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(71) Applicant (*for all designated States except US*): **OWEC TOWER AS** [NO/NO]; Boks 6028, Postterminalen, N-5892 Bergen (NO).

(72) Inventors; and
(75) Inventors/Applicants (*for US only*): **FOSS, Gunnar** [NO/NL]; Leeuweriklaan 14, NL-2566 JE DEN HAAG (NL). **HAUGSØEN, Per, Bull** [NO/NO]; Risalleen 53, N-0776 OSLO (NO).

(74) Agent: **HÅMSØ PATENTBYRÅ AS**; P.O. Box 171, N-4302 SANDNES (NO).

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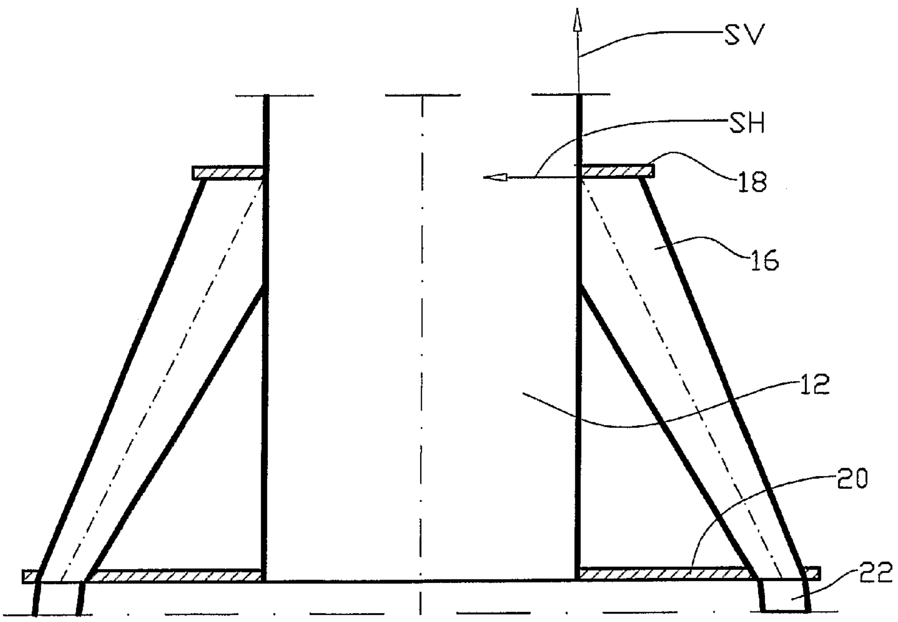
(54) Title: A DEVICE FOR A BENDING MOMENT DEFICIENT STRUT CONNECTION



(57) Abstract: A device for a diagonal strut connection between a pipe (12) and an adjacent structure (14) including at least two diagonal struts (16), in which horizontal and vertical forces in the pipe are transmitted to the diagonal strut by means of a first set of shear forces along the attachment of the diagonal strut (16) to the pipe (12) and via a second set of shear forces along the attachment of the diagonal strut to an annular plate (18) surrounding and projecting radially from the pipe (12), the central axis of the diagonal strut (16) extending through or close to the intersection of the resultants of the first and the second sets of shear forces.

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A DEVICE FOR A BENDING MOMENT DEFICIENT STRUT CONNECTION

This invention relates to a bending-moment-deficient strut connection. More particularly, it concerns a strut connection forming part of a connection between a supporting structure and an adjacent structure, in which the adjacent structure may be a trusswork structure, for example.

The device is illustrated hereinafter by means of a supporting tower structure of a windmill, a structure of this kind adequately showing the challenges addressed by the invention. The invention is not limited to a tower for windmills, but can be used in a number of structures, in which similar force patterns exist.

To avoid collision with the blades of the windmill, the upper portion of a windmill tower must be formed as a slim structure. From land-based windmills it is known that this slim structure, which is often formed by a pipe, is connected to a base in the ground.

When windmills are placed off shore and more often in relatively deep water, it is not practical to use one pipe extending from the base of the windmill up to the nacelle of the windmill.

Therefore, the supporting tower structure of known windmills that are placed off shore, often comprises a tubular upper portion and a lower portion, in which the lower portion may be formed by a trusswork structure, for example.

