section 2 and the upper transition section 3 only have their maximum diameter at one end 6, 7. Accordingly, this end 6, 7 can be arranged at or near an end portion of a rail car, where the size constraints are less strict than at the centre portion or the rail car. The end 5, 8 with the minimum diameter can be arranged at the centre portion of the rail car, and thereby the stricter size constraints can also be met.

Since the cable mounting section 4 has a small height, it can be accommodated entirely at or near an end portion of a rail car.

Fig. 2 is a side view of a wind turbine tower 1 according to a second embodiment of the invention. The wind turbine tower 1 of Fig. 2 is very similar to the wind turbine tower 1 of Fig. 1, and it will therefore not be described in detail here.

However, in the wind turbine tower 1 of Fig. 2, the lower transition section 2 has a tapered part arranged immediately below the cable mounting section 4 and a cylindrical part arranged between its lower end 5 and the tapered part. The remarks set forth above with reference to Fig. 1 also apply to the embodiment of Fig. 2.

Fig. 3 is a side view of a wind turbine tower 1 according to a third embodiment of the invention. The wind turbine tower 1 of Fig. 3 is very similar to the wind turbine tower 1 of Fig. 1, and it will therefore not be described in detail here.

However, the wind turbine tower 1 of Fig. 3 does not comprise a cable mounting section. Instead the lower transition section 2 and the upper transition section 3 are attached directly to each other. Accordingly, the ends 6, 7 with the maximum diameter of the lower transition section 2 and the upper transition section 3, respectively, form a direct interface between the lower transition section 2 and the upper transition section 3. This interface further defines the maximum diameter of the wind turbine tower 1.

The stay cables 9 are connected to the lower transition section 2 at a cable mounting position near the upper end 6 of the lower transition section 2. Thus, the stay cables 9 are connected to the wind turbine tower

1 at a position with a large diameter. Accordingly, the remarks set forth above with reference to Fig. 1 also apply to the embodiment of Fig. 3.

Figs. 4 and 5 illustrate two transition sections 2, 3 of a wind turbine tower according to an embodiment of the invention arranged on a rail car 10. The transition sections 2, 3 could, e.g., be the lower transition section 2 and the upper transition section 3, respectively, of the wind turbine tower of Fig. 1 or the wind turbine tower of Fig. 3.

Fig. 4 is a side view of the rail car 10 and the transition sections 2, 3, and Fig. 5 is a top view of the rail car 10 and the transition sections 2, 3.

It can be seen that the transition sections 2, 3 are arranged on the rail car 10 with the ends 5, 8 having the minimum diameter arranged at a centre portion 11 of the rail car 10, and with the ends 6, 7 having the maximum diameter arranged at opposite end portions 12, 13 of the rail car 10.

In Fig. 5, dashed lines 14 illustrate the size constraints in the centre portion 11 of the rail car 10. It can be seen that the size constraints 14 at the centre portion 11 of the rail car 10 are stricter than at the end portions 12, 13 of the rail car 10. It can also be seen that the ends 6, 7 of the transition sections 2, 3 having the largest diameter would not be able to be accommodated at the centre portion 11 of the rail car 10. However, the ends 5, 8 of the transition sections 2, 3 can be accommodated at the centre portion 11 of the rail car 10. Furthermore, the ends 6, 7 of the transition sections 2, 3 having the largest diameter fulfil the size constraints at the end portions 12, 13 of the rail car 1. Accordingly, the transition sections 2, 3 can be transported by means of the rail car 10 when positioned as illustrated in Figs. 4 and 5

CLAIMS

1. A wind turbine tower (1) mounted on a foundation and arranged to carry at least one nacelle, wherein at least one stay cable (9) is connected at one end to the tower (1), at a cable mounting position, and at the other end to a stay cable foundation, wherein the tower (1) has a first tower diameter at the cable mounting position, and wherein the tower (1) comprises a lower transition section (2) and an upper transition section (3), the lower transition section (2) forming part of the tower (1) immediately below the cable mounting position and the upper transition section (3) forming part of the tower (1) immediately above the cable mounting position, and wherein the diameter of the lower transition section (2) increases along an upwards direction, and the diameter of the upper transition section (3) decreases along an upwards direction.

2. A wind turbine tower (1) according to claim 1, wherein the wind turbine tower (1) further comprises a cable mounting section (4) arranged between the lower transition section (2) and the upper transition section (3), the cable mounting section (4) including the cable mounting position.

