(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
22 June 2017 (22.06.2017)

(10) International Publication Number
WO 2017/102925 Al

(51) International Patent Classification:
F03D 13/10 (2016.01) *E04H 12/16* (2006.01)
E04H 12/12 (2006.01) *F03D 13/20* (2016.01)

(21) International Application Number:
PCT/EP20 16/08 1148

(22) International Filing Date:
15 December 2016 (15. 12.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1562706 17 December 201 5 (17. 12.2015) FR

(71) Applicant: **LAFARGE** [FR/FR]; 61, rue des Belles Feuilles, 75 116 Paris (FR).

(72) Inventors: **DOBRUSKY, Svatopluk;** 6 place Bir Hakeim, 69003 Lyon (FR). **RIVOAL, Jean-Nicolas;** 91 rue Jaboulay, 69007 Lyon (FR). **ZHANG, Qing;** 6 rue Danton, 69003 Lyon (FR).

(74) Agent: **REGIMBEAU;** 139 rue Vendome, 69477 Lyon Cedex 06 (FR).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available):* AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available):* ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK,

[Continued on nextpage]

(54) Title: METHOD FOR CONSTRUCTING A MAST OF CONCRETE INTENDED FOR A WINDMILL

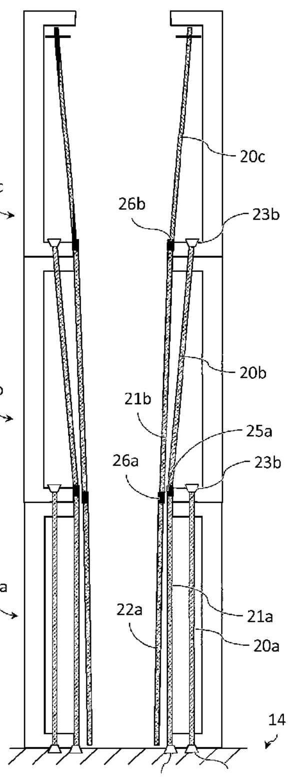

FIG. 7c

(57) Abstract: The invention relates to a method for constructing a mast of concrete intended for a windmill, said mast comprising at least an upper section (10b, 10c) and a lower section (10a, 10b) each comprising: a first portion intended to exert a bearing force on a lower adjacent part of the windmill, and a second portion intended to form a bearing support for another upper adjacent part of the windmill, the method comprising the following step: stacking an upper section (10b, 10c) on the top of a lower section (10a, 10b), the first portion of the upper section facing the second portion of the lower section; anchoring a first post-tensioning element (20) pre-installed in the lower section to the first portion of the upper section, and coupling a second post-tensioning element (21, 22) pre-installed in the lower section to a post-tensioning element (20, 21) pre-installed in the upper section.

WO 2017/102925 A1

SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

METHOD FOR CONSTRUCTING A MAST OF CONCRETE INTENDED FOR A WINDMILL

CONTEXT AND BACKGROUND OF THE INVENTION

The present invention relates to the technical field of superstructures.

More particularly, the subject of the present invention is a section of concrete intended to form a mast, notably for a windmill, a method for manufacturing the section of concrete, a mast of concrete comprising a set of sections comprising one or more of this section and a method to construct such a mast.

As the technology for producing electricity from wind energy has developed, it has been noted that there is a link between the power which can be delivered by the windmill and the dimensions of the windmill.

It is thus accepted that, in order to construct windmills capable of delivering high production powers, it is necessary to increase the length of the blades and therefore the height of the mast.

However, when increasing the height of a mast it is necessary to take into account a set of criteria which are connected on the one hand to the desired technical performance of the mast, and on the other hand to the logistics of constructing the mast.

The technical performance criteria can comprise the load that has to be supported by the mast, and hence the compression resistance of the used materials, but also the tensile resistance of these materials.

Indeed, the tensile resistance is important as the loadings on the mast can cause significant tensile stresses.

The criteria linked to the logistics to be applied during the construction of the mast can, for their part, comprise the transportation of the various elements forming the mast from the production site where these elements are produced to the installation site, but also the conditions of assembling these elements on the installation site.

Together, these criteria have led to the production of masts made of concrete, to the detriment of steel, notably in order to facilitate transportation to the installation site and to reach higher heights.

Moreover, concrete masts have an additional advantage compared to steel. Unlike steel welds, concrete joints present a good resistance to fatigue loading, which increases the durability of the mast and makes it a material of choice for the construction of masts of great height.

As illustrated on figure 1, a mast 1, notably for a windmill 2, comprises a plurality of sections 10 of concrete stacked one on top of the other. French Patent application No. 146171 3 describes such sections.

As illustrated in Figure 2, a section 10 can be of a single piece or else, as illustrated in Figure 3, a section 10 can comprise a plurality of segments 3. Then, such a section is a modular section 10.

In the example shown in Figure 3, the modular section 10 comprises four segments 3a, 3b, 3c, and 3d. These segments 3 can be assembled together by using means known to those skilled in the art, for example with vertical joints like those described in the document WO 201 3/029743 A1.

The use of segments greatly facilitates the transportation of the elements of the mast to the site, since the segments can be stacked horizontally one on top of the other on a truck then assembled into sections at the installation site.

Furthermore, the use of segments also makes it possible to significantly increase the diameter of the sections and therefore the height of the mast.

The use of concrete to form the segments allows, for its part, to increase the thickness of the sections and therefore also the height of the mast. However, assembling the segments to build the sections on the installation site require a lot of time.

As shown in Figures 2 and 3, a concrete section 10 presents an outer face E and an inner face I opposite the outer face E and arranged facing the internal volume V of section 10. In the examples presented, section 10 is in the form of a hollow cylinder.

Section 10 extends in a longitudinal direction X and comprises:

- a first portion 11, intended to exert a bearing force on a lower adjacent part of the windmill 2, said first portion 11 comprising a first flange 11' extending substantially transversely from an internal face I of section 10 opposite the internal volume V of section 10, and

- a second portion 12 intended to form a bearing support for another upper adjacent part of the windmill 2, said second portion 12 comprising a second flange 12' extending substantially transversely from the internal face I of section 10 opposite the internal volume V of section 10.

The considered parts of the windmill 2 can be a lower adjacent section 10a of mast 1, an upper adjacent section 10b of mast 1, but also a nacelle, a transition piece of windmill 2 or the foundation structure of mast 1.

It is known practice to use post-tensioning elements to increase the tensile resistance of the concrete elements forming the mast. However, the construction of the mast, which includes the application of stress by the post-tensioning elements on the installation site, can be lengthy and tedious and can be slowed down or stopped because of bad weather conditions.

Furthermore, the stress exerted on the concrete can vary over time because of the phenomenon of creep of concrete and of relaxation of the post-tensioning elements. In some cases, it is no longer possible, once the mast is erected, to control the post-tensioning elements which could inform about the effect of the phenomenon of creep of concrete and of relaxation of the post-tensioning elements.

That can considerably increase the industrial risk of failure and can even make the installation of such masts made of concrete prohibitive.

It therefore appears necessary to retain the possibility of controlling, and even more the possibility of readjusting if needed, the stress exerted on the concrete elements during the service life of the mast.

Some solutions have been proposed for applying stress to the concrete elements on the production site in such a way as to improve the tensile resistance. For instance, French patent application FR3029231 proposes in an embodiment a section as described above, wherein post-tensioning elements are arranged to apply a stress between the first portion 11 and the second portion 12 of a section 10.

As shown in the example of Figure 4, three sections 10a, 10b, and 10c are stacked one on the top of the other. The bars 13a facing the first section 10a are anchored to the foundation 14 and to the first portion 11b of the second section 10b, which is the upper adjacent section for the first section 10a. The bars 13b facing the second section 10b are anchored to the second portion 12a of the first section 10a, which is the lower adjacent section for the second section 10b, and are anchored to the first portion 11c of the upper section 10c, which is the upper adjacent section for the second section 10b.

More precisely, as shown in Figure 5, which illustrates the interface of the first section 10a and of the second section 10b, the bars 13a pre-installed in the first section 10a pass through holes in the second flange 12'a of said first section 10a and though holes in the first flange 11'b of the second section 10b. These bars 13a are anchored to the second section 10b by anchoring devices 15a such as nuts screwed on threaded parts of the bars 13a. The bars 13b pre-installed in the second section 10b are anchored to the second flange 12'a of the first section 10a in a similar way.