The transition between the upper slim portion of the tower and the lower structure is often formed by a relatively heavy and complicated structure. The reason is, among other things, that construction principles that are known from sea-based oil recovery equipment, are applied. Such equipment is dimensioned for considerable wave forces and for handling heavy equipment, and for allowing personnel to be present on the structure at all times.

In windmill installations it is, also off shore, normally the wind forces that determine the design of the structure.

Transitions of this prior art are relatively soft. They have to be adjusted in such a way that the natural period of the tower will be short enough for the windmill concerned. This contributes to a further increase in the weight of the tower.

The invention has as its object to remedy or reduce at least one of the drawbacks of the prior art.

The object is achieved in accordance with the invention through the features specified in the description below and in the following Claims.

A cylindrical or conical pipe is connected to an adjacent structure by means of tubular diagonal struts. The diagonal struts are connected to the pipe by means of an annular plate projecting outwards from and encircling the pipe.

The diagonal struts are placed in such a way that the axial central line of the diagonal strut extends through the pipe wall near the circle of attachment of the annular plate to the pipe. Thus, the diagonal strut has been given a shape so that roughly one half of the projected circumference of the diagonal strut is connected to the pipe, whereas the remaining portion of the projected pipe circumference is connected to the annular plate.

The diagonal struts, the pipe and the annular plate are typically connected by means of weld joints, but may also be formed by moulded connections. For practical reasons the welding seam may be continuous or divided.

The pipe and the annular plate are produced from a material of a relatively small thickness. Thus, essentially only membrane stresses will occur in the joints between the diagonal strut and the two details mentioned.

If it is taken as a starting point that the pipe stands vertically and that the annular plate thereby encircles the pipe in the horizontal plane, the vertical force is transmitted from the pipe to the diagonal strut by a first set of shear forces along the connecting line between the diagonal strut and the pipe, whereas the horizontal force is transmitted from the pipe to the annular plate and further on to the diagonal strut via a second set of shear forces between the diagonal strut and the annular plate. The annular plate is sufficiently rigid for the pipe to maintain its circular shape, even though the diagonal strut works only on a limited part of the circumference of the pipe.

As the central line of the diagonal strut runs through the intersection of the resultants of the shear forces mentioned, the diagonal strut is, in the main, not subjected to a bending moment at its attachment to the pipe. This condition simplifies, to a substantial degree, the connection between the pipe and the adjacent structure.

In a preferred embodiment, in which the diagonal strut corresponds with the main columns of a trusswork structure, the pipe is passed through the annular plate and on (down) to a torsion plate. The torsion plate is further connected to the trusswork structure in the region where the diagonal struts are connected to the structure. The torsion plate is designed to absorb torques about the central axis of the pipe, but essentially do not absorb axial forces from the pipe.

A force working radially on the pipe, will cause the creation of a bending moment in the pipe. The bending moment causes the creation of a force pair which is absorbed by the annular plate and the torsion plate. Vertical forces in the pipe are absorbed, as described above, only by the diagonal struts.

To be able to absorb lateral forces and axial forces, the pipe must be provided with two or more diagonal struts. In a structure which is exposed to forces from several directions there must be at least three struts.

If the lower portion of the tower includes a trusswork structure, it is advantageous for the central lines of the main column to meet at the point where a lateral force on the tower is working, for example from the turbine of the windmill. Thereby, the horizontal force is divided into tensile forces and compressive forces in the main columns, whereby the struts of the trusswork are subjected to forces only to a minor degree. Thus, it may be advantageous for compressive forces in the trusswork to be absorbed by compression rods, whereas tensile forces are absorbed by tie rods in the form of tightened ropes.

Such compression rods and ropes may be connected to the columns by means of mechanical connecting elements, for example bolt connections. This renders welding superfluous, to a substantial degree, and provides for a rational production of the trusswork.

The nodes of the trusswork may be welded, moulded or cold-formed, for example.

It may be advantageous to arrange the diagonal struts in such a way that their central lines extend coaxially with their connected column from the column to the pipe. As far as a windmill is concerned, such a structure involves that the diagonal struts may get in the way of the turbine blades. In that case, the central axis of the windmill turbine must point somewhat upwards in order for the blades of the turbine to rotate freely.

The above-mentioned structural features have the effect that forces can be transmitted between a pipe and an adjacent structure by means of a relatively light connection. Compared with known structures, this structure exhibits a considerably improved rigidity.

During the installation of a support on the sea bed, it is common to drive down piles through the guide attached to the trusswork. Such work causes vibrations that are harmful to a possible turbine already mounted.

