(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) **EP 4 741 568 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
13.05.2026 Bulletin 2026/20

(21) Application number: **24211434.6**

(22) Date of filing: **07.11.2024**

(51) International Patent Classification (IPC):
D07B 1/02 *(2006.01)* ***D07B 1/04*** *(2006.01)*
D07B 1/16 *(2006.01)*

(52) Cooperative Patent Classification (CPC):
D07B 1/025; D07B 1/16; D07B 2401/2055;
D07B 2501/2015; D07B 2501/2061

(84) Designated Contracting States:
AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL NO PL PT RO RS SE SI SK SM TR
Designated Extension States:
BA
Designated Validation States:
GE KH MA MD TN

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(54) **SYNTHETIC FIBER BASED TENDONS**

(57) A tendon (10, 20, 30) for technical constructions, especially for use as tension leg and/or for stabilizing a structure of a wind turbine, comprises:
a) A load-bearing core (11, 21, 31) comprising or consisting of a plurality of individual synthetic fiber-based strength members (11a, 21a, 31a);
b) An enveloping layer (12, 22, 32) of synthetic material surrounding the load-bearing core (11, 21, 31).

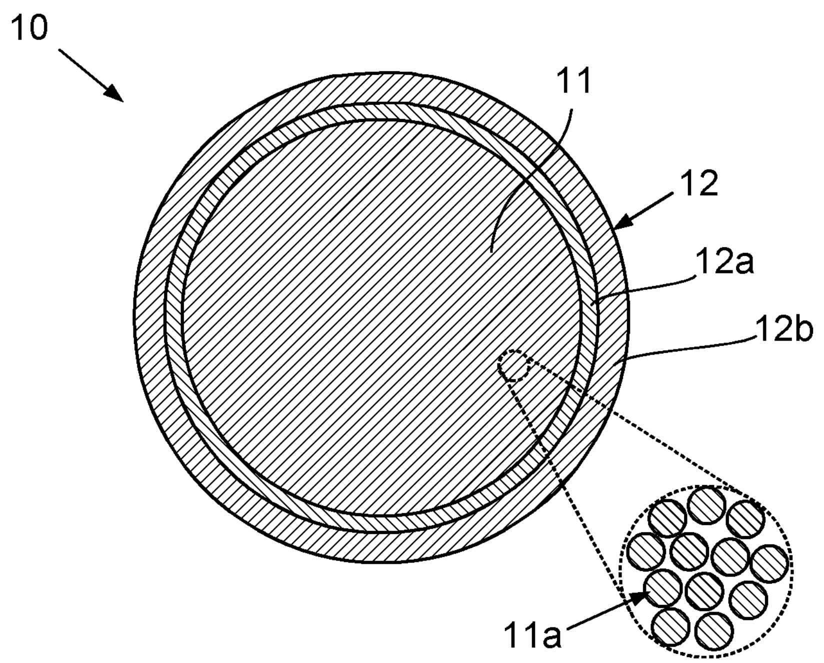

Fig. 1

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Description

Technical field

[0001] The invention relates to a tendon for technical constructions, especially for use as tension leg and/or for stabilizing a structure of a wind turbine as well as a method for producing such tendons. Further aspects of the invention are related to the use of specific tendons for as a tension leg and/or for stabilizing a structure of a wind turbine, especially a multi-rotor wind turbine, and to a wind turbine or a tension leg platform comprising a specific tendon.

Background art

[0002] In engineering and construction, a "tendon" usually refers to a high-strength cable or bar that provides tension in a structure and/or transmits tensile forces. Tendons are essential in modern engineering, enabling the construction of lighter and more efficient structures.

[0003] For example, in post-tensioned concrete construction, tendons are placed within ducts in concrete elements. Once the concrete has cured, the tendons are tensioned and anchored, allowing the concrete to bear higher loads and resist cracking.

[0004] Also, tendons are used in the construction of bridges and high-rise buildings to enhance structural integrity and load distribution. They help manage forces in the structure, improving its stability and durability.

[0005] In tension-based constructions, tendons play a critical role in maintaining shape and stability by holding various components under tension.

[0006] A special type of tendons are so called tension legs. A tension leg is a type of cable used primarily in offshore installations, particularly in tension leg platforms (TLPs) for oil or gas exploration, or in renewable energy production, e.g. in wind energy production. These platforms are anchored to the seabed using vertical tension legs, which provide stability and allow the platform to float above the water.