Post-tensioning operations are performed on each bar 13. It is therefore needed to mobilize devices for post-tensioning at different levels of the mast during the construction, i.e. for each section 10 except the upper one. Since iterative post-tensioning operations may be done to compensate for stress loss due to the deformation introduced by post-tensioning new bars, such operations can be burdensome.

In addition, many anchoring points are required on each section 10. As a result, the section 10 must be designed to be able to accommodate a large number of anchoring points. Reinforcement portions may be needed, whereas the many holes in the flanges weaken the sections.

In conventional methods, bars or other post-tensioning elements such as cables must be installed on the sections after they have been stacked on the top of the other. This is a lengthy and burdensome task, especially for the higher sections. For example, patent application WO2010/098716 discloses prefabricated concrete wall elements for a tower construction stacked on each other and connected by means of bar elements. The bar elements may be connectable by threads and nuts. The bar elements are anchored at the top and bottom of the tower construction by means of anchorage.

In some methods, post-tensioning elements may be much longer than a section, because they are anchored to the foundation and to a higher section of the mast. The longer the post-tensioning elements, the more difficult it is to bring them up and to install them on site. For example, patent application US2015/0052841 discloses post-tensioning strands which are anchored to the foundation of the tower and are capped off at different levels of the tower, which result in lengthy post-tensioning strands.

SUMMARY OF THE INVENTION

The present invention aims at resolving all or some of these drawbacks mentioned above. In particular, the invention proposes a method for constructing a mast of concrete intended for a windmill which allows easier post-tensioning operations while simplifying the design of the sections and the construction process.

To this end, it is proposed a method for constructing a mast of concrete intended for a windmill, said mast comprising at least an upper section of concrete and a lower section of concrete, each section comprising:

- a first portion intended to exert a bearing force on a lower adjacent part of the windmill, and

- a second portion intended to form a bearing support for another upper adjacent part of the windmill,

the method comprising the following step:

- stacking an upper section on the top of a lower section, the first portion of the upper section extending the second portion of the lower section;

- anchoring a first post-tensioning element pre-installed in the lower section to the first portion of the upper section, and

- coupling a second post-tensioning element pre-installed in the lower section to a post-tensioning element pre-installed in the upper section,

wherein before stacking the sections, the first post-tensioning element and the second post-tensioning element are pre-installed to the lower section by an attaching device, the method comprising the step of, after the stacking of the sections, releasing the first post-tensioning element and the second post-tensioning element from the lower portion before anchoring the first post-tensioning element and coupling the second post-tensioning element, respectively.

Other preferred, although non limitative, aspects of the method are as follows, isolated or in a technically feasible combination:

- an upper end of the post-tensioning element pre-installed in the upper section is attached to said upper section by an attaching device while coupling a lower end of said post-tensioning element pre-installed in the upper section to the second post-tensioning element pre-installed in the lower section;

- post-tensioning elements coupled together form an inter-section post-tensioning element, and each post-tensioning element is either anchored to the foundation or is part of an inter-section element intended to be anchored to the foundation, said inter-section post-tensioning element comprising at least one post-tensioning element pre-installed in one section coupled to another post-tensioning element pre-installed in another section.

- the concrete is an ultra-high performance concrete or an ultra-high performance concrete reinforced with fibres and/or with ordinary reinforcement;

- for each section of concrete:

- the first portion comprises a first flange extending substantially transversely from an internal face of the section opposite the internal volume of the section,

- the second portion comprises a second flange extending substantially transversely from the internal face of the section opposite the internal volume of the section,

and the first post-tensioning element pre-installed in the lower section is anchored to the first flange of the first portion of the upper section.

In another aspect, the invention relates to a section of concrete adapted to be used in the method for constructing a mast of concrete, said section having an internal volume and comprising;

- a first portion intended to exert a bearing force on a lower adjacent part of the windmill, and

- a second portion intended to form a bearing support for another upper adjacent part of the windmill,

wherein the section comprises:

- a pre-installed first post-tensioning element attached to the section in the internal volume of said section and configured to be anchored in the first portion of an upper section of the mast, and

- a pre-installed second post-tensioning element attached to the section in the internal volume of said section and configured to be coupled to a post-tensioning element pre-installed in an upper section of the mast,

wherein the first post-tensioning element and the second post-tensioning element are pre-installed to the lower section by an attaching device adapted to release the first post-tensioning element and the second post-tensioning element from the lower portion before anchoring the first post-tensioning element and coupling the second post-tensioning element, respectively.

In another aspect, the invention relates to a mast of concrete intended for a windmill, said mast comprising at least an upper section of concrete and a lower section, said upper section being stacked on the top of the lower section, the first portion of the upper section extending the second portion of the lower section, each section comprising

- a first portion exerting a bearing force on a lower adjacent part of the windmill, and

- a second portion forming a bearing support for another upper adjacent part of the windmill,

wherein

- a first post-tensioning element pre-installed in the lower section by an attaching device is anchored to the first portion of the upper section after release from the attaching device, and

- a second post-tensioning element pre-installed in the lower section by an attaching device is coupled to a post-tensioning element pre-installed in the upper section after release from the attaching device.

Preferably, post-tensioning elements coupled together form an inter-section element, and each post-tensioning element is either anchored to the foundation or is part of an inter-section post-tensioning element anchored to the foundation, said inter-section post-tensioning element comprising at least one post-tensioning element facing one section coupled to another post-tensioning element facing another section.

BRIEF DESCRIPTION OF THE DRAWINGS

Other aspects, objects and advantages of the present invention will become better apparent upon reading the following detailed description of preferred embodiments thereof, given as non-limiting examples, and made with reference to the appended drawings wherein:

- Figure 1, already discussed, shows an overview of a mast in situ for a windmill, and an exploded projection of the same mast into several sections;

- Figure 2, already discussed, shows an overview of a section of the mast illustrated in Figure 1;

- Figure 3, already discussed, shows an overview of a variant of the section illustrated in Figure 2;

- Figure 4, already discussed, shows an overview of an example of a mast of three concrete sections according to the state of the art;

- Figure 5, already discussed, shows a detail of the junction between two concrete sections of the example of figure 4;

- Figure 6 shows a junction between two concrete sections according to a possible embodiment of the invention;

- Figures 7a-7c show steps of a method for constructing a mast of concrete intended for a windmill according to a possible embodiment of the invention.

DETAILED DESCRIPTION

In reference to figures 6 and 7a-7c, the following description provides an example of a method for constructing a mast 1 of concrete intended for a windmill 2 as in Figure 1 with sections 10 as in Figures 2 and 3.

As explained above, a concrete section 10 presents an outer face E and an inner face I opposite the outer face E and arranged facing the internal volume V of section 10. In the examples presented, section 10 is in the form of a hollow cylinder.

Section 10 extends in a longitudinal direction X and comprises:

- a first portion 11, intended to exert a bearing force on a lower adjacent part of the windmill 2, said first portion 11 comprising a first flange 11' extending substantially transversely from an internal face I of the section 10 opposite the internal volume V of the section 1,

- a second portion 12 intended to form a bearing support for another upper adjacent part of the windmill 2, said second portion 12 comprising a second flange 12' extending substantially transversely from the internal face I of the section 10 opposite the internal volume V of section 10.

The considered parts of the windmill 2 can be a lower adjacent section 10a of the mast 1, an upper adjacent section 10b of the mast 1, but also a nacelle, a transition piece of the windmill 2 or the foundation structure of the mast 1.

Advantageously, the section is made of ultra-high performance concrete or of ultra-high performance concrete reinforced by fibres, for example with compressive strength of at least 120 MPa, preferentially of at least 150 MPa at 28 days and/or with tensile strength at 28 days of at least 5 MPa, preferentially of at least 7 MPa, even more preferentially 9 MPa and/or with a Young's modulus of at least 45 GPa, preferentially of at least 50 GPa and more preferentially of at least 55 GPa.

Of course some ordinary reinforcementdevices, as steel grids, can be used.

This concrete can, for example, be of the type of that marketed by the company Lafarge under the trademark Ductal®.

The use of this type of concrete makes it possible to produce a lighter mast 1 than with a traditional concrete while retaining a reduced section diameter that notably allows for the transportation of sections presenting a length from 10 m, preferentially 20 m, even more preferentially 25 m as one entire section from the production site to the installation site.

In particular, a section 10 made of one entire concrete section, which can be made of one-piece concrete section 10 if it is not formed from a plurality of segments 3, can have an outer diameter that can range up to the local transportability limits on roads, for example up to 4.2 m or 4.4 m. .