3. A wind turbine tower (1) according to claim 2, wherein the cable mounting section (4) is substantially cylindrical with a cylinder diameter being equal to the first tower diameter.

4. A wind turbine tower (1) according to claim 1, wherein the cable mounting position forms part of the lower transition section (2) or the upper transition section (3).

5. A wind turbine tower (1) according to any of the preceding claims, wherein the first tower diameter defines a maximum tower diameter of the tower (1).

6. A wind turbine tower (1) according to any of the preceding claims, wherein at least three stay cables (9) are connected to the tower (1) at the cable mounting position.

7. A wind turbine tower (1) according to any of the preceding claims, wherein the first tower diameter is smaller than or equal to 4.0 m.

8. A wind turbine tower (1) according to any of the preceding claims, wherein the lower transition section (2) and/or the upper transition section (3) has a tapered shape, wherein the diameter of the transition section (2, 3) varies between a maximum diameter at a first end (6, 7), the maximum diameter being equal to the first tower diameter, and a minimum diameter at a second end (5, 8) arranged opposite to the first end (6, 7).

9. A wind turbine tower (1) according to claim 8, wherein the minimum diameter of the lower transition section (2) and/or the upper transition section (3) is smaller than or equal to 3.68 m.

10. A method for transporting a wind turbine tower (1) according to any of the preceding claims, the method comprising the steps of:

- arranging a first transition section (2, 3) on a rail car (10) with the end (5, 8) having the smallest diameter arranged at a centre portion (11) of the rail car (10) and the end (6, 7) having the largest diameter arranged at or near an end portion (12, 13) of the rail car (10), and

- transporting the transition section (2, 3) by means of the rail car (10).

11. A method according to claim 10, further comprising the step of arranging a second transition section (2, 3) on the rail car (10) with the end (5, 8) having the smallest diameter arranged at the centre portion (11) of the rail car (10) and the end (6, 7) having the largest diameter arranged at or near an end portion (12, 13) of the rail car (10) opposite to the end (12, 13) where the largest diameter of the first transition section (2, 3) is arranged.

