

## **Ship For Transporting A Wind Turbine Onto An "Offshore" Site And Method For Placing It**

The present invention relates to a ship for transporting to an "offshore" site, that is one located in the open ocean, a wind turbine provided with a so-called "gravity type" foundation.

It also relates to a process for placing a wind turbine on an "offshore" installation site, using a ship.

Currently, most wind farms are installed on offshore sites in two main steps. The first consists of a phase involving installation of the foundations for the wind turbines, while the second consists of the installation of the wind turbines themselves, that is placing their pylon, their cowlings and their blades.

For the foundations, there are several types of ships allowing them to be transported on-site and to be installed. These ships depend on the type of foundation. They can consist of a barge or a ship of the "jack up" (self-lifting) type, a barge-mounted crane of the "shear leg" type, or even various crane-equipped ships.

There exist several types of foundations for wind turbines. Thus mono-pile, jacket, gravity, tripod, suction pile etc. foundations can be mentioned.

For the lightest foundations (to wit, the mono-pile and tripod types), ships with small lifting capacity are suitable; they are more or less expensive and fairly common.

For the heaviest foundations, ships with high lifting capacity are needed, to wit more than 3000 tons for gravity foundations. The latter are scarce, hence having low availability, and expensive.

Operating time at sea has necessarily a higher cost than the same operations carried out on land.

Jack-up type ships spend a certain amount of time lifting themselves on their legs and in retracting them each time a wind turbine or foundation is laid. They carry out a piecewise erection of the wind turbine by means of cranes. This type of erection includes hazards connected with the multiplicity of operations and these are limited by meteorological conditions, particularly wind conditions (especially for mounting the blades).

In order to reduce operating time at sea, the idea of transporting the foundation and its associated wind turbine as a single piece to the offshore installation site has already been thought of. The complete assembly of the wind turbine is performed for example at a port site in proximity to the wind farm. A ship then comes to take the wind turbine assembled to its foundation to convey it to the site and to set it in place.

Examples of such techniques can be found in the documents of patents WO 2001/34 977, WO 2001/59 489, US 7 234 409, FR 2 923 454 and WO 2010/02 87 62.

Thus, in the first of these documents, a device is described, for installing a wind turbine on an offshore site, which allows its transportation without having to support the entire weight of this wind turbine.

The latter is capable of floating so long as its foundation holds little or no water.

In certain embodiments, the device has the form of a ship provided with jaws to grip the pylon of the wind turbine. Viewed from above, this ship has the form of a U-shaped fork with a longitudinal slot the facing edges

whereof have a spacing that is slightly greater than the diameter of the wind turbine's pylon.

For transportation, it is stated that the upper surface of the foundation comes into contact with the bottom of the ship and is held to it by cables, chains or similar elements.

Though this device seems to generally give satisfaction, the operation consisting of handling and placing the wind turbine on the sea bed under conditions that ensure stability that is as perfect as possible is perfectible.

Indeed, depositing a heavy package such as a wind turbine equipped with its foundation on the sea bed, from a ship that is floating and is therefore mobile on the water with six degrees of freedom, requires a tool that is both rigid for guiding the package and for stabilizing it up to its target on the water bottom, and flexible so that, once the package is deposited, the ship does not transmit excess horizontal forces to the base.

Thus, this objective may be attained in conformity with embodiments of the present invention.

A first aspect of the invention provides a ship for transporting to an "offshore" site a wind turbine provided with a so-called "gravity" foundation, that is one able to stabilize the wind turbine on a sea bottom under the influence of its own weight supplemented by that of the wind turbine, this ship having, viewed from above, the general shape of a "U" with two "branches" defining the hulls as well as a junction bridge connecting them, the space separating the hulls allowing engagement within it of the wind turbine's pylon, characterized by the fact that it comprises a plurality of rigid and vertical "piles" passing clear through said ship, their lower end being provided with deformable arrangements for connection to matching arrangements

borne by said foundation, these piles being movable, on demand, in the vertical direction, so that, by a descending movement of these piles, said wind turbine is guided and stabilized during this descending movement, and that, by a rising movement, said piles transmit a rising movement to said wind turbine.