As the prior art section as illustrated on Figure 2, the section 10 extends in a longitudinal direction and preferably comprises:

- a first flange 11' extending substantially transversely from an inner face I of section 10 in the internal volume V of section 10, said first flange intended to exert a bearing force on a lower adjacent part of the windmill 2 in the longitudinal direction; and

- a second flange 12' extending substantially transversely from the inner face I of section 10 in the internal volume V of section 10, said second flange intended to form a bearing support for another upper adjacent part of the windmill 2 in the longitudinal direction.

The sections 10 are built on a production site and are brought to the construction site where the mast 1 is to be erected. As shown by figure 7a, after a first section 10a is erected on a foundation, a second section 10b is stacked above the first section 10a, which becomes the lower section.

In a section 10 are pre-installed post-tensioning elements 20, 21, and 22. The post-tensioning elements 20, 21, and 22 are typically cables, and in the following description, cables are used in a non-limiting way as examples of post-tensioning elements.

More precisely, at least two types of post-tensioning cables 20, 21, and 22 are pre-installed in a section 10:

- first post-tensioning cables 20 that are intended to be anchored to the first portion of the upper adjacent section with respect said section 10, and

- second post-tensioning cables 21, 22 that are intended to be coupled to other cables pre-installed in upper sections.

For example, in first section 10a are pre-installed:

- first post-tensioning cables 20a that are intended to be anchored to the first portion of the second section 10b, which is the upper adjacent section with respect to the first section 10a, and

- second post-tensioning cables 21a and 22a that are intended to be coupled to other cables pre-installed in upper sections.

Post-tensioning cables 20, 21, and 22 of both types are distributed over the circumference of a section 10, and their number depends of the post-tensioning to be performed.

Post-tensioning cables 20a, 21a, and 22a pre-installed in the first section 10a of the both types are intended to be anchored by their lower ends to the foundation 14 on which the first section 10 a is erected.

As shown in figure 7b, the upper ends of the first post-tensioning cables 20 are then anchored to the first section 11b of the second section 10b at anchorages 23. More precisely, they are anchored to the first flange 11'b of the second section 10b by means of an anchoring device 15a. The lower ends of the first post-tensioning cables 20 are then anchored to the foundation 14 on which is erected the first section 10a by anchorages 24a.

As for the first section 10a, two types of cables are pre-installed in the second section 10b:

- first post-tensioning cables 20b that are intended to be anchored to the first portion of an upper adjacent section by their upper ends, and

- second post-tensioning cables 21b that are intended to be coupled to other cables pre-installed in upper sections by their upper ends.

Post-tensioning cables 20b and 21b pre-installed in the second section 10b of the both types are intended to be coupled by their lower ends to post-tensioning cables 21 and 22 pre-installed in the lower sections, i.e. pre-installed in the first section 10a.

After stacking the second section 10b on the top of the first section 10a the first portion 11 of the first section 10a extending the second portion 12 of the second section 10b, the first post-tensioning element 20a pre-installed in the first section 10a are anchored to the first portion of the second section 10b, more precisely to the first flange 11' by an anchorage 23a. The second post-tensioning elements 21a, 22a pre-installed in the first section 10a are coupled to the post-tensioning element 20b, 21b pre-installed in the second section 10b, by couplers 25a, 26a.

The coupled post-tensioning cables 21a, 22a, 20b, and 21b passes in the internal volume V of the concrete section 10. They do not need to enter hole in flanges 11 and

12, and the couplers 25a, 26a between cables can stay outside of the concrete section 10. This reduces the occupation of holes on the flanges. As the number of holes on the flanges 11 and 12 is limited, the stresses taken by each hole can be reduced for a total given amount of stress to be applied, which is beneficial of a lower risk of cracking.

In the depicted examples, before stacking of the sections, the post-tensioning cables 20, 21, and 22 pre-installed in a section 10 are pre-installed to said section 10 by releasable attaching devices, preferably arranged on the inner face I of section 10. The post-tensioning cables 20, 21, and 22 are thus temporarily fixed to the section 10. Tower internals such as a platform of a ladder, fixed to a section 10, may also serve as attaching devices, by attaching the post-tensioning cables 20, 21, and 22 to said tower internals.

In the depicted example, the post-tensioning cables 20, 21, 22 are pre-installed to their respective sections 10 so that their lower ends are free. This allows anchoring or coupling said lower ends of the post-tensioning cables 20, 21, 22. It should be noted however that the lower ends of post-tensioning cables 20, 21, 22 pre-installed in a section 10 may be attached to said section 10, especially during transportation from the production site, before being released for the purpose of anchoring or coupling them with post-tensioning cables 20, 21 pre-installed in the lower adjacent section 10.

Similarly, the post-tensioning cables 20, 21, 22 are depicted attached by their upper ends to the inner face I of each section 10. Indeed, the upper ends of the post-tensioning cables 20, 21, 22 are kept attached to the section 10 when the lower ends of post-tensioning cables 20, 21, 22 are anchored or coupled. This allows keeping the post-tensioning cables 20, 21, 22 in a favourable handling configuration. The upper ends of the post-tensioning cables 20, 21, 22 are released when they have to be anchored to the upper adjacent section 10 or coupled with post-tensioning cables 20, 21, 22 pre-installed in the upper adjacent section 10.

As a result, after they have been coupled to the post-tensioning cables 20a, 21a, and 22a of the first section 10a, the post-tensioning cables 21b and 22b pre-installed in the second section 10b are still attached to the second section 10b by their upper ends and are therefore ready to be used with an upper adjacent section.

Similarly, the anchors can be pre-installed on each section 10 at the anchorage points, so that the post-tensioning cables 20, 21, and 22 can be anchored without having to bring up the anchors.

At the end of the step illustrated by Figure 7b, a first post-tensioning operation can be performed on the first post-tensioning cables 20a.

As illustrated by Figure 7c, a third section 10c is then stacked above the second section 10b. The upper ends of the first post-tensioning cables 20b pre-installed in the second section 10b are then released from their attaching device and anchored to the first portion of the third section 10c, and more precisely to the first flange of said third section 10c by anchorages 23b.

Each inter-section post-tensioning cable formed by a second post-tensioning cable 21a pre-installed in the first section 10a and coupled to a first post-tensioning cable 20b pre-installed in the second section 10b is anchored to the foundation 14 on which is erected the first section 10a by anchorages 24b.

In other words, the lower ends of the second post-tensioning cables 21a pre-installed in the first section 10a and coupled to the first post-tensioning cables 20b pre-installed in the second section 10b are anchored to the foundation 14 on which is erected the first section 10a by anchorages 24b.

In this example, the mast 1 comprises four sections 10. Of course, this is only a simplified example, and a mast 1 may comprise more or less than four stacked concrete sections 10. For a mast 1 of more than four concrete sections 10, the erection of the others sections 10 is similar as for the second section 10b, except for the penultimate section and the last uppermost section, which may be different.

For the sake of simplicity, a fourth section 10d is mentioned in order to allow the third section 10c to be properly post-tensioned, and therefore is described as a section without pre-installed post-tensioning elements anchored above it. In reality, every concrete section 10 must be post-tensioned with post-tensioning elements anchored above said concrete section. Post-tensioning elements pre-installed in the uppermost section of the concrete mast 1 should therefore normally be anchored to a transition piece between the concrete mast 1 and the nacelle of the windmill. Alternatively, the fourth section 10d may be construed as a transition steel piece and the third section 10c as the uppermost section.

In the present case, the third section 10c is the penultimate section before the top of the mast 1, i.e. it has only one upper section. As a result, there are no second post-tensioning cables 21 and 22 intended to be coupled to other cables pre-installed in upper sections. Only first post-tensioning cables 20c are pre-installed in this third section 10c, which are intended to be anchored to the first portion of the upper adjacent section. The lower ends of the first post-tensioning cables 20c are coupled to the second post-tensioning cables 21b pre-installed in the second section 10b by means of a coupler 26b.

As illustrated by Figure 7d, the fourth section 10d is then stacked above the third section 10c. In this example, it is the uppermost section of the mast 1. There is thus no adjacent upper section. Accordingly, the uppermost section 10d does not have pre-installed first post-tensioning cables 20 intended to be anchored to the upper adjacent section with respect said section 10, or pre-installed second post-tensioning cables 21 and 22 intended to be coupled to other cables pre-installed in upper sections.