[0007] In particular, tendons play a crucial role in stabilizing the structure and optimizing performance of multi-rotor wind turbines, especially on offshore platforms. These systems represent an innovative approach to harnessing wind energy in offshore regions featuring multiple smaller rotor turbines mounted on a single floating platform. In this regard, on the one hand, tendons are required as tension legs to anchor the floating platform to the seabed, providing stability against wind forces and wave action. This prevents excessive movement and ensures the turbines maintain optimal alignment with the wind. On the other hand, in multi-rotor systems, tendons help to distribute the loads from the individual turbines evenly across the platform. This reduces stress on specific areas, enhancing the overall structural integrity.

[0008] Tendons are typically made from high-strength steel, designed to withstand significant tensile forces. The required tension or tensile force of tendons used as tension legs usually is at least 300 tons. Tendons used for multi-rotor wind turbines may a tension or tensile force up to 800 tons or even up to 3’000 tons. However, the large diameters required for producing such kind of tendons and the heavy weight of steel significantly limits the application of tendons in heavy-duty applications.

[0009] Thus, there is still a need to develop improved solutions that do not have the disadvantages mentioned above or have them to a lesser extent.

Summary of the invention

[0010] It is the object of the invention to provide improved tendons. Especially, the tendons should be as light as possible and at the same time have the highest possible tensile strength. In particular, the tendons should be suitable for use as tension legs for offshore installations and/or for stabilizing the structure and/or optimizing performance of wind turbines, in particular multi-rotor wind turbines, especially on offshore platforms.

[0011] The solution of the invention is specified by the features of claim 1. Accordingly, the core of the invention relates a tendon for technical constructions, especially for use as tension leg and/or for stabilizing a structure of a wind turbine, in particular a multi-rotor wind turbine, the tendon comprising:

a) A load-bearing core comprising or consisting of a plurality of individual synthetic fiber-based strength members;

b) An enveloping layer of synthetic material surrounding the load-bearing core.

[0012] The tendon according to the invention turned out to be highly beneficial. When compared with steel-wire based tendons, the weight of the tendons can be reduced significantly thanks to the synthetic fiber-based strength members and the enveloping layer of synthetic material while the breaking force can be kept at a high level. Furthermore, tendons according to the invention can be produced with rather small diameters while still having a high breaking force.

[0013] Thereby, the enveloping layer of synthetic material allows for protecting the load-bearing core and to adapt it to specific requirements by selecting an appropriate material, thickness, surface structure and the like. Likewise, the load-bearing core can be adapted to different requirements, e.g. by providing cores with different structures and/or different fibers materials.

[0014] In particular, it is possible to produce the tendons according to the invention without any metallic components. This in particular results in reduced problems associated with metal or steel based constructions, such as e.g. a reduced risk of corrosion.

[0015] Overall, highly advantageous tendons are provided. In particular, the tendons are highly suitable for use as tension legs for offshore installations. In addition, the tendons according to the invention are beneficial for stabilizing the structure and/or optimizing performance of wind turbines, especially multi-rotor wind turbines, in particular on offshore platforms.

[0016] Further aspects and advantageous embodiments of the invention are subject of the further claims and outlined throughout the description.

[0017] In particular, the enveloping layer is in direct contact with an outermost layer of the synthetic fiber-based strength members of the core. In this case, no intermediate layer is provided in between the load-bearing core and the enveloping layer.

[0018] According to an exemplary embodiment, the enveloping layer is materially bonded to the outermost layer of the synthetic fiber-based strength members and/or the outermost layer of the synthetic fiber-based strength members is at least partly embedded in the enveloping layer. In this manner, the enveloping layer and the load-bearing core form a cohesive structure.

[0019] According to another exemplary embodiment, the enveloping layer of synthetic material surrounding the load-bearing core is not materially bonded to the load-bearing core and/or the outermost layer of the synthetic fiber-based strength members is not embedded in the enveloping layer. In this manner, the load-bearing core and the enveloping layer can move relative to each other within certain limits. This may help to obtain a more even transmission of forces between the ends of the tendon.

[0020] The enveloping layer in particular comprises or consists of an extruded layer. In this case, especially, there is no connecting seam running along the longitudinal direction of the tendon. E.g. by selecting an appropriate dye, extruded layers can be produced with various outer surfaces. For example, very homogeneous outer surface or highly structured outer surface can be realized.

[0021] According to another preferred embodiment, the enveloping layer comprises or consists of a wrapping foil. Such an enveloping layer can be produced by simply wrapping a foil of synthetic material around the tendons with one or more turns. A free longitudinal end of the foil then can be connected to the other longitudinal end of the foil and/or an underlying section of the foil.

[0022] In an exemplary embodiment, the wrapping foil comprises a connecting seam, e.g. a welding seam, running along the longitudinal direction of the tendon, in particular along the entire length of the tendon.