According to the invention, piles may be driven into the sea bed before the tower is mounted, as the tower is provided at its lower portion with sleeves that are open at their lower portions and that fit complementarily over the piles. The sleeves are preferably formed with annular stops that will abut the upper edge of the pile. The piles are driven down to the same elevation and the tower will, thereby, automatically be vertical. The sleeves are attached to the piles by, for example, injecting concrete between the sleeves and the piles.

In waters where ice occurs, the ice that forms about a tower having one column in the sea, a so-called monotower, will normally be broken up by means of a conical element, so that the horizontal forces from the ice are minimized. A corresponding conical element may be mounted on each main column. In a trusswork tower of the kind described above, the compression rods and tie rods will possibly also be subjected to ice forces. It may, therefore, be advantageous for the trusswork to be formed without struts in a zone where the ice will be working. The increased flexibility that this will entail in the trusswork structure, may, within certain limits, be compensated for in a manner known in itself.

Further, it is of great importance practically and costwise for as many towers as possible to be built identically in serial production. If the respective towers are to be used at different water depths, this could be compensated for by piles, which are possibly preinstalled, having a length which is adjusted to the water depth, so that, fully installed, identically built towers will have the same height above the water surface.

Expensive erosion protection in the form of, for example, gravel often has to be laid around the structure on the sea bed. Normally, the erosion depth is 1.5 times the diameter of a structural element, for example the diameter of a monopile, if no erosion protection has been laid out. The structure in question may be designed for erosion corresponding to 1.5 times the diameter of piles or main columns as these have a considerably smaller diameter, for example 1 metre, than the diameter of a monotower, for example 4.5 m.

In what follows, there is described a non-limiting example of a preferred embodiment which is visualized in the accompanying drawings, in which:

Figure 1 shows a windmill which is placed in a region of relatively deep water, the tower of the windmill including an upper pipe column and a lower trusswork structure;

Figure 2 shows on a larger scale, viewed from one side and at an upward angle, a section of the area at the transition between the pipe column and the trusswork;

Figure 3 shows a sketch, viewed radially outwards from inside the pipe and at an downward angle, in which the shear forces between the diagonal strut and the pipe column, respectively the diagonal strut and the annular plate, are indicated by arrows, the details in the sketch being shown transparently;

Figure 4 shows a section through the pipe and two diagonal struts, in which the first and the second resulting shear forces intersect at the central axis of the diagonal strut; and

Figure 5 shows the windmill of Figure 1 during installation on piles which has been driven into the sea bed in advance.

In the drawings the reference numeral 1 identifies a windmill including a turbine 2 and a tower 4. The tower 4 of the windmill 1 is partially submerged below the sea surface 6. The tower 4 is connected to piles 8 which have been driven into the sea bed 10.

The tower 4 includes an upper vertical pipe 12 and lower trusswork 14.

The pipe 12 is connected to the trusswork by means of hollow diagonal struts 16, an annular plate 18 and a torsion plate 20, see Figure 2. Both the ring plate 18 and the torsion plate 20 encircle and project radially from the pipe 12. The annular plate 18 is located at a level somewhat higher up than the torsion plate 20, the torsion plate 20 being connected to the main columns 22 of the trusswork 14.

The diagonal struts 16 each extend from a respective main column 22 up to the pipe 12 and the annular plate 18, the central axis of the diagonal struts 16 intersecting the pipe 12 near the connecting line of the annular plate 18 to the pipe 12 (see below).

The pipe 12, diagonal struts 16, annular plate 18 and torsion plate 20 are all made of a relatively thin material, so that the stresses between them are mainly made up of membrane stresses.

Torsional forces in the pipe 12 are transmitted to the trusswork 14 via the torsion plate 20. Vertical forces in the pipe 12 are transmitted to the diagonal struts 16 via first shear forces V, see Figure 3, at the attachment between the pipe 12 and the diagonal strut 16. Horizontal forces working on the pipe 12 create a bending moment in the pipe 12. This bending moment is absorbed by a force pair between the annular plate 18 and the torsion plate 20. From the annular plate 18 this horizontal force is transmitted to the diagonal struts 16 by means of second shear forces H, see Figure 3, between the annular plate 18 and the diagonal struts 16.