First post-tensioning cables 20c pre-installed in the third section 10c are anchored to the first portion of the fourth section 10d. The upper ends of the first post-tensioning cables 20c pre-installed in the third section 10c are then released from their attaching devices and anchored to the first portion of the fourth section 10d, and more precisely to the first flange of said fourth section 10d by anchorages 23c.

Each inter-section cable formed by a second post-tensioning cable 22a pre-installed in the first section 10a and coupled with a second post-tensioning cable 21b pre-installed in the second section 10b which is coupled with a first post-tensioning cable 20c pre-installed in the third section 10c is anchored to the foundation 14 on which is erected the first section 10a by an anchorage 24c.

In other words, the lower ends of the second post-tensioning cables 22a pre-installed in the first section 10a and coupled with the second post-tensioning cables 21b pre-installed in the second section 10b which are coupled with the first post-tensioning cables 20c pre-installed in the third section 10c are anchored to the foundation 14 on which is erected the first section 10a by anchorages 24c.

Each post-tensioning cable 20, 21, and 22 is either anchored to the foundation 14 or is part of an inter-section post-tensioning cable anchored to the foundation 14. In fact, only the first post-tensioning cables 20a pre-installed in the first section 10a is directly anchored to the foundation 14. The other post-tensioning cables 20, 21, and 22 are parts of inter-section post-tensioning cables.

Since these inter-section cables are anchored by anchorages 24b and 24c to the foundation 14, post-tensioning can be applied at the level of the foundation of the mast 1. Consequently, there is no need to mobilize post-tensioning devices at different heights of the mast 1 during its construction. In addition, during the construction of the mast, iterative post-tensioning operations can be done much more easily to compensate for stress loss due to the deformation introduced by post-tensioning new cables.

Additionally, since no post-tensioning devices are required to be brought to the levels of the different sections 10, there is no need for the sections 10 to be able to accommodate these post-tensioning devices. Indeed, in prior art masts, the post-tensioning devices are arranged on the top surface of the flanges 11', 12' during post-tensioning of the post-tensioning elements. The flanges 11', 12' therefore need to have a minimum free space left on the top surface of the flanges 11', 12' extending from the inner face I of a section 10 in order to accommodate post-tensioning devices. It is usual to keep at least 6 cm between the inner face I and the anchorage points of the post-tensioning elements.

Here, since no such free space is required, the design of the flanges 11', 12' can be optimised. In particular, anchorages 23 can be close to the inner face I of the section 10, closer than 6 cm. The flanges 11', 12' can thus be made shorter, i.e. less protruding in the internal volume V. Furthermore, the eccentricity (with respect to the walls of the section 10) of the applied stress is reduced. The moment of force applying to the flanges 11', 12' is therefore reduced.

The anchorage points 24 for the cables are positioned at the foundation level of the mast 1 and on the top surface of the first flanges 11 of the concrete sections 10. This enables a stiffer design, which is very beneficial for reducing the stress concentration within the section 10, especially near the flanges 11' and 12'. For example, the second flange 12' may have stiffeners arranged in the internal volume V along the inner face I of the section 10. It shall be noted that fewer couplers 25, 26 are required for achieving a same target post-tensioning stress as in the prior art. The reduction is also beneficial for a more optimized site construction procedure.

While the present invention has been described with respect to certain preferred embodiments, it is obvious that it is in no way limited thereto and it comprises all the technical equivalents of the means described and their combinations. In particular, it will be apparent to those skilled in the art that various changes and modifications may be made without departing from the scope of the invention as defined in the appended claims.

Claims

1. A method for constructing a mast of concrete intended for a windmill (2), said mast (1) comprising at least an upper section (10b, 10c) of concrete and a lower section (10a, 10b) of concrete, each section (10) comprising:

- a first portion (11) intended to exert a bearing force on a lower adjacent part of the windmill (2), and
- a second portion (12) intended to form a bearing support for another upper adjacent part of the windmill (2),

the method comprising the following step:

- stacking an upper section (10b, 10c) on the top of a lower section (10a, 10b), the first portion (11) of the upper section extending the second portion (12) of the lower section;
- anchoring a first post-tensioning element (20) pre-installed in the lower section to the first portion of the upper section, and
- coupling a second post-tensioning element (21, 22) pre-installed in the lower section to a post-tensioning element (20, 21) pre-installed in the upper section,

wherein before stacking the sections (10), the first post-tensioning element (20) and the second post-tensioning (21, 22) element are pre-installed to the lower section by an attaching device, the method comprising the step of, after the stacking of the sections, releasing the first post-tensioning element and the second post-tensioning element from the lower portion before anchoring the first post-tensioning element and coupling the second post-tensioning element, respectively.

2. The method according to claim 1, wherein an upper extremity of the post-tensioning element pre-installed in the upper section is attached to said upper section by an attaching device.

3. The method according to any one of claims 1 to 2, wherein post-tensioning elements coupled together form an inter-section element, and each post-tensioning element is either anchored to the foundation or is part of an inter-section element intended to be anchored to the foundation (14).

4. The method according to any one of claims 1 to3, wherein the concrete is an ultra-high performance concrete or an ultra-high performance concrete reinforced with fibres and/or with ordinary reinforcement.

5. The method according to any one of claims 1 to 4, wherein for each section of concrete:

- the first portion comprises a first flange (11') extending substantially transversely from an internal face (I) of the section (10) opposite the internal volume (V) of the section (10),

- the second portion comprises a second flange (12') extending substantially transversely from the internal face (I) of the section (10) opposite the internal volume (V) of the section (10),

wherein the first post-tensioning element pre-installed in the lower section is anchored to the first flange of the first portion of the upper section.

6. A section of concrete intended to be used in the method according to any one of claims 1 to 5 for constructing a mast of concrete, said section (10) having an internal volume (V) and comprising;

- a first portion (11) intended to exert a bearing force on a lower adjacent part of the windmill (2), and

- a second portion (12) intended to form a bearing support for another upper adjacent part of the windmill (2),

characterised in that the section (10) comprises:

- a pre-installed first post-tensioning element (20) configured to be anchored in the the first portion of an upper section of the mast, and

- a pre-installed second post-tensioning element (21, 22) configured to be coupled with a post-tensioning element (20, 21) pre-installed in an upper section of the mast,

wherein the first post-tensioning element (20) and the second post-tensioning (21, 22) element are pre-installed to the lower section by an attaching device adapted to release the first post-tensioning element and the second post-tensioning element from the lower portion before anchoring the first post-tensioning element and coupling the second post-tensioning element, respectively.

7. A mast of concrete intended for a windmill (2), said mast (1) comprising at least an upper section of concrete and a lower section, said upper section being stacked on the top of the lower section, the first portion of the upper section extending the second portion of the lower section, each section (10) comprising

- a first portion intended to exert a bearing force on a lower adjacent part of the windmill (2), and

- a second portion intended to form a bearing support for another upper adjacent part of the windmill (2),

wherein

- a first post-tensioning element pre-installed in the lower section by an attaching device is anchored to the first portion of the upper section after release from the attaching device, and

- a second post-tensioning element pre-installed in the lower section by an attaching device is coupled to a post-tensioning element pre-installed in the upper section after release from the attaching device.

8. A mast according to claim 7, wherein post-tensioning elements coupled together form an inter-section element, and each post-tensioning element is either anchored to the foundation or is part of an inter-section post-tensioning element anchored to the foundation, said inter-section post-tensioning element comprising at least one post-tensioning element facing one section coupled to another post-tensioning element facing another section.