[0023] According to a special embodiment, the enveloping layer comprises a wrapping foil and an extruded layer. In this case, in particular, the extruded layer is arranged outside the wrapping foil and preferably is in direct contact with the wrapping foil. Particularly, the wrapping foil in this configuration is in direct contact with the load-bearing core. In this manner, the extruded layer can be decoupled from the load-bearing core, especially such that the load-bearing core and the extruded layer can move relative to each other within certain limits. Similar as described above, this may help to obtain a more even transmission of forces between the ends of the tendon.

[0024] However, other arrangements in which the wrapping foil is located outside the extruded layer are possible as well.

[0025] The synthetic material of the enveloping layer, especially the extruded layer and/or the wrapping foil, preferably is selected from thermoplastic polyurethane (TPU), thermoplastic elastomers (TPE, TPEE), and/or polyethylene (PE). Especially, the thermoplastic elastomers is a thermoplastic polyester elastomer (TPEE). However, other materials are possible as well.

[0026] In case there is an extruded layer and a wrapping foil, the extruded layer and the wrapping foil may consist of the same material or of different materials. Different materials may be beneficial to adapt the tendon to specific requirements. Same materials may facilitate the production process.

[0027] The individual synthetic fiber-based strength members represent basic load bearing elements of the tendon that can be adapted to different requirements

[0028] The individual synthetic fiber-based strength members in particular comprise or consist of carbon fibers, aramid fibers, high-density polyethylene fibers, glass fibers, basalt fibers, polyester fibers, and/or LCP fibers. LCP fibers are liquid crystal polymer fibers. Especially, the LCP fibers comprise aromatic rings with ester and/or amide linkages, in particular arranged in a highly ordered, semi-crystalline state.

[0029] Preferably, the individual synthetic fiber-based strength members are based on or consist of fibers with a tensile strength of at least 600 MPa, preferably at least 1’000 MPa, in particular at least 1’800 MPa, more preferred at least 2’500 MPa or at least 3’000 MPa.

[0030] Especially, each of the individual synthetic fiber-based strength members comprises a plurality of synthetic fibers. Thereby, the synthetic fibers of the individual synthetic fiber-based strength members may be twisted or untwisted.

[0031] For example, the individual synthetic fiber-based strength members comprise or consist of synthetic fiber cords, synthetic fiber strands and/or synthetic fiber ropes. However, other configurations are possible as well.

[0032] The individual synthetic fiber-based strength members can, at least partly, be interconnected. In another possible embodiment, the individual synthetic fiber-based strength members are not connected with each other in the core.

[0033] According to a preferred embodiment, the individual synthetic fiber-based strength members are aligned in parallel, in particular along a longitudinal axis of the tendon, especially without being twisted and/or without being interconnected.

[0034] In another preferred embodiment, the individual synthetic fiber-based strength members are twisted together. This can be helpful to increase the stability of the tendon.

[0035] Especially, the individual synthetic fiber-based strength members in particular are not woven together. Thus, in this case, the individual synthetic fiber-based strength members together in particular do not form a woven fabric or a textile formed by weaving.

[0036] In a special embodiment, the tendon does not comprise any metallic strength members and/or metallic reinforcement layers, and/or the tendon is free of metallic elements. This allows for reducing the weight of the tendon and/or to avoid problems associated with metallic elements. Nevertheless, for special applications, metallic components, such as e.g. metallic strength members and/or metallic reinforcement layers, are possible as well.

[0037] According to a further preferred embodiment, the individual synthetic fiber-based strength members are essentially identical with respect to their structure and/or with respect to a property selected from tensile strength, length and/or diameter. This allows inter alia for obtaining a highly homogeneous load distribution across the whole cross-section of the tendon. This in turn is beneficial with respect to the breaking force and/or the lifetime of the tendon.

[0038] With respect to the selected property, each individual strength member preferably does not deviate by more than 2%, especially not more than 1%, in particular not more than 0.5%, from an arithmetic average of the property of all individual strength members.

[0039] Preferably, a breaking force of the tendon is at least 500 kN, particularly at least 5000 kN, in particular at least 10000 kN, for example at least 15000 kN, at least 20000 kN or at least 30000kN. The breaking force in particular is determined with a method as described in standard ISO 3108:2017 (using the method of resin socketing).

[0040] A diameter of the tendon especially is in the range of 50 - 450 mm, in particular 50 - 350 mm or 350-450 mm.

[0041] In particular, at least at one end, there is a connection element arranged at the tendon, which enables a force-transmitting connection from the load-bearing core of the tendon to a third element. Especially, there is a connection element at both ends of the tendon.