The ship in question can be of the catamaran type.

Thus these piles, fifty or so meters long for example, allow this rigidity, for depositing a wind turbine on a bottom as much as 45 m deep, to be obtained.

The deformable connection arrangements, when they have a length of some ten meters, make it possible to have flexibility when moving within a cone of freedom of about ten degrees, corresponding to the horizontal motions of the ship related to the dynamic positioning performance (1 or 2 m deviation about the target position).

This design does not require arrangements to compensate for heave or other motions such as are found on many offshore cranes which deposit or pick up foundations on the water bottom or on another ship.

If four winches, installed on the ship, with cables connected to the foundation of the wind turbine were used, there would be a risk of having lateral displacements that would be difficult to control, due to the relative motions between the floating ship and the wind turbine during descents. These movements could either lead to instability of the wind turbine itself, or to undesired contact between the pylon of the wind turbine and the ship, or to unacceptable accuracy for the deposit on the bottom with respect to the required target. In addition, the current could also amplify these lateral position offsets.

According to other advantageous but not limiting features:

- said piles are four in number and are positioned, as seen from above, at the four square corners of a notional quadrilateral;

- said piles are so positioned that, for some, they are at the edge of said junction bridge, and for others, of said hulls;

- the length of said deformable arrangements is determined in such a way that the deformable arrangements compensate or absorb the motions of the ship so that the "package" consisting of the wind turbine and its foundation remains "stable" during placement on the "offshore" site;

- it includes arrangements for driving said piles in vertical motion;

- these arrangements include pinions which mesh with racks borne by said piles;

- said deformable means consist of slings;

- said deformable arrangements are provided, at their free end, with a system for connection to said foundation, these arrangements being preferably automatic and remotely operated;

- it includes arrangements capable of blocking the wind turbine during its transportation;

- said arrangements consisting of channels formed in the surface of the hull and having a vertical orientation, with an opening directed downward, while the foundation includes an equal number of protruding members, so arranged that they enter said channels and are locked into it;

- it is of the semi-submersible type.

Another aspect of the invention provides to a method for placing on an "offshore" installation site, a wind turbine provided with a so-called "gravity" foundation, that is one that is able to stabilize the wind turbine on a sea bed under the influence of its own weight supplemented by that of the wind turbine, using a ship as defined in the first aspect, this wind turbine previously resting on a submerged site,

characterized in that it comprises the following steps:

a/ moving the ship until the lower end of the piles is vertically above or substantially above the matching connection arrangements borne by the foundation;

b/ lowering the piles and connecting the deformable means to said matching arrangements;

c/ raising the piles with the connected wind turbine, the foundation of the latter always remaining at least partially submerged;

d/ moving said ship toward the installation site while increasing its draft to improve its stability;

e/ positioning the ship vertically above the installation location;

f/ lowering the piles until the foundation rests on the sea bed;

g/ disconnecting the deformable arrangements and withdrawal of the ship.

According to advantageous and not limiting features of this method:

- between steps d/ and e/, the draft of said ship is further increased;

- said draft is increased by filling ballast compartments included in the ship with water;

- after said step f/, ballast compartments included in the foundation are filled.

Other features and advantages of the present invention will appear upon reading the description that follows. This will be carried out with reference to the appended drawings wherein:

- Figures 1 and 2 are simplified views, perspective and facing, respectively, illustrating the construction, on a port or other site, of the foundation

of a wind turbine;

- Figure 3 is also a perspective, simplified view of a tug moving two floating foundations like those of Figure 1;

- Figure 4 is a perspective view showing the assembly of a wind turbine using a crane and pylon sections carried by a barge to a so-called assembly site, located in a port or other area;

- Figure 5 is also a perspective view showing the foundation of the wind turbine in place on a chocking cradle, before erection of the pylon sections;