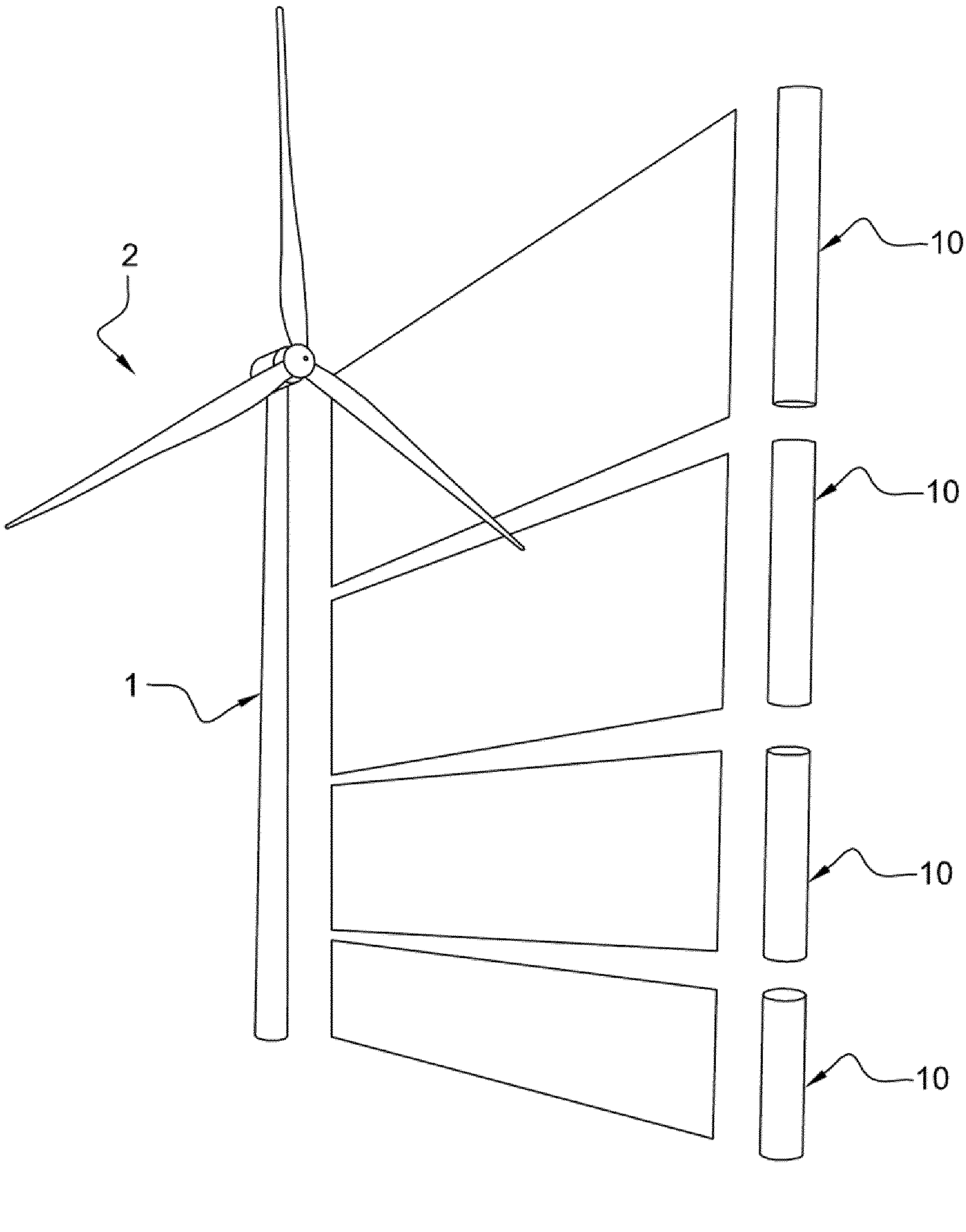

Fig. 1

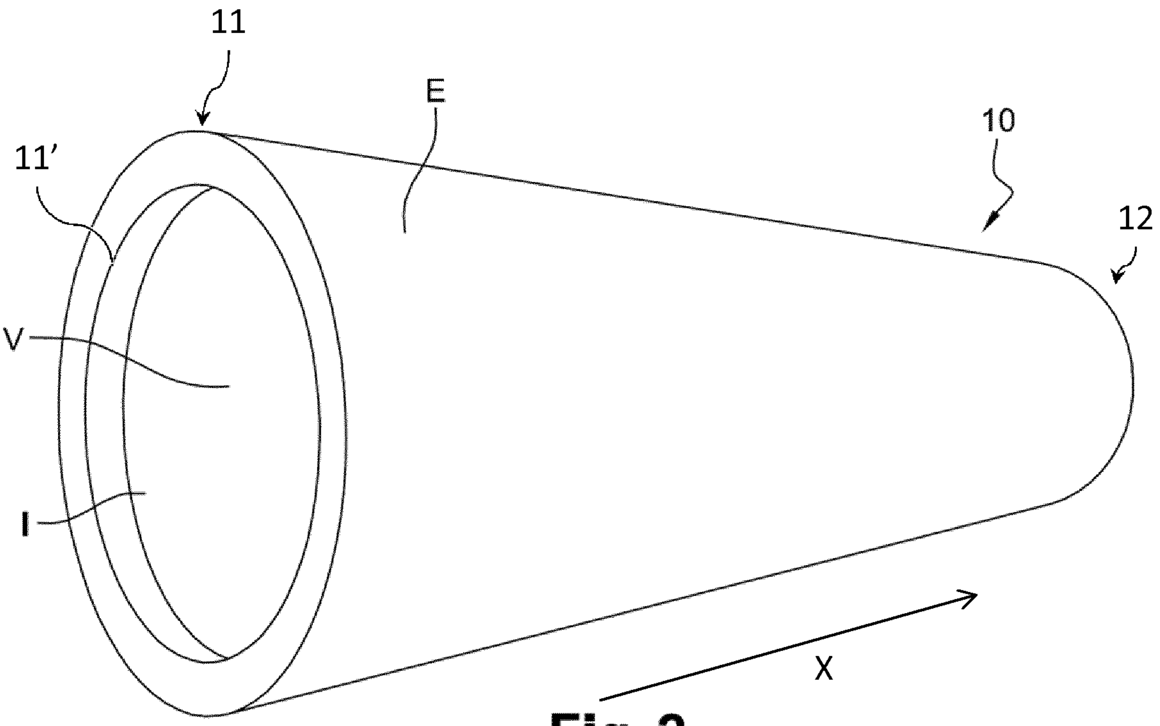

Fig. 2

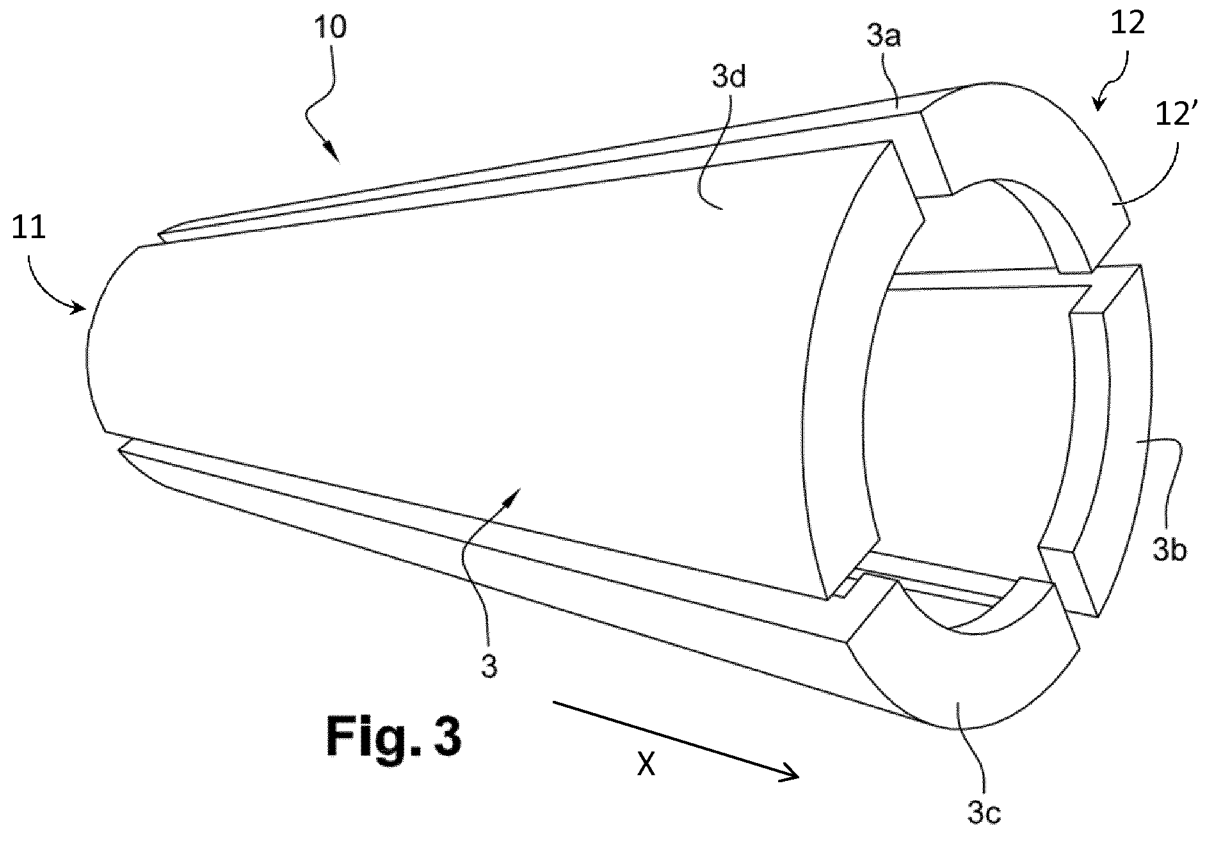

Fig. 3

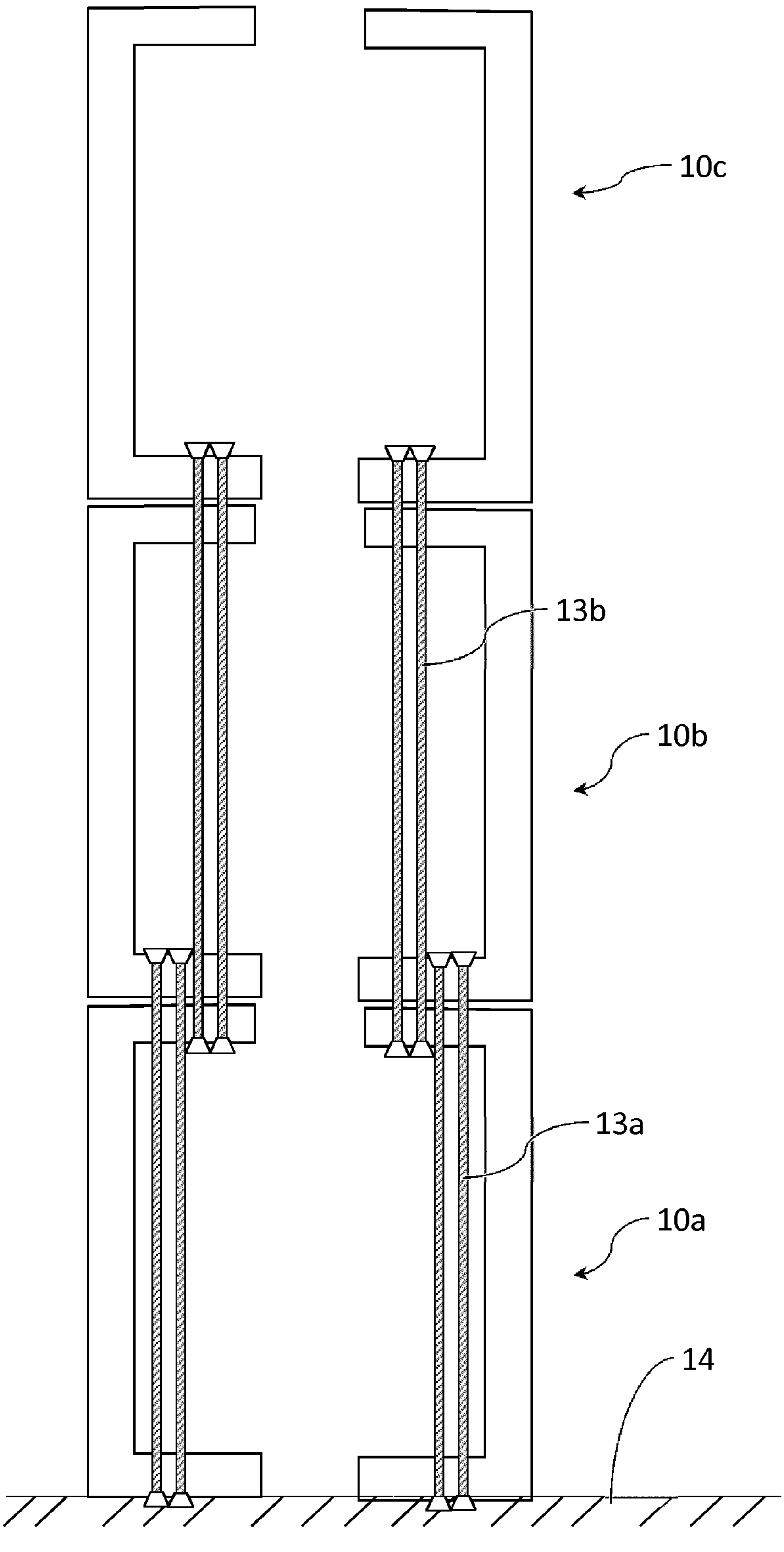

FIG. 4