[0042] The connection between the connection element and the load bearing core of the tendon may for example be established by a clamp connection and/or by a material connection. A material connection can inter alia be realized with an adhesive.

[0043] A further aspect of the present invention is related to a wind turbine, especially a multi-rotor wind turbine, comprising a tendon as described above.

[0044] Thereby, preferably, the tendon is arranged as a structural component, especially as a tension member, for stabilizing a structure of the wind turbine, in particular for stabilizing a support and/or a beam that carries a main rotor of the wind turbine; and/or the tendon is arranged in a multi-rotor wind turbine to interconnect two support elements, e.g. beams, carrying the main rotors of two individual wind turbines.

[0045] Due to the rather low weights and small diameters in combination with high breaking forces, the tendons according to the invention turned out to be highly beneficial structural components for wind turbines, which usually are subjected to very high forces.

[0046] Another aspect of the present invention is directed to a tension-leg platform, whereby the tension-leg platform is connected with seabed anchors via one or more tendons as described above. Especially, the tension-leg platform comprises an installation for the offshore production of oil, gas and/or renewable energy.

[0047] Also in this type of application, the rather low weights and small diameters in conjunction with high breaking forces make the tendons according to the invention very advantageous tension legs.

[0048] Especially, the tension-leg platform comprises a wind turbine, especially a multi-rotor wind turbine. Thereby, the one or more tendons according to the invention are used for connecting the tension-leg platform with seabed anchors while (a) further tendon(s) is/are arranged as a structural component of the wind turbine or the multi-rotor wind turbine as described above.

[0049] A still further aspect of the present invention is directed to a method for producing a tendon as described above, the method comprising the steps of:

a) providing or producing a load-bearing core comprising or consisting of a plurality of individual synthetic fiber-based strength members;

b) surrounding the load-bearing core with an enveloping layer of synthetic material.

[0050] Features described as advantageous above with respect to the tendons also realized in preferred implementations of the method.

[0051] Another aspect of the invention is directed to the use of a tendon as described above as a tension leg and/or for stabilizing a structure of a wind turbine, especially a multi-rotor wind turbine. Thereby, the tension leg and the wind turbine are defined as described above.

[0052] Other advantageous embodiments and combinations of features result from the detailed description below and the entirety of the claims.

Brief description of drawings

[0053] The drawings used to explain the embodiments show:

Fig. 1 A cross-section of a first exemplary tendon comprising a load-bearing core consisting of a plurality of individual synthetic fiber-based strength members arranged in parallel;

Fig. 2 A longitudinal cross-section of the tendon according to Fig. 1;

Fig. 3 A cross-section of a second exemplary tendon comprising a load-bearing core consisting of a plurality of individual synthetic fiber-based strength members in the form of twisted synthetic ropes;

Fig. 4 Across-section of a third exemplary tendon comprising an extruded enveloping layer that is materially bonded to the outermost layer of the synthetic fiber-based strength members;

Fig. 5 An arrangement comprising a tension-leg platform that is fixed to seabed anchors with tendons as shown in Fig. 1;

Fig. 6 A multi-rotor wind turbine with two wind turbines mounted on separate support members that are interconnected with a tendon a shown in Fig. 1.

[0054] In the figures, the same components are given the same reference symbols.

Exemplary embodiments

[0055] Fig.1 shows a cross-section of a first exemplary tendon 10 comprising a load-bearing core 11 consisting of a plurality of individual synthetic fiber-based strength members 11a (see magnification on the lower right side). Fig. 2 shows a longitudinal cross-section of the tendon 10.

[0056] The individual synthetic fiber-based strength members 11a in tendon 10 are e.g. arranged in parallel and along the longitudinal axis L (cf. Fig. 2). For example, the individual synthetic fiber-based strength members 11a consist of fibers strands made from aramid. The load-bearing core 11 is surrounded by an enveloping layer 12 comprising a wrapping foil 12a in direct contact with the core 11 and an outer extruded layer 12b. The wrapping foil 12a and the extruded layer 12b both are made from synthetic material, such as e.g. TPU.

[0057] Fig. 3 shows a cross-section of a second exemplary tendon 20. Tendon 20 comprises a load-bearing core 21 consisting of a plurality of individual synthetic fiber-based strength members 21a in the form of twisted synthetic ropes. The load-bearing core 21 is surrounded by an enveloping layer 22 consisting of a wrapping foil. The wrapping foil comprises a connecting seam 22.1 in the form of a welding seam running along the longitudinal direction of the tendon along the entire length of the tendon 20. For example, the wrapping foil 22 is made from polyethylene (PE).