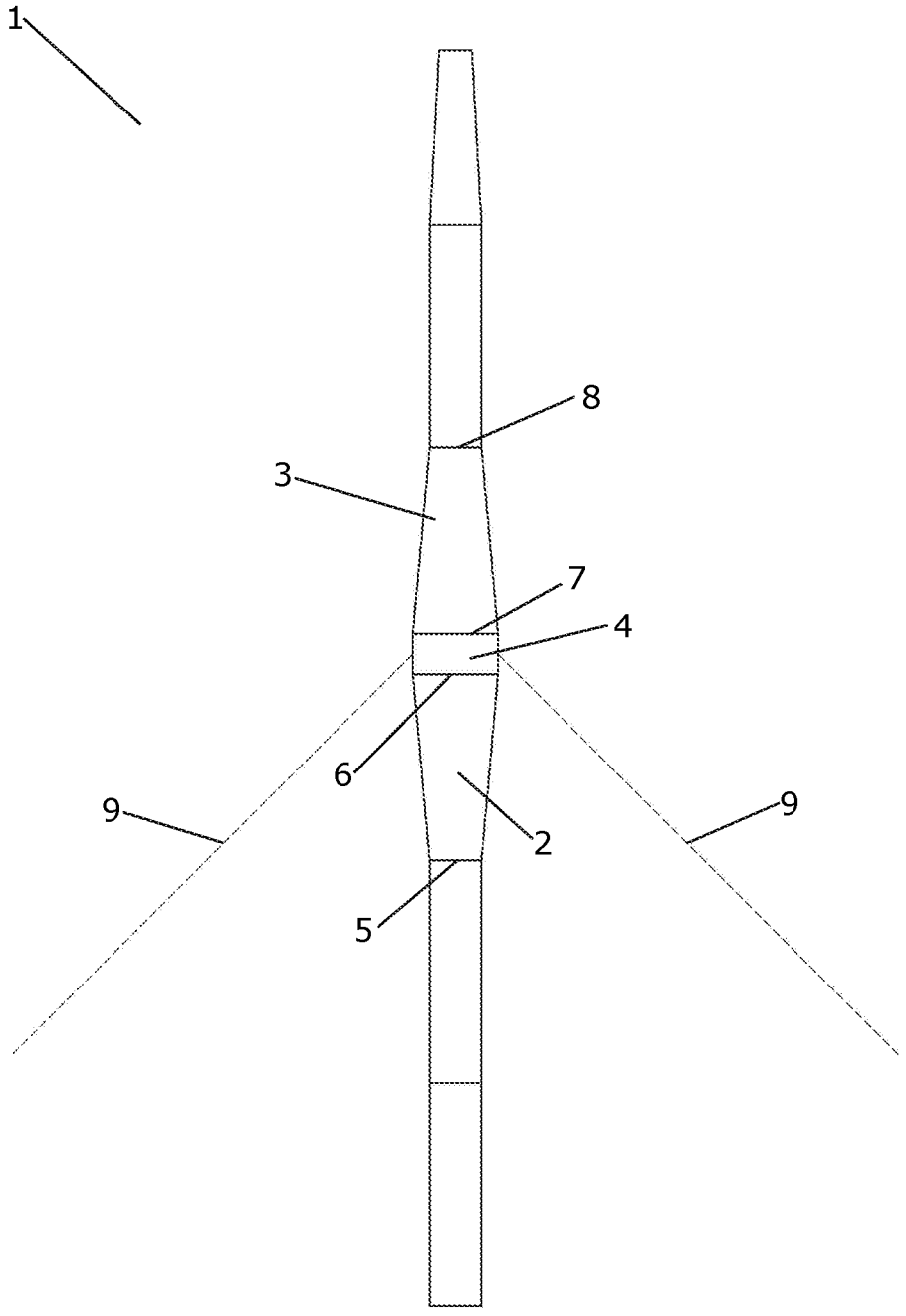


Fig. 1

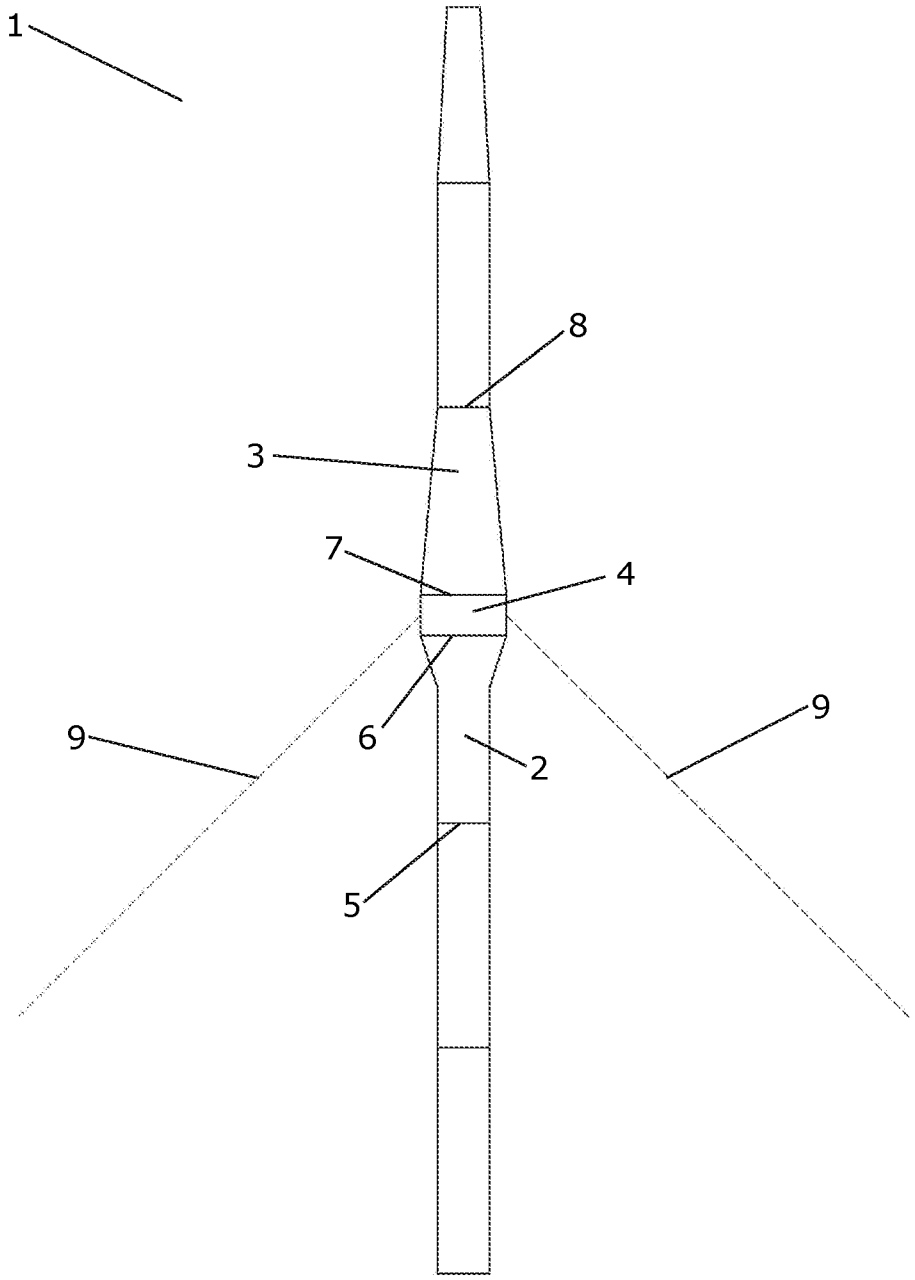


Fig. 2

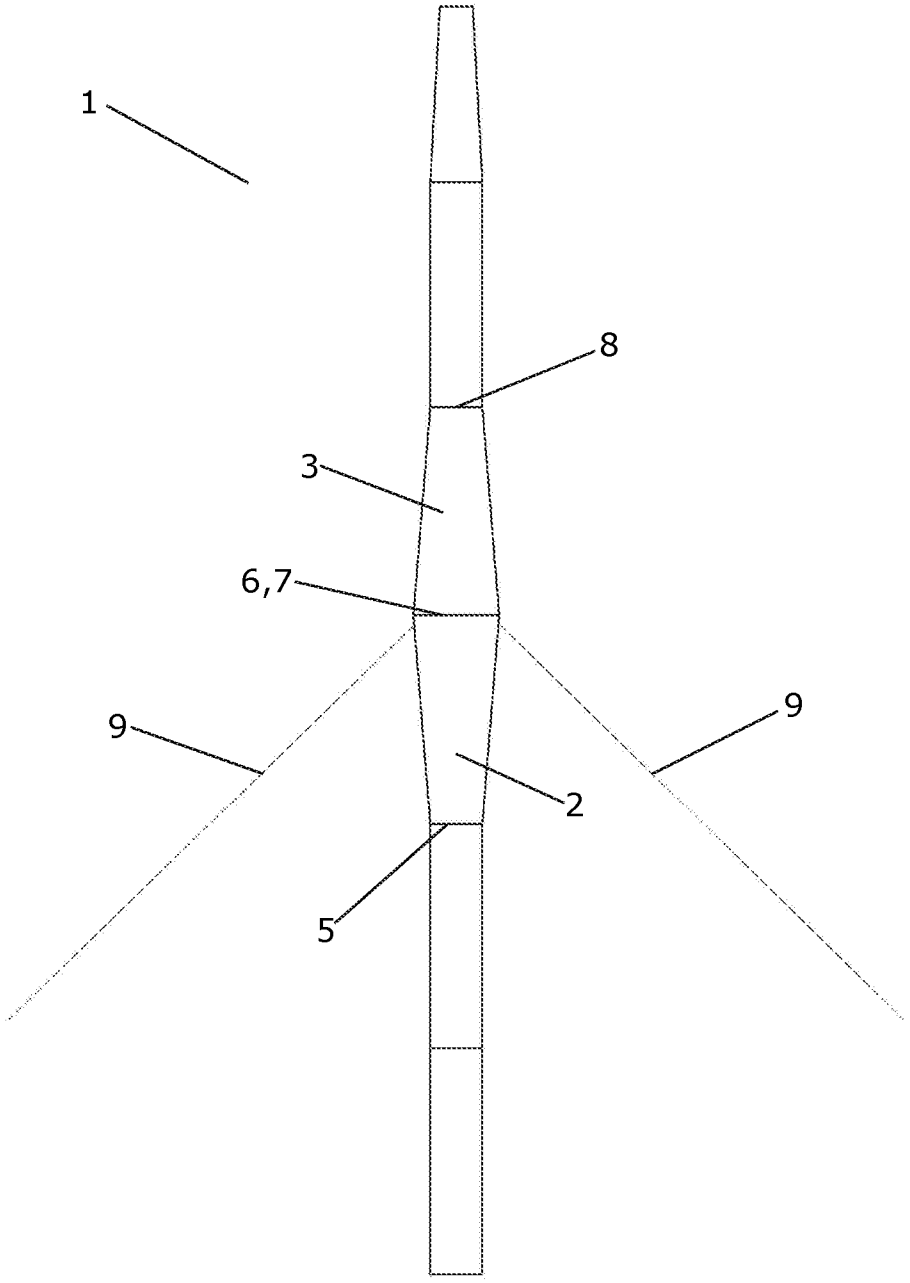


Fig. 3

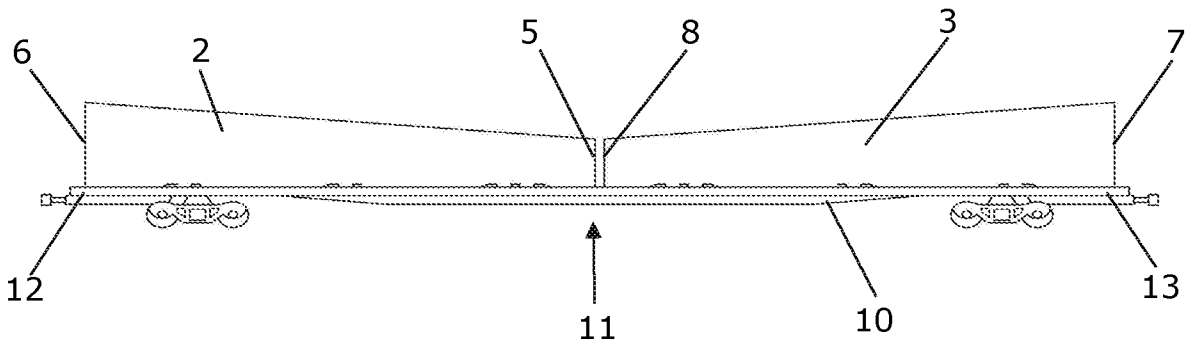


Fig. 4

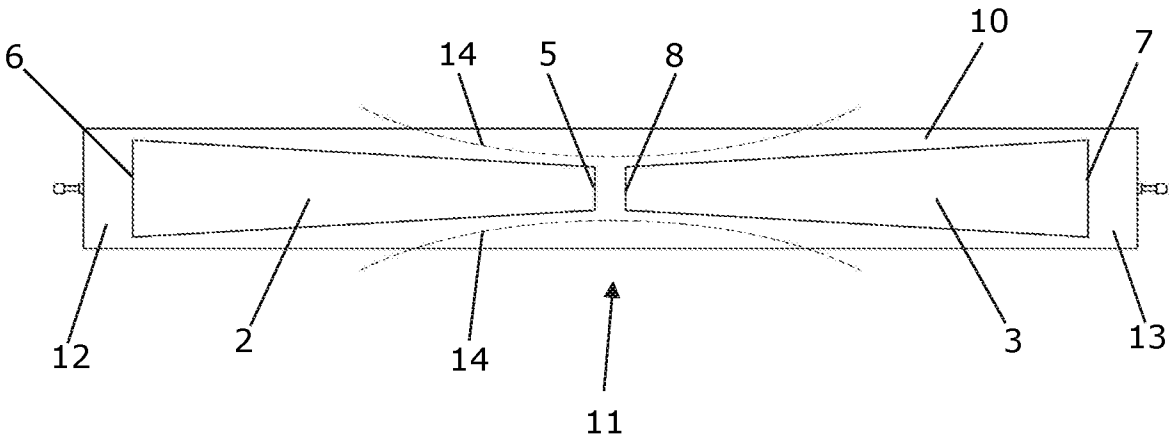


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2018/050313

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D13/20 F03D13/40
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.
X	EP 1 234 978 A2 (BRIESE REMMER DIPL-ING [DE]) 28 August 2002 (2002-08-28) paragraphs [0034], [0035]; figures 1-5	1-9
X	EP 1 150 010 A1 (SOUDEE EN ABREGE CS CONST [BE]) 31 October 2001 (2001-10-31) paragraph [0028]; figures 3,4,6,9,10	1-9
X	US 2005/002749 A1 (ANDERSEN KARSTEN [US] ET AL) 6 January 2005 (2005-01-06) figure 3	10,11
X	US 2011/058956 A1 (ZUTECK MICHAEL D [US]) 10 March 2011 (2011-03-10) figures 4-7	1

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

[X] See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
18 February 2019	25/02/2019

Name and mailing address of the ISA/	Authorized officer
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Form PCT/ISA/210 (second sheet) (April 2005)

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2018/050313

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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