- Figure 6 is a top view showing the ship according to the invention in operation approaching the wind turbine;

- Figure 7 is a partial view, substantially similar to the foregoing, but from another viewing angle;

- Figure 8 is a perspective view of the wind turbine and of the ship, which is shown in phantom lines;

- Figure 9 is a perspective view of the foundation of the wind turbine and of part of its pylon, as well as of the four piles which equip the ship of the invention;

- Figure 10 is a partial view in a median and vertical section plane of one of these piles;

- Figure 11 is a partial view of the foundation intended to show the arrangements allowing it to be chocked relative to the ship;

- Figure 12 is a view from another angle of the foregoing arrangements which cooperate with slots made in the hull of the ship;

- Figures 13 and 14 are simplified perspective views illustrating the transportation of the wind turbine by the ship toward the installation site;

- Figures 15 and 16, for their part, show the wind turbine lowering and placing operation at the

offshore site;

- finally, Figures 17 and 18 illustrate the withdrawal of the ship's piles relative to the foundation, as well as the departure of the ship, leaving the wind turbine in place on its site.

In Figures 1 and 2 is shown, very schematically, the manufacture of a wind turbine foundation, for example on the floor of a dry-dock, of a form of construction which is able, if required, to be transported by a barge to a final assembly area of the wind turbine (Fig. 3).

Preferably, such a foundation consists of a steel shell, ballasted with concrete and capped with a trunk also made of steel, so that its geometry and its mass are compatible with the technical characteristics of the ship that will transport it,

As a variation, such foundations can be made exclusively of reinforced concrete.

The existence of sleeves 12 will be noted on the two opposite faces of this parallelepipedal foundation wherein are socketed, with the possibility of vertical movement, posts 13 (see Figure 3).

The advantage of these posts will be explained further on in the description.

Furthermore, the foundation does not necessarily have a parallelepipedal shape.

In order to allow optimization of cost and to secure the transit of these foundations 1, they are preferably compartmented into a certain number of adjoining cells 10, in a cross-shaped assembly 11, some being filled with concrete while others are empty. The latter are, however, designed to be ballasted by admitting water into their interior space or, for some filled with concrete in a subsequent step.

Purely by way of indication, at this step, the total mass of steel of this assembly can be 1300 tons,

while the mass of concrete can be 2000 tons.

In a subsequent step, not shown, the floating of the foundation is carried out, particularly with a view to its transit to an assembly site for the wind turbine.

It is possible, as shown in Figure 3, to connect two foundations (or more) together and move the assembly with a tug R of known type to, for example a foundation storage location in a port area.

On this figure as well as the following ones, the surface of the water and the sea bed are respectively labeled SE and FM.

By way of indication, the draft of the foundations during this transfer is on the order of 4.5 m.

The transfer of the foundation is carried out to the assembly site where there is a crane G capable of continuing and finishing the assembly of a wind turbine 2 onto its foundation 1. To this end, segments 22 of the pylon 23 of the wind turbine 2 have been placed in advance in proximity to the crane. The label 24 has been assigned to the cowl of the wind turbine and, for the sake of simplicity, the blades borne by it are not visible here. These elements can be brought by land or by sea by means of at least one barge such as that labeled B shown in the figure.

Figure 5 shows substantially the same situation as the preceding figure, except the foundation has been placed on a concrete or gravel cradle 3 allowing the assembly to be stabilized during this assembly phase.

In the two situations of Figures 4 and 5, care has been taken to fill with water the ballast compartments that were empty up until now and to complete the ballasting by filling certain compartments with concrete to reach 3800 tons of concrete, which are in addition to approximately 1300 tons of steel mentioned earlier.

When the pylon, the cowl and the blades are also

considered, this mass is increased by approximately 900 tons to reach a total of approximately 6000 tons. With a view to the transit of the "package" consisting of the wind turbine and its foundation, the water ballast compartments are then totally or partially emptied so that the apparent weight of this package reaches about 1400 tons due to the partial or total submersion of the foundation.