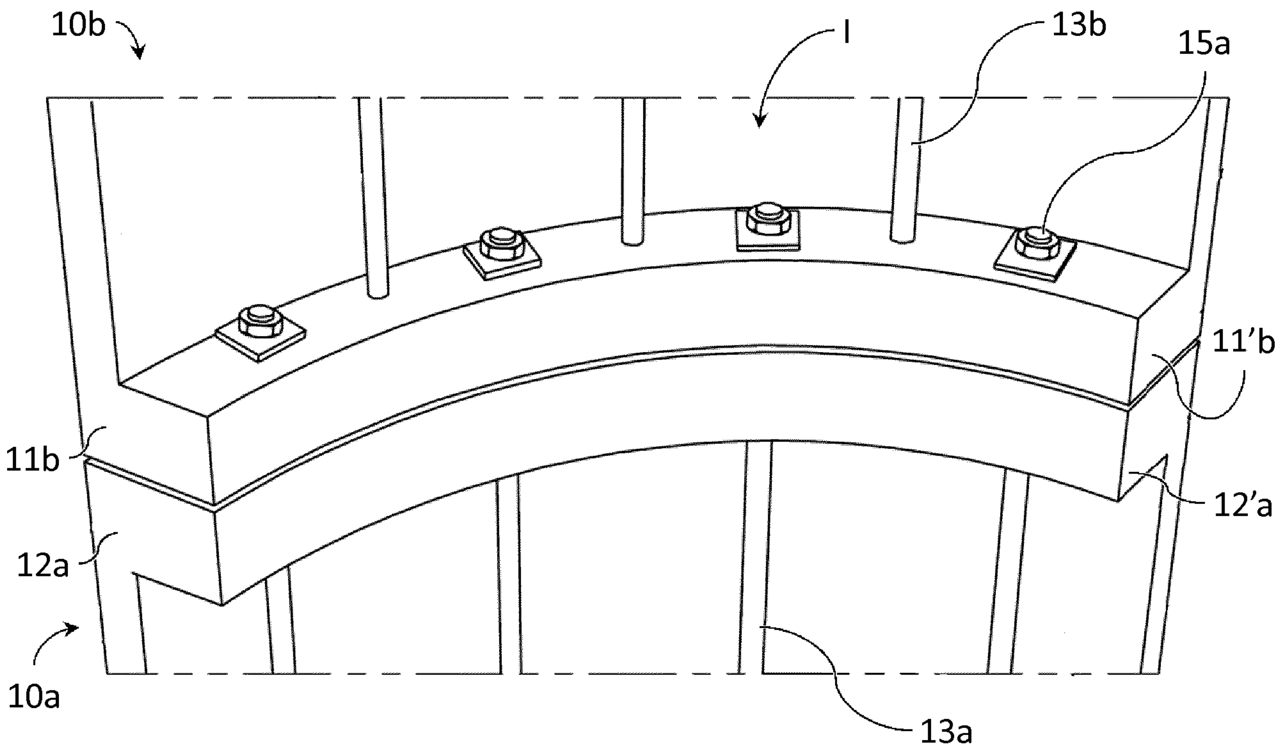
10b
I
13b
15a
11'b
11b
12'a
12a
10a
13a

FIG. 5

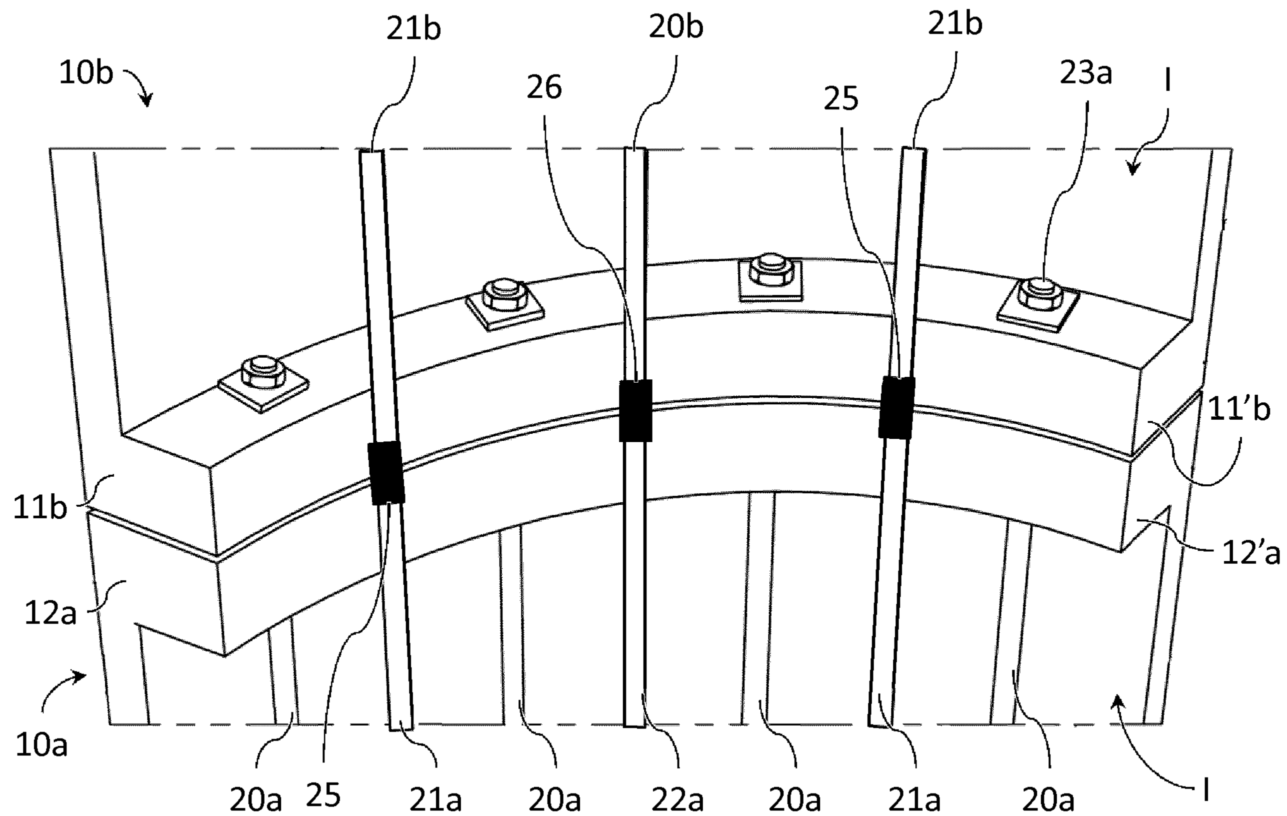
21b
20b
21b
10b
26
25
23a
I
11'b
11b
12'a
12a
10a
20a
25
21a
20a