[0058] Fig. 4 shows a cross-section of a third exemplary tendon 30. Tendon 30 comprises a load-bearing core 31 consisting of a plurality of individual synthetic fiber-based strength members 31a in the form of twisted synthetic ropes, i.e. similar to the core 31 of the second tendon 20 of Fig. 2. The load-bearing core 31 is surrounded by an enveloping layer 32 consisting of an extruded layer. The enveloping layer 32 or the extruded layer, respectively is materially bonded to the outermost layer of the synthetic fiber-based strength members 31a and the outermost layer of the synthetic fiber-based strength members is partly embedded in the enveloping layer 32.

[0059] Fig. 5 shows an arrangement 100 comprising a tension-leg platform 101 with an installation 102 for the offshore production of oil located in an open sea area. The platform 101 is anchored below the water surface W to seabed anchors 103 placed on the seabed S via tendons 10, e.g. as shown in Fig. 1.

[0060] Fig. 6 shows a multi-rotor wind turbine 200 with two turbines 201a, 201b. Each if the turbines 201a, 201b is mounted on an angled support tower 202a, 202b carrying the rotor with the blades as well as the generator at the upper end. At an area of the upper end, the support towers 202a, 202b are connected to each other via a tendon 10 as shown in Fig. 1. Thereby, the tendon 10 fulfills the function of a structural element stabilizing the structure of the multi-rotor wind turbine 200.

[0061] The exemplary embodiments are not to be understood as restrictive and can be modified within the scope of the invention.

[0062] For example, instead of a parallel alignment, the individual synthetic fiber-based strength members 11a of the tendon 10 in Fig. 1 can be twisted together and/or interconnected in any other way. Also, the wrapping foil 12a or the extruded layer 12b can be omitted and/or replaced by another layer.

[0063] With the tendon 20 of Fig. 3, for example, the core 21 can be designed differently, e.g. with another arrangement of the individual synthetic fiber-based strength members 21a and/or with individual synthetic fiber-based strength members 21a having a smaller and/or larger diameter. Also, instead of the wrapping foil of the enveloping layer 22 a wrapping foil wrapped several times around the core 21 can be used. Furthermore, in the enveloping layer 22, the wrapping foil can be replaced by an extruded layer similar to the configuration of Fig. 1 and/or an extruded layer can be arranged outside or inside the wrapping foil additionally.

[0064] Likewise, the core 31 and/or the enveloping layer 32 of the tendon of Fig. 4 can be modified, e.g. in order to adapt the tendon to special requirements.

[0065] Especially, in the arrangement 100 of Fig. 5, instead or in addition to the installation 102 for the offshore production of oil located in an open sea area, a wind turbine, e.g. a multi-rotor wind turbine as shown in Fig. 6 can be arranged.

[0066] Furthermore, apart from the exemplary applications shown in Fig. 5 and 6, the tendons according to the invention can be used for other applications, especially heavy-duty applications.

[0067] In summary, it is to be noted that the invention provides highly beneficial tendons for technical constructions based on synthetic fiber-based strength members.

Claims

1. A tendon (10, 20, 30) for technical constructions, especially for use as tension leg and/or for stabilizing a structure of a wind turbine, the tendon comprising:

   a) A load-bearing core (11, 21, 31) comprising or consisting of a plurality of individual synthetic fiber-based strength members (11a, 21a, 31a);
   b) An enveloping layer (12, 22, 32) of synthetic material surrounding the load-bearing core (11, 21, 31).

2. The tendon according to claim 1, whereby the enveloping layer (12, 22, 32) of synthetic material surrounding the load-bearing core (11, 21, 31) is not materially bonded to the load-bearing core (11, 21, 31) and/or an outermost layer of the synthetic fiber-based strength members (11a, 21a, 31a) is not embedded in the enveloping layer (12, 22, 32).

3. The tendon according to any of preceding claims, whereby the enveloping layer (12, 22, 32) comprises or consists of an extruded layer, especially a seamless extruded layer.

4. The tendon according to any of preceding claims, whereby the enveloping layer (12, 22, 32) comprises or consists of a wrapping foil, whereby, in particular, the wrapping foil comprises a connecting seam (22.1), e.g. a welding seam, running along the longitudinal direction (L) of the tendon, in particular along the entire length of the tendon.

5. The tendon according to any of preceding claims, whereby the synthetic material of the enveloping layer (12, 22, 32) is selected from thermoplastic polyurethane (TPU), thermoplastic elastomers (TPE, TPEE), and/or polyethylene (PE).

6. The tendon according to any of preceding claims, whereby the individual synthetic fiber-based strength members (11a, 21a, 31a) comprise or consist of carbon fibers, aramid fibers, high-density polyethylene fibers, glass fibers, basalt fibers, polyester fibers, and/or LCP fibers.