In Figures 6 and 7 are shown, from different angles, the approach phases of a ship that will allow the wind turbine 2 assembled on its foundation to an offshore site.

Initially, it is stated that the foundation described above is of the so-called gravity type, which means that it is stable on the sea bed under the influence of its own weight supplemented by that of the wind turbine itself.

It is therefore incapable of floating under any condition, once the wind turbine is set in place.

The aforementioned ship, labeled 4 in the figures, is of the semi-submersible catamaran type and has, seen from above, the general shape of a U the two "branches" whereof define parallel hulls 40, as well as a junction bridge 41 which connects them. Consequently there exists a space which separates the hulls 40 and which makes possible the engagement within it of the pylon 23 of the wind turbine, while the foundation 1 occupies a space sometimes located below the ship and sometimes located between the floats of the ship, depending on which step of the procedure is considered.

A stiffening crossmember, visible only in Figure 13 and labeled 45, allows an improvement in the resistance of the ship to strains and also allows an improvement in the hydrodynamic quality of the foundation which remains partially or totally submerged during transportation.

This crossmember is arranged underneath and at a distance from the junction bridge 41.

This bridge bears a superstructure 42 which constitutes the cockpit of the boat.

Finally, the junction bridge 41 has an extension 410 in the general shape of a U which is located vertically above the empty space and houses the service spaces.

One particularly important feature of the invention consists of the fact that the ship includes a plurality of rigid and vertical piles 5 which extend clear through it.

What is meant by the term "piles" is rigid vertical tubes which can be solid but are preferably hollowed out in their internal volume.

In the present case, these piles each have a height of about 55 m.

They are at a minimum three in number, but preferably four in number. In this case, they are arranged, viewed from above, at the three square corners of a fictitious quadrilateral which extends at the extension 410 of the junction bridge 41. These piles are driven any known mechanical system 411, such as for example a rack and pinion 53 which allows the pile assembly to be raised and lowered relative to the ship.

In Figure 10, one embodiment of such a pile is shown in cutaway. This pile 5 is hollow here. It has at its top a cowling 50 and is provided inside with stiffening platforms 51 through which it is possible to descend through openings through which passes a ladder.

Such a system allows in particular a safety inspection in order to ensure that all the parts relating to the piles are operating normally.

Also according to an essential claim of the invention, the lower end of the piles is provided with

deformable arrangements 6 for connection to matching arrangements 8 borne by the foundation.

Here in the embodiments shown these are slings 6 consisting of an assembly of links.

They could however consist of cables or any other deformable means. By way of indication, the length of this sling is on the order of 6 m.

Figures 8 and 9 make it possible to understand the position of the piles 5, the mechanical system 411 built into the ship and the slings 6 with respect to the ship and the foundation.

Referring to 9, it is noted that the foundation 1 has on its upper face and near its four corners wells 8 made up of a hollow tube which extends upward in a trunconical shape 80 with conicity diverging upward, serving as lifting points. A locking system 7, not visible, using a hook for example, allows the slings 6 to be connected to said lifting points 8 on the foundation.

During simultaneous descending motion of the piles 5 the location whereof is directly above the wells 8, it is possible to engage the slings 6 in the wells 8 and to firmly attach them through locking arrangements 7. When this operation is carried out, the foundation and the associated wind turbine are connected to the ship.

It is then possible to control the raising of the piles until the foundation 1 comes into abutment against the hull of the ship, as can be seen in Figure 14. It is possible to lock the wind turbine to the ship 4, for example by making use of arrangements shown in Figures 9 and 12.

These consist here of channels 44 made in each of the hulls of the ship 4, having a vertical orientation with a downward-facing opening, while the foundation 1 has an equal number of protruding members 9, so arranged that they enter into the channels 44 and come into

abutment against their bottom. Holding in this position of abutment is provided by a vertical pre-tension in the mechanical pile-raising system, no vertical movement (in the Z direction) then being possible.

More precisely, the protruding members are provided with plates 90 which enter into the channels 44.