22a
20a
21a
20a
I

FIG. 6

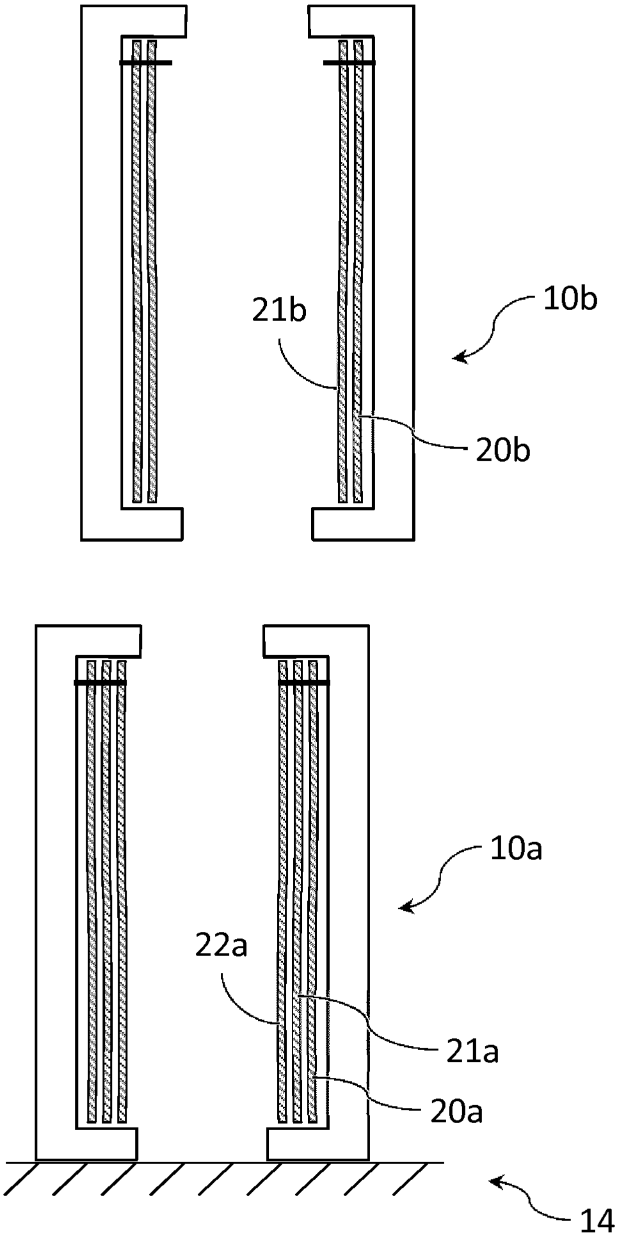
21b
10b
20b
10a
22a
21a
20a
14

FIG. 7a

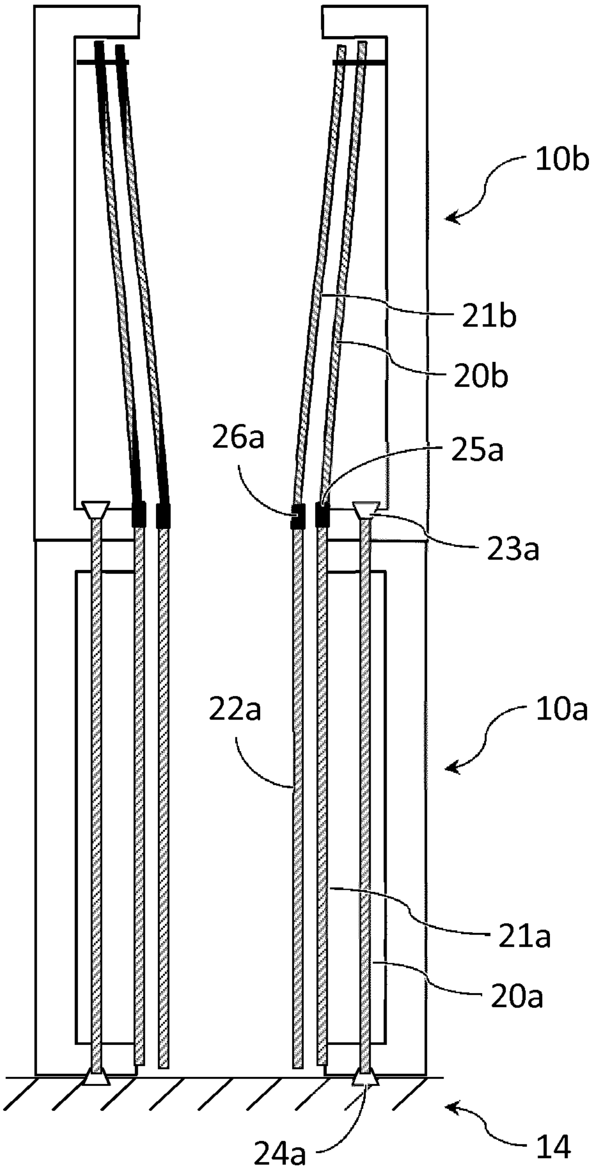
10b
21b
20b
26a
25a
23a
22a
10a
21a
20a
24a
14