7. The tendon according to any of preceding claims, whereby the individual synthetic fiber-based strength members (11a, 21a, 31a) comprise or consist of synthetic fiber cords, synthetic fiber strands and/or synthetic fiber ropes.

8. The tendon according to any of preceding claims, whereby the individual synthetic fiber-based strength members (11a, 21a, 31a) are aligned in parallel without being twisted.

9. The tendon according to any of claims 1 - 7, whereby the individual synthetic fiber-based strength members (11 a, 21a, 31a) are twisted together.

10. The tendon according to any of preceding claims, whereby the tendon does not comprise any metallic strength members and/or metallic reinforcement layers, and/or the tendon is free of metallic elements.

11. The tendon according to any of preceding claims, whereby the individual synthetic fiber-based strength members (11a, 21a, 31a) are essentially identical with respect to their structure and/or with respect to a property selected from tensile strength, length and/or diameter.

12. The tendon according to any of preceding claims, whereby a breaking force of the tendon is at least 500 kN, in particular at least 5000 kN, for example at least 10000 kN or at least 30000 kN and/or a diameter of the tendon is in the range of 50 - 450 mm, in particular 50 - 350 mm or 350-450 mm.

13. A wind turbine (200), especially a multi-rotor wind turbine, comprising a tendon (10, 20, 30) according to any of claims 1 - 12, whereby, preferably, the tendon is arranged as a structural component, especially as a tension member, for stabilizing a structure of the wind turbine, in particular for stabilizing a support and/or a beam that carries a main rotor; and/or the tendon is arranged in a multi-rotor wind turbine to interconnect two support elements (202a, 202b), e.g. beams, carrying the main rotors of two individual wind turbines (201a, 201b).

14. A tension-leg platform (101), especially comprising an installation for the offshore production of oil, gas and/or renewable energy (102), whereby the tension-leg platform (101) is connected with seabed anchors (103) via one or more tendons (10, 20, 30) according to any of claims 1-12.

15. Method for producing a tendon (10, 20, 30) according to any of claim 1 - 12 comprising the steps of:

    a) providing or producing a load-bearing core (11, 21, 31) comprising or consisting of a plurality of individual synthetic fiber-based strength members (11a, 21a, 31a);
    b) surrounding the load-bearing core (11, 21, 31) with an enveloping layer (12, 22, 32) of synthetic material.

16. Use of a tendon (10, 20, 30) according to any of claims 1 - 12 as a tension leg and/or for stabilizing a structure of a wind turbine, especially a multi-rotor wind turbine.