As this design generates large vertical forces at the slings and the lifting points 8 (the dimensioning of the lifting points "carried" by the foundation also being critical), one variation would be to place a frame in the upper part of the piles and a system for blocking the motions of the foundation in the plane (in the X and Y directions) with respect to the ship. The degree of freedom in the Z (vertical) direction, with respect to the ship, then being free.

In this variation, the dimensioning of the lifting system is less problematic because it is not then pre-loaded and no longer handles dynamic moments, but only the forces due to the apparent weight of the package alone.

Thus lashed to the ship, the foundation has an apparent weight on the order of 1400 tons, due to the Archimedes thrust which is exerted on the partially or totally submerged foundation.

The ship is then moved, preferably while increasing the draft of the ship 4 so as to improve its stability. To this end, the ship is of the semi-submersible type, which means that its hull includes ballast tanks which it is possible to fill with seawater.

During this maneuver, the draft is for example 10 m.

Once arrived at the site, the posts 13 are initially driven to lower them with respect to the sleeves 12 of the foundation 1 so that they project beyond the lower face of the foundation. Then

preparations are made to move the wind turbine to place it on the sea bed FM. To that end, the draft of the ship is increased if necessary, for example to 15 m, and the simultaneous lowering of the piles 5 is commanded.

Such a foundation, equipped with posts movable in the vertical direction, can be used independently of the ship described here.

It is easily understood that depositing a "heavy package" such as this wind turbine and its foundation on the sea bed from a ship 4 that is afloat (and therefore mobile on the water according to its motions) requires a rigid tool that guides the package and stabilizes it to its target on the water bottom.

In this case this consists of the piles 5. This tool must however be flexible so that, once the package is deposited, the ship does not transmit excessive horizontal forces to the foundation.

In this case, this involves the slings 6. These slings make it possible to have that flexibility by moving within a cone of freedom of some ten degrees, which corresponds to the horizontal motions of the ship connected with the dynamic positioning performance of the ship (1 or 2 m excursion about the target position. This technique does not require arrangements for compensating for heave or other motions, such as are normally found on many offshore cranes which deposit or lift packages on the water bottom or on another ship.

During this lowering motion, the posts 13 previously extended from their sleeve 12 penetrate into the sea bed FM, which considerably increases the stability of the wind turbine in the plane without disturbing the ground under the foundation. The closer the foundation 1 approaches the sea bed FM, the more the ship's heave is reduced due to the suction effect between the sea bed and the foundation.

Thus, upon contact between the foundation and the ground, the impact is reduced, as well as the danger of having the foundation lifted off the ground after having been deposited. As the load is gradually transferred from the ship to the sea bed, the ship's draft is reduced (on the order of 2 m in all). Once this operation is carried out, the connection arrangements 7 are remotely disconnected and the lifting tool is raised.

In a final step shown in Figure 18, the withdrawal of the ship then proceeds.

The filling of the air ballast spaces of the foundation with seawater can be triggered from the ship before its withdrawal, or by means of another ship capable of coming alongside the wind turbine while carrying out a simple valve opening operation near the water's surface SE.

CLAIMS

1. A ship for transporting to an "offshore" site a wind turbine provided with a so-called "gravity" foundation, that is one able to stabilize the wind turbine on a sea bottom (FM) under the influence of its own weight supplemented with that of the wind turbine, this ship having, viewed from above, the general shape of a "U" with two "branches" defining hulls, as well as a junction bridge connecting them, the space separating them allowing the engagement within it of the pylon of the wind turbine, characterized by the fact that it includes a plurality of rigid and vertical "piles" passing clear through said ship, their lower end being provided with deformable arrangements for connecting to matching arrangements borne by said foundation, these piles being movable on demand in a vertical direction so that, by a descending movement of these piles, said wind turbine is guided and stabilized during this descending movement and that, by a rising movement, said piles transmit a rising motion to said wind turbine.