FIG. 7b

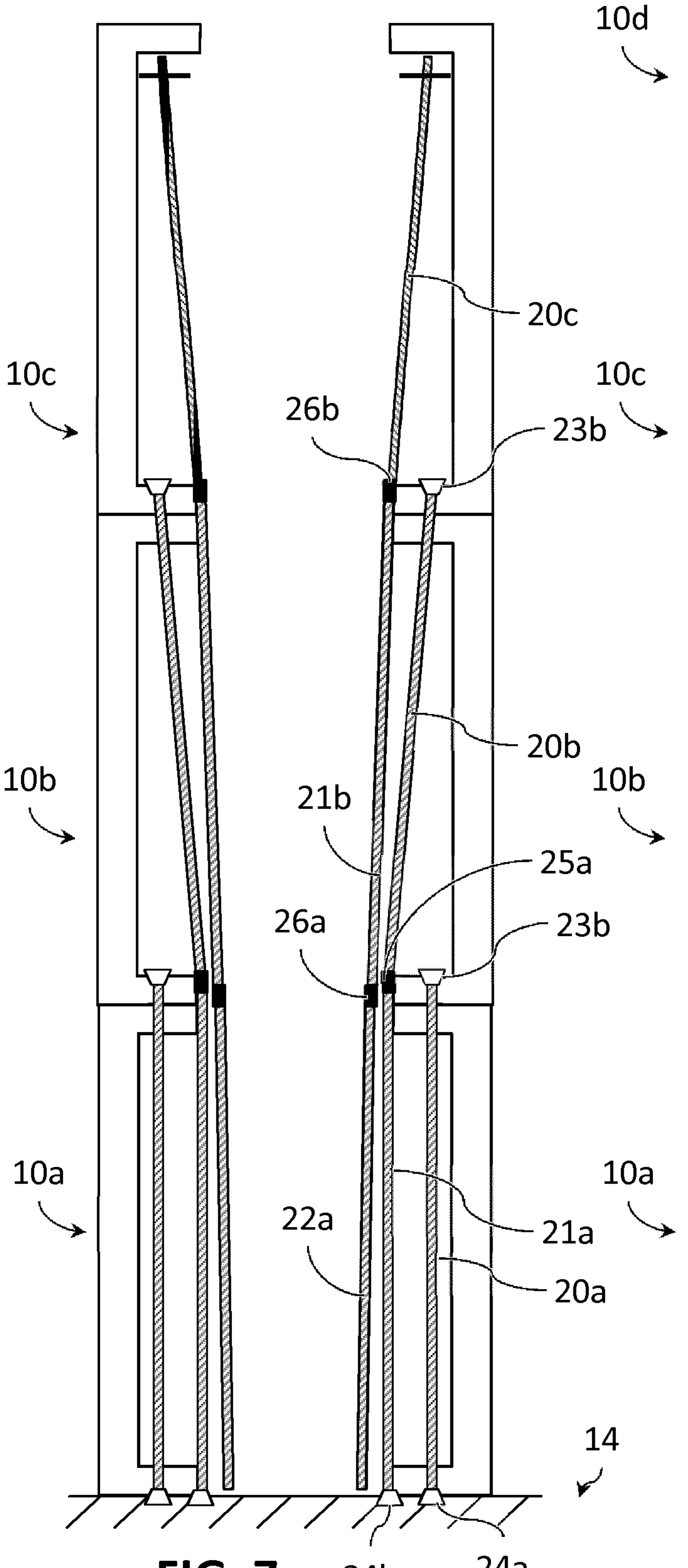
10c
26b
23b
20c
10b
21b
20b
26a
25a
23b
10a
22a
21a
20a
14
24b
24a

FIG. 7c

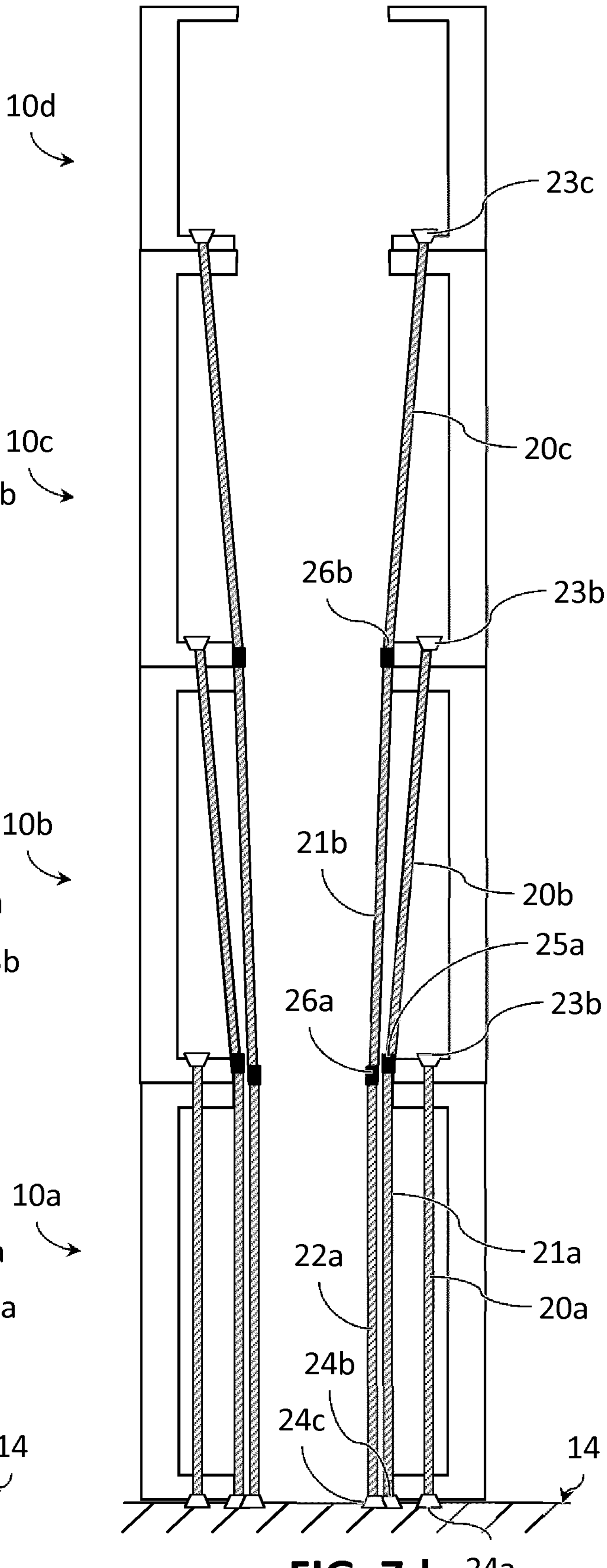
10d
23c
10c
20c
26b
23b
10b
21b
20b
25a
26a
23b
10a
22a
21a
20a
24b
24c
14
24a

FIG. 7d

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/081148

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D13/10 E04H12/12 E04H12/16 F03D13/20
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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	EP 2 746 580 A2 (ACCIONA WINDPOWER SA [ES]) 25 June 2014 (2014-06-25) paragraphs [0001], [0003], [0004], [0012], [0014], [0026] - [0042]; figures 1-9	1-8 1-8
Y	WO 2010/098716 A1 (ERICSSON ROGER [SE]) 2 September 2010 (2010-09-02) figures 5a-5c,8a, 8b	1-8
Y	JP 2008 255602 A (TODA CONSTRUCTION; NIPPON HUME CORP) 23 October 2008 (2008-10-23) abstract; figures 1,3, 5,6, 11,12	1-8

-/-

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

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
27 February 2017	09/03/2017

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, Fax: (+31-70) 340-3016	Decker, Robert

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2016/081148

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2015/052841 AI (KIRKLEY KEVIN L [US] ET AL) 26 February 2015 (2015-02-26) paragraphs [0078], [0102], [0136]; figure 36 -----	1-8
A	WO 2015/132436 AI (ESTEYCO S A P [ES]) 11 September 2015 (2015-09-11) figures 1-13 -----	1-8

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2016/081148

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 2746580 A2	25-06-2014	EP 2746580 A2	25-06-2014
		ES 2471641 A1	26-06-2014
		ES 2551597 T3	20-11-2015
		US 2015096240 A1	09-04-2015
WO 2010098716 A1	02-09-2010	EP 2401454 A1	04-01-2012
		JP 2012519244 A	23-08-2012
		SE 0950105 A1	28-08-2010
		US 2012042585 A1	23-02-2012
		WO 2010098716 A1	02-09-2010
JP 2008255602 A	23-10-2008	JP 4874152 B2	15-02-2012
		JP 2008255602 A	23-10-2008
US 2015052841 A1	26-02-2015	NONE	
WO 2015132436 A1	11-09-2015	AU 2015226086 A1	27-10-2016
		BR 102014011880 A2	01-12-2015
		CA 2941682 A1	11-09-2015
		CN 106232917 A	14-12-2016
		EP 3118393 A1	18-01-2017
		ES 2547584 A1	07-10-2015
		UY 36022 A	30-09-2015
		WO 2015132436 A1	11-09-2015