WO 202128016 A1 describes a vessel and device for upending an elongate element from a deck of the vessel using a lifting means. A number of support structures, mutually coupled and running parallel to each other, for supporting an elongate element in lying position can be displaced collectively, parallel to the deck, relative to the position of the lifting means by displacing means provided for this purpose. A support structure of the device comprises an upending tool which is connected for pivoting around an axis running parallel to an edge of the vessel to the relevant support structure and is configured to support an elongate element received in the support structure when this element is upended with the lifting means, wherein the upending tool is rotated around the axis. With the device elongate elements can be moved within reach of a lifting means.

EP 3575199 A1 describes a monopile fastening system for retaining a monopile during transport, comprising a frame for supporting the monopile, which frame comprises supporting elements at a predetermined distance from each other, which distance is selected to enable the frame to receive and support the monopile, wherein the supporting elements are embodied as vertical standards, wherein at least a first vertical standard is provided with at least one pivotable and upstanding arm having its pivot in common with the first vertical standard, and that at least one flexible element or band is provided to connect the first vertical standard with a second vertical standard, wherein the at least one flexible element or band is embodied with two extremities distant from each other at the ends of the flexible element or band, and wherein a first extremity of the at least one flexible element or band connects to the upstanding arm at a position distant from the pivot which the arm has in common with the first vertical standard, and a second extremity of the at least one flexible element or band connects to the second vertical standard.

One disadvantage with these known solutions is that they do not allow pile movements without use of other auxiliary equipment such as heavy lift cranes. In addition to an increase in complexity and operation cost, use of such auxiliary equipment may reduce accuracy as well as an increased need of human interventions. The latter may also involve serious health hazard.

Embodiments of the present invention seek to provide a method and a related system that allows displacement of a pile from its parking position with high degree of accuracy.

Embodiments of the present invention also seek to provide a method and a related system that reduces the need of human intervention during such pile displacement, i.e. that allows for a high degree of automation.

SUMMARY OF THE INVENTION

The present invention is set forth and characterized in the main claims, while the dependent claims describe other characteristics of the claimed invention.

According to a first aspect of the present invention, there is provided a method for displacing a horizontally oriented monopile for an off-shore wind turbine parallel to a base floor by use of a pile displacement system. Note that a pile is herein defined as any elongated object such as steel construction beams, monopiles for wind turbines or wind turbine blades.

The pile displacement system comprises a first subsystem and a second subsystem arranged adjacent to each other along a longitudinal axis *L* of the pile.

Each of the first and the second subsystems comprises a height adjustable support and a pile support unit arranged on the height adjustable support such that the pile support unit is movable along the pile's longitudinal axis *L*.

The inventive method comprises the following steps:

A. arranging the pile to be handled onto the pile support units of the first and second subsystems such that the pile's longitudinal axis *L* is oriented parallel to the base floor,
B. lowering the height adjustable support of at least the first subsystem towards the base floor by use of height adjusting means such as hydraulic cylinders until at least part of the weight of the pile has been transferred from the at least first subsystem to an external support structure aligned along the pile's longitudinal axis *L*, adjacent to the first subsystem,
C. moving the pile support unit of the first subsystem a distance in direction away from the external support structure, the distance being less or equal to a length of the height adjustable support of the first subsystem along the longitudinal axis *L*,
D. raising the height adjustable support of the first subsystem away from the base floor until the at least part of the weight of the pile is transferred from the external support structure back to the first subsystem and
E. moving the pile support units of the first and the second subsystems a distance in direction towards the external support structure, thereby shifting the position of the pile along its longitudinal axis *L* more towards the external support structure.

As for step C, the distance in step E is less or equal to a minimum length of the height adjustable supports along the longitudinal axis *L*.

The pile displacement system is preferably connected to a dedicated control system that allows remote operations of at least the movements in steps B to E.

In an exemplary configuration of the claimed invention, the method further comprises the step of moving the pile displacement system sideways along the base floor in

The design of the external support structure is preferably mirror symmetric around a vertical center plane, for example a cradle form or a horizontal beam. In this case the vertical center plane is the plane intercepting a midpoint of the external support structure along the horizontal extent perpendicular to the longitudinal axis *L*. In case the external support structure is not mirror symmetric, the vertical center plane can be defined as the vertical plane intercepting the center of mass of the external support structure. Alternatively, the center of gravity may be used.

In another exemplary configuration of the claimed invention the base floor is a deck constituting part of a vessel suitable for transporting a plurality of wind turbine monopiles between a port and an installation site and the external support structure constitutes part of a pile upending tool configured to tilt one of the plurality of monopiles between a horizontal orientation parallel to the deck and located at least partly within the deck boundaries and a vertical orientation outside the deck boundaries.

The pile upending tool may further comprise an end support