The resultant of the first shear stresses V is represented in Figure 4 by the force SV, whereas the resultant of the second shear forces H is represented by the force SH. The force SH is normally not completely vertical, as the part of the diagonal strut 16 connected to the pipe 12 follows the cylindrical surface of the pipe 12. The resulting force from the forces SV and SH works on the diagonal strut 16. The central line of the diagonal strut 16 cuts through the intersection of the forces SV and SH. Thereby, the diagonal struts 16 are subjected to bending moment at the attachment to the pipe 12 only to an insignificant degree.

The trusswork 14 comprising, besides the main columns 22, struts 24, is provided with a number of sleeves 26 at its lower portion. The sleeves 26 which are provided with stops, not shown, are arranged to be moved down on piles 8, the piles having been driven into the sea bed 10 in advance. Stops are arranged to make the tower automatically be vertical when the piles have been driven to the same vertical elevation. The sleeves 26 may be attached to the piles 8 by means of, for example, concrete.

C L A I M S

1. A device for a diagonal strut connection between a pipe (12) and an adjacent structure (14) comprising at least two diagonal struts (16), c h a r a c t e r i z e d i n that horizontal and vertical forces in the pipe are transmitted to the diagonal strut by means of a first set of shear forces along the attachment of the diagonal strut (16) to the pipe (12) and via a second set of shear forces along the attachment of the diagonal strut to an annular plate (18) encircling and projecting radially from the pipe (12), the central axis of the diagonal strut (16) extending through or close to the intersection of the resultants of the first and second sets of shear forces.

2. The device in accordance with claim 1, c h a r a c - t e r i z e d i n that the rigidity of the annular plate (18) helps to maintain the circular shape of the pipe (12).

3. The device in accordance with claim 1, c h a r a c - t e r i z e d i n that a torsion plate (20) is arranged at a distance from the annular plate (18), the torsion plate (20) being arranged to absorb torques in the pipe (12).

4. The device in accordance with claim 3, c h a r a c - t e r i z e d i n that, together, the annular plate (18) and the torsion plate (20) are arranged to absorb a pair of forces in the radial direction of the pipe (12).

5. The device in accordance with claim 1, c h a r a c - t e r i z e d i n that the adjacent structure (14) is formed by a trusswork structure including main columns (22) and struts (24).

6. The device in accordance with claim 5, characterized in that the central lines of the main columns (22) intersect at or close to a point on the central axis of a turbine (2).

7. The device in accordance with claim 5, characterized in that the struts (24) of the trusswork structure (24) include compressive rods and tie rods, at least one of the tie rods being formed by a rope strut.

8. The device in accordance with claim 5, characterized in that the trusswork structure (14) is provided, at its lower portion, with sleeves (26) complementarily fitting over respective piles (8).

9. The device in accordance with claim 8, characterized in that the sleeve (26) are fitted with stops which are arranged to make the tower automatically be vertical when the piles have been driven to the same vertical elevation.

10. The device in accordance with claim 9, characterized in that the piles (8) for different towers (4) have different heights above the sea bed and, thereby, are arranged to receive like towers (4), the towers extending equally high above the sea surface after installation.

11. The device in accordance with claim 9, characterized in that the trusswork (14) is formed without struts (24) in a zone in which ice will affect the struts (24), conical elements encircling the main columns (22) being arranged to break up any ice that may attach to the main columns (22).