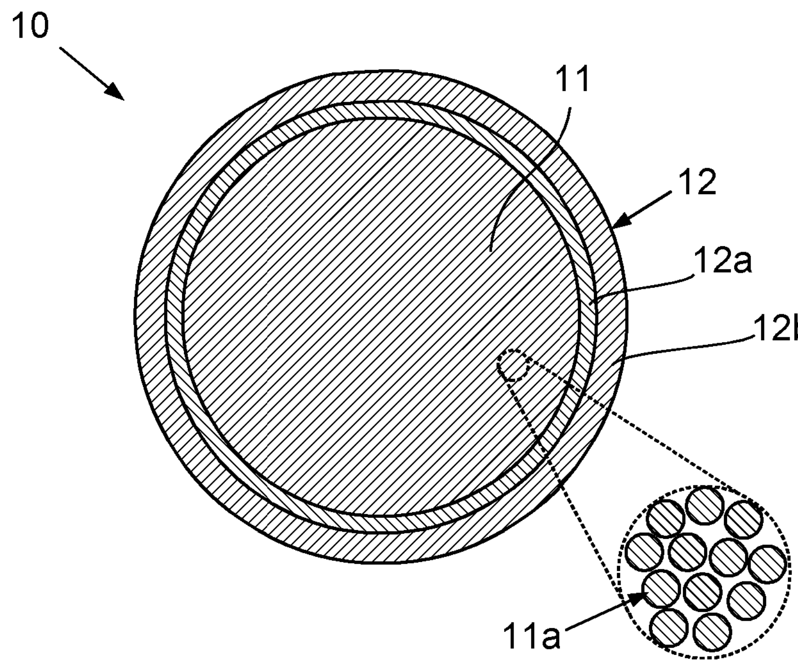

Fig. 1

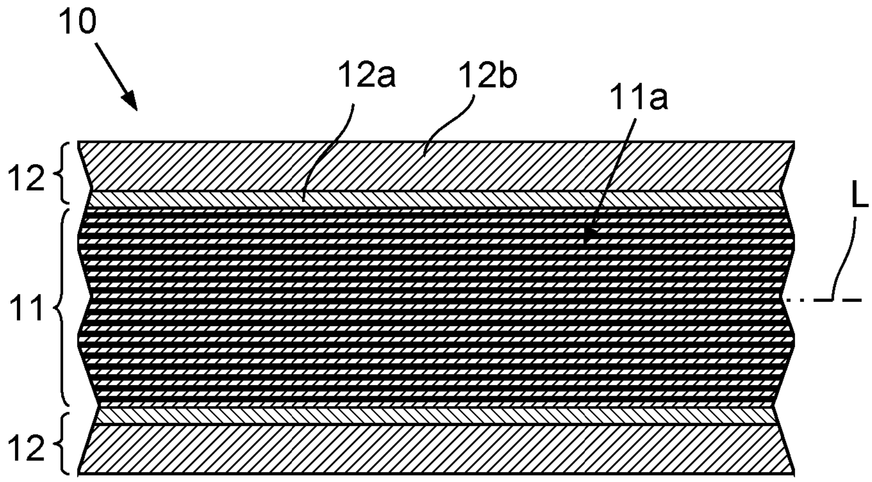

Fig. 2

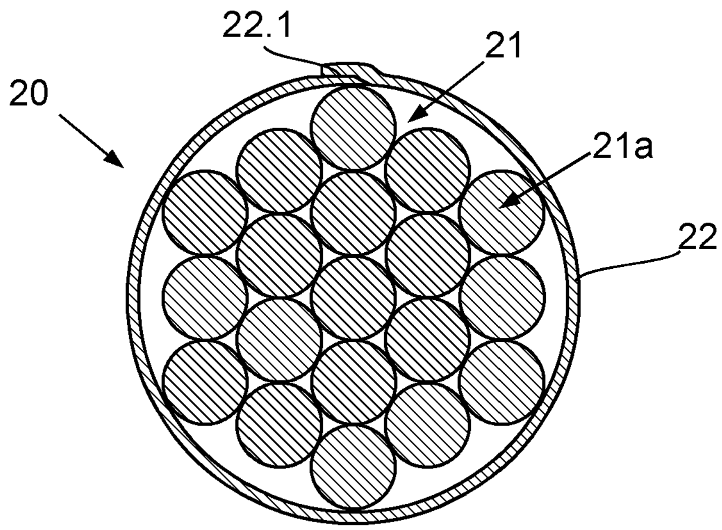

Fig. 3

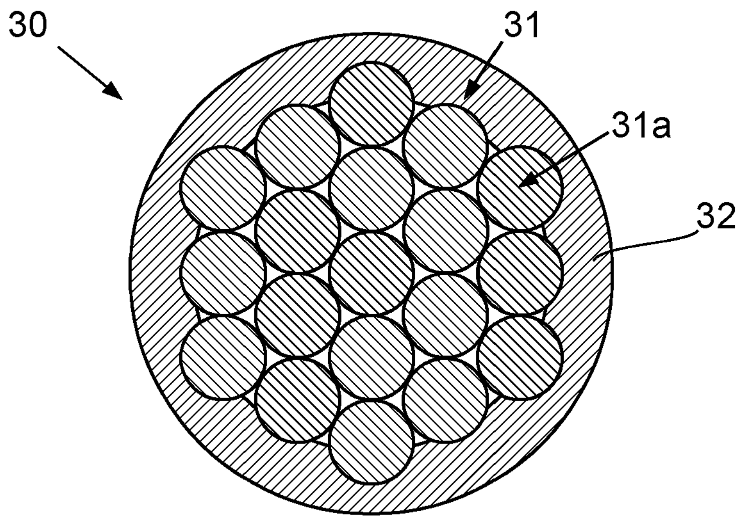

Fig. 4

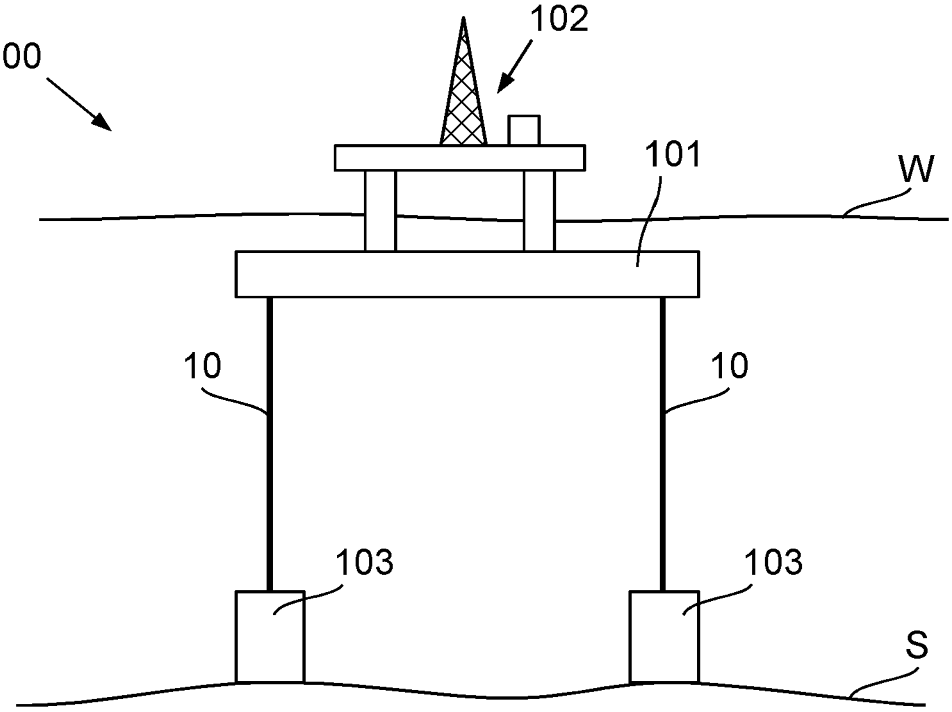

Fig. 5

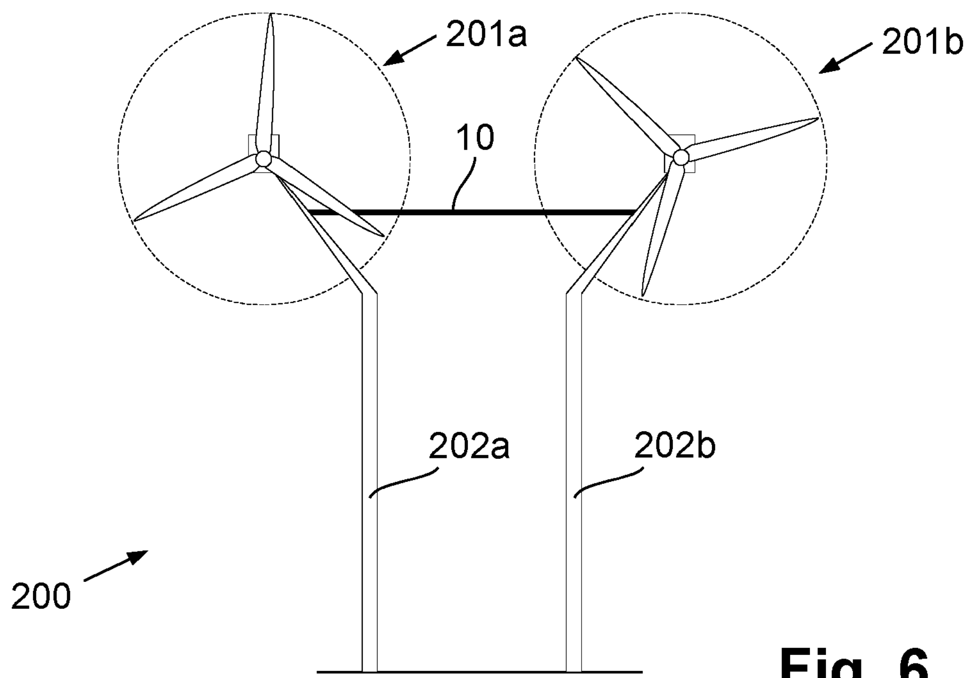

Fig. 6

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EUROPEAN SEARCH REPORT

Application Number
EP 24 21 1434

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X Y	EP 3 924 245 B1 (RWE RENEWABLES GMBH [DE]) 29 March 2023 (2023-03-29) * paragraphs [0062], [0063], [0070], [0034]; claim 1; figures 2,4 *	1-3,5-8, 10,11, 13-16 4	INV. D07B1/02 D07B1/04 D07B1/16
X Y	CN 112 301 534 A (YANGZHOU JUSHEN ROPE CABLE CO LTD) 2 February 2021 (2021-02-02) * paragraphs [0006] - [0026]; claim 1; figures 1-3; example 3 *	1-3,7, 9-12,15 4	
Y	EP 1 288 558 B1 (BRUGG ROHRSYSTEME GMBH [DE]) 2 January 2004 (2004-01-02) * claims 1-2; figures 1-2 *	4	

TECHNICAL FIELDS SEARCHED (IPC)

D07B
B63B
B29C
F16L
D04B

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
Munich	1 April 2025	Messai, Sonia

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 24 21 1434

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