2. A ship according to Claim 1, characterized by the fact that said piles are four in number and are positioned, viewed from above, at the four square corners of the of a fictitious quadrilateral.

3. A ship according to one of the foregoing claims, characterized by the fact that said piles are positioned in such a way that some are at the edge of said junction bridge and the others at the edge of said hulls.

4. A ship according to one of the foregoing claims, characterized by the fact that the length of said deformable connection arrangements is determined so that the arrangements compensate for or absorb the motions of the ship, so that the "package" consisting of the wind turbine and its foundation remains "stable" during the placing of the foundation on the "offshore" site.

5. A ship according to one of the foregoing claims, characterized by the fact that it includes arrangements for driving said piles in vertical translation.

6. A ship according to Claim 5, characterized by the fact that the arrangements include pinions which mesh with toothed racks borne by said piles.

7. A ship according to one of the foregoing claims, characterized by the fact that said deformable arrangements consist of slings.

8. A ship according to one of the foregoing claims, characterized by the fact that said deformable arrangements are provided at their free end with a system for connection to said foundation, these arrangements being preferably automatic and remotely operated.

9. A ship according to one of the foregoing claims, characterized by the fact that it includes arrangements capable of blocking the wind turbine during its transportation.

10. A ship according to Claim 9, characterized by the fact that said arrangements consist of channels

formed in the surface of the hull and having a vertical orientation, with a downward-directed opening, while the foundation has an equal number of protruding members, so disposed that they enter said channels and are locked into them.

11. A ship according to one of the foregoing claims, characterized by the fact that it is of the semi-submersible type.

12. A method for placing, on an "offshore" installation site, a wind turbine provided with a so-called "gravity" foundation, that is one that is able to stabilize the wind turbine on a sea bed under the influence of its own weight supplemented by that of the wind turbine, using a ship conforming to one of Claims 1 through 10, in combination with Claim 11, this wind turbine previously resting on a submerged site, characterized by the fact that it includes the following steps:

a/ moving the ship until the lower end of the piles is vertically above or substantially above the matching connection arrangements borne by the foundation;

b/ lowering the piles and connection of the deformable arrangements to said matching arrangements;

c/ raising the piles with the connected wind turbine, the foundation of the latter always remaining at least partially submerged;

d/ moving said ship toward the installation site while increasing its draft to improve its stability;

e/ positioning the ship vertically above the installation location;

f/ lowering the piles until the foundation

rests on the sea bed;

g/ disconnection of the deformable arrangements and withdrawal of said ship.

13. A method according to claim 12, characterized by the fact that, between steps d/ and e/, the draft of the ship is increased still further.

14. A method according to one of Claims 12 or 13, characterized by the fact that said draft is increased by filling with water some ballast compartments built into the ship.

15. A method according to one of Claims 12 through 14, characterized by the fact that after said step f/, the ballast compartments built into the foundation are filled with water.

ABSTRACT**SHIP FOR TRANSPORTING A WIND TURBINE ONTO AN "OFFSHORE"  
SITE AND METHOD FOR PLACING IT**

The present invention relates in particular to a ship (4) for transporting onto an "offshore" site a wind turbine (2) provided with a so-called "gravity" foundation (1), that is one capable of stabilizing the wind turbine (2) on a sea bed (FM) under the influence of its own weight supplemented by that of the wind turbine, this ship (4) having, viewed from above, the general shape of a "U," with two "branches" defining hulls (40), as well as a junction bridge (41) connecting them, the space separating these hulls (40) allowing the pylon (23) of the wind turbine (2) to enter, characterized by the fact that it includes a plurality of rigid vertical "piles" (5), which extend clear through said ship (4), their lower end being provided with deformable arrangements (6) for connection to matching arrangements (8) borne by said foundation (1), these piles being movable, on demand, in the vertical direction, so that, by a descending motion of these piles (5), said wind turbine (2) is guided and stabilized during this descending motion, and so that, by a rising motion, said piles (5) transmit a rising motion to said wind turbine (2).

FIG. 18