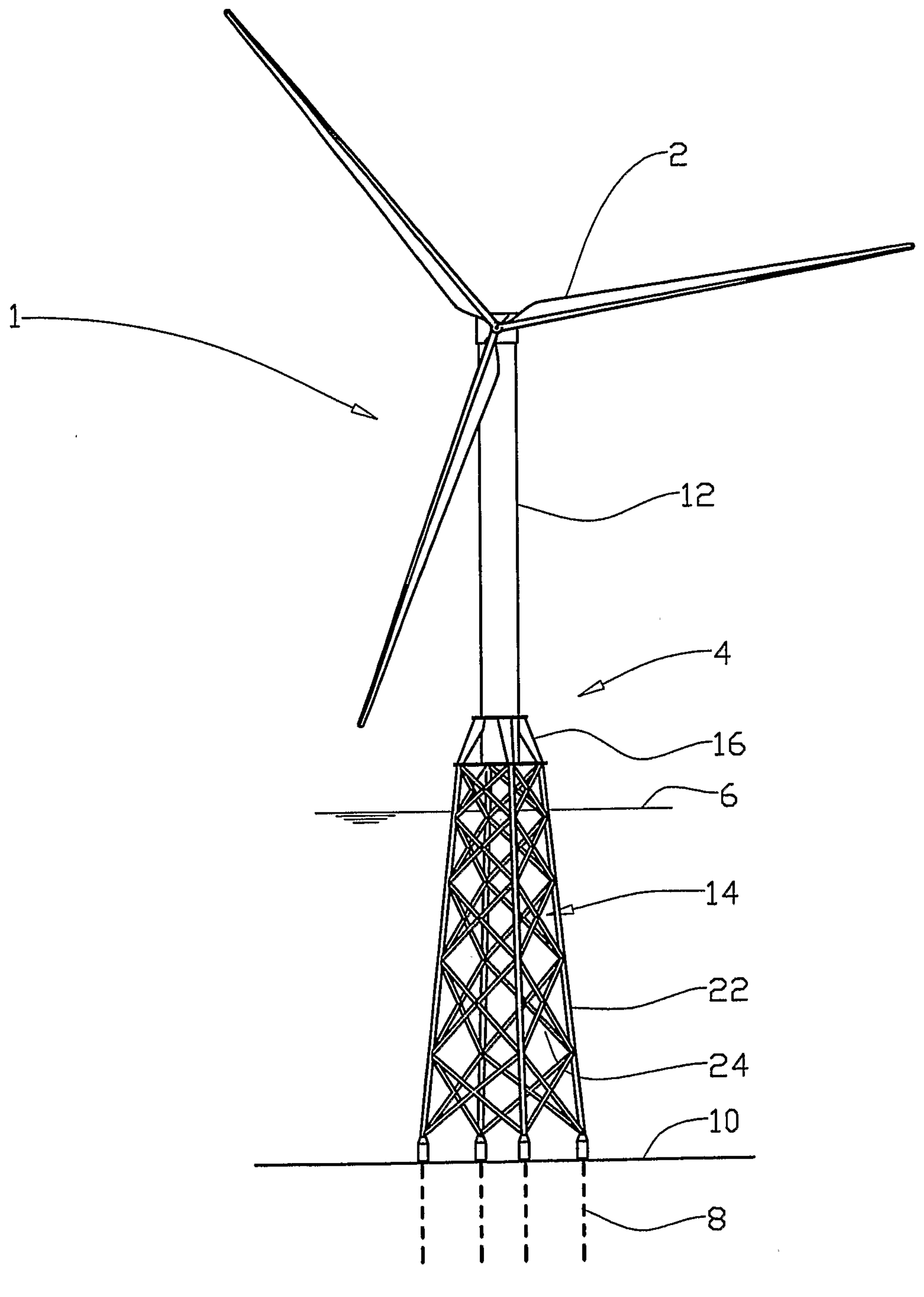

Fig. 1

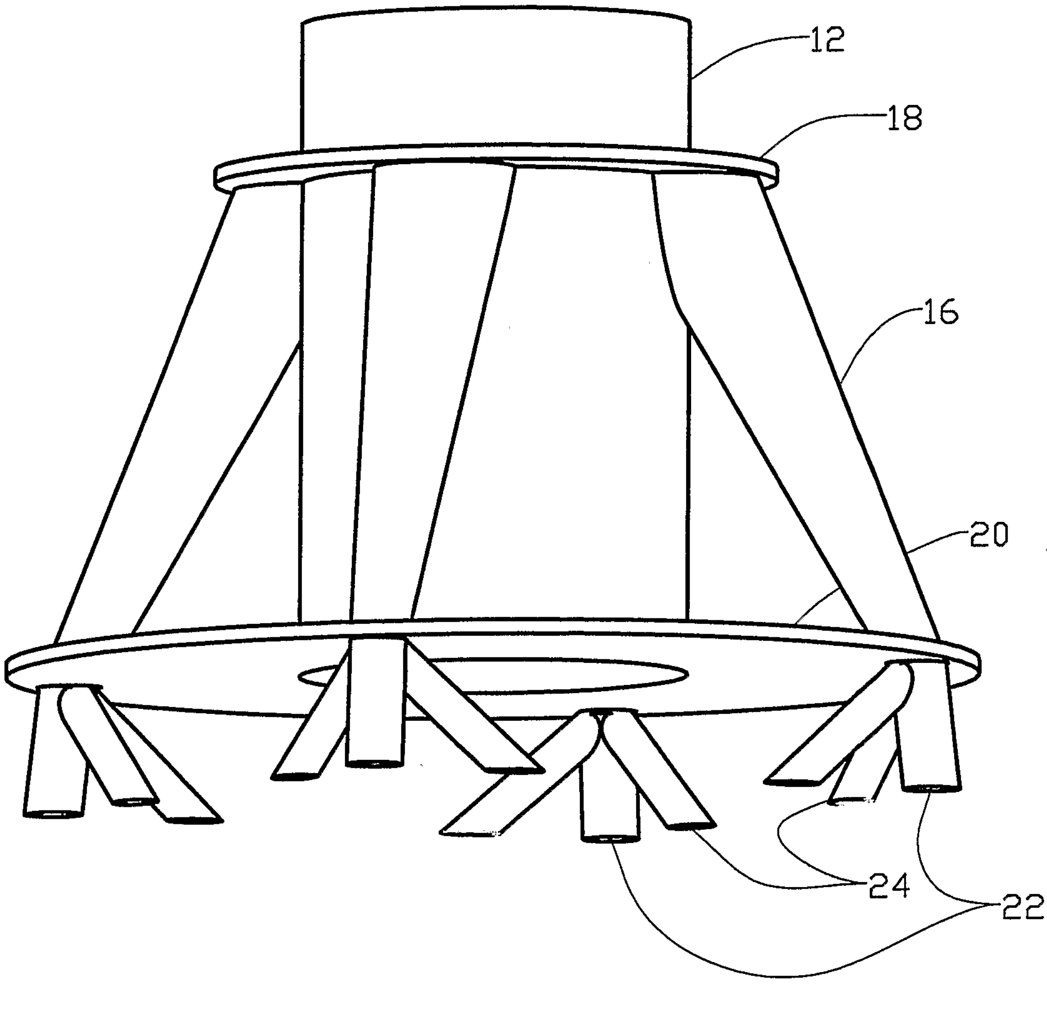

Fig. 2

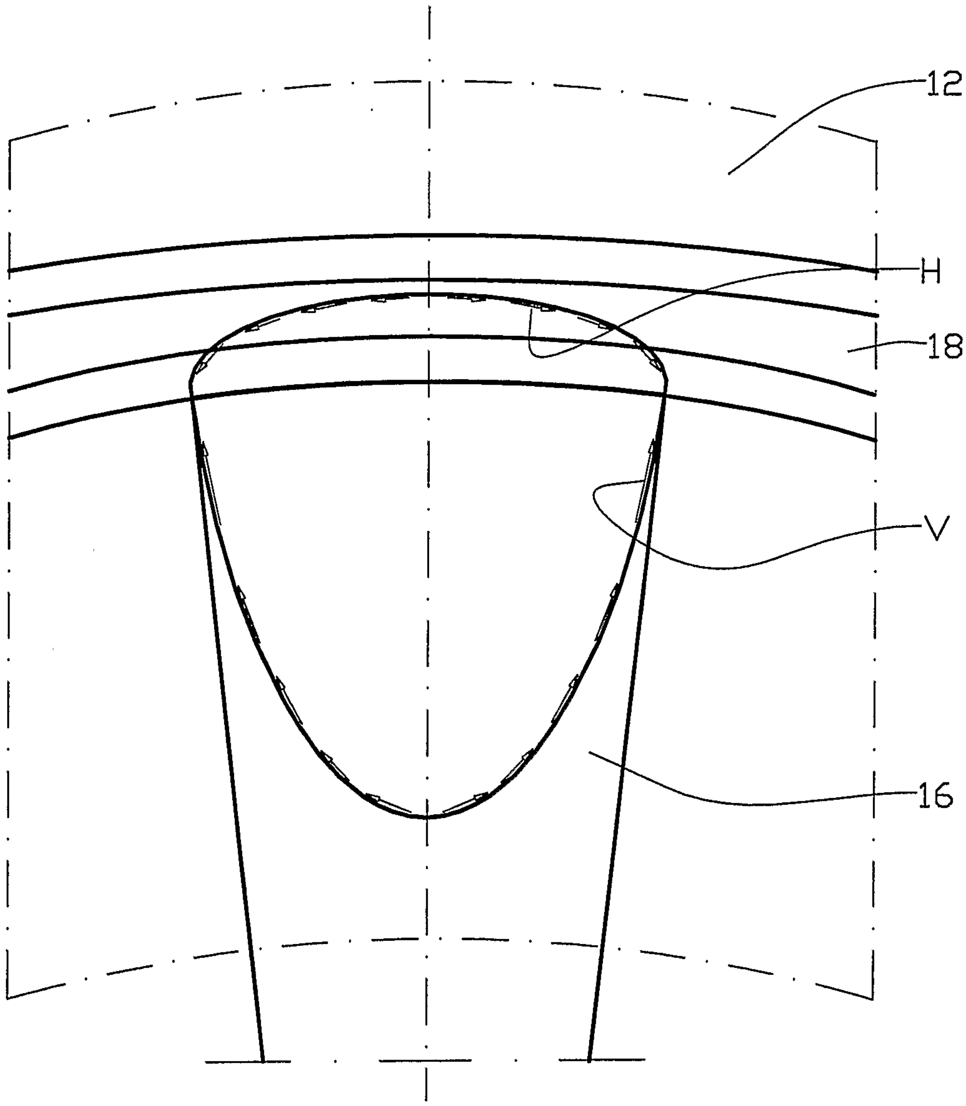

Fig. 3

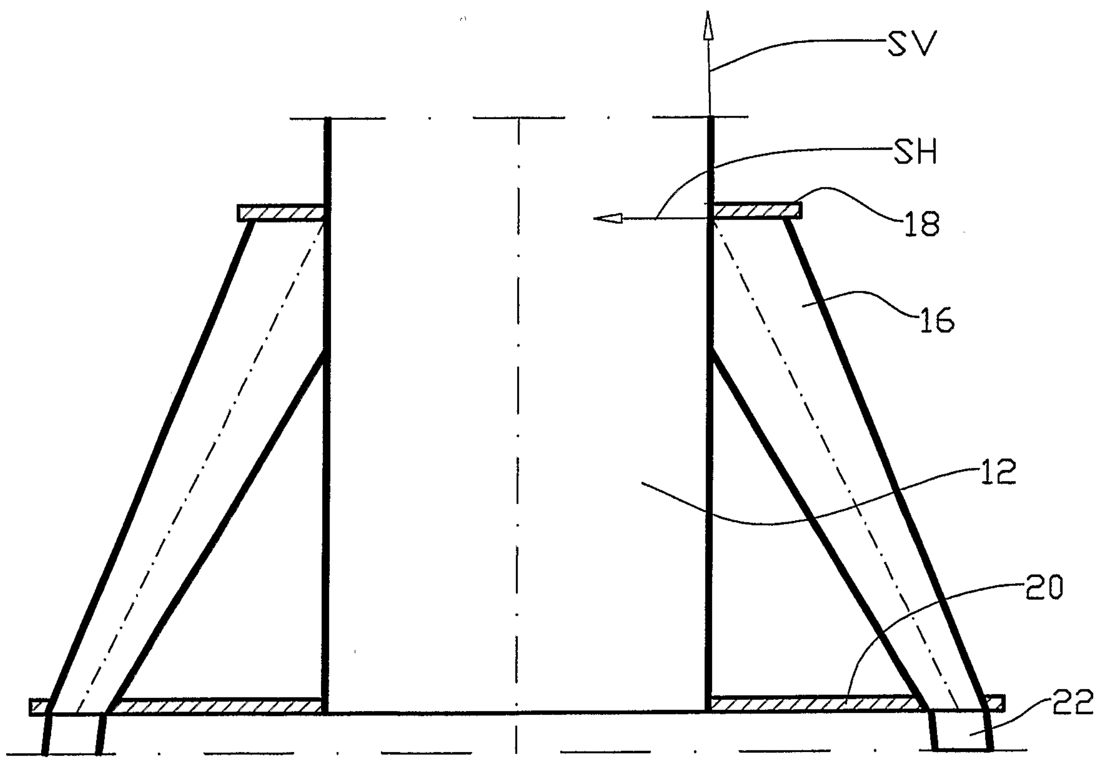

Fig. 4

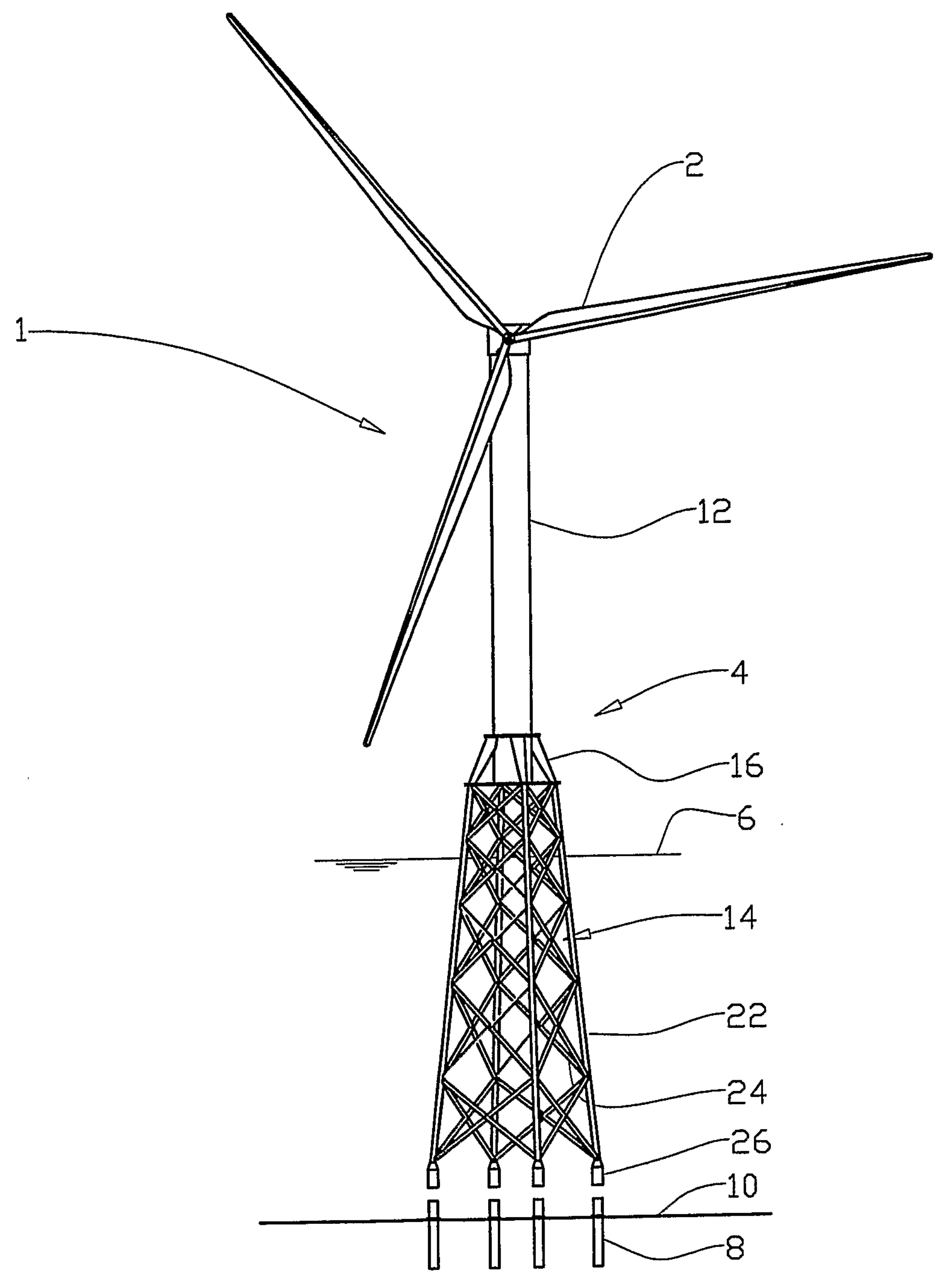

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 2005/000231

A. CLASSIFICATION OF SUBJECT MATTER

IPC7: E04H 12/10, F03D 11/04

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)

IPC7: E04H, F03D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5832688 A (M.E. CRISSEY ET AL), 10 November 1998 (10.11.1998) --	1-11
A	WO 03066427 A1 (FRED. OLSEN RENEWABLES LTD.), 14 August 2003 (14.08.2003) --	1-11
A	EP 1101935 A2 (BONUS ENERGY A/S), 23 May 2001 (23.05.2001) --	1-11
A	EP 1234978 A2 (BRIESE, R.), 28 August 2002 (28.08.2002) -- --------	1-11

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

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"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
26 October 2005	27 -10- 2005

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Åke Olofsson / MRo Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT
Information on patent family members

01/10/2005

International application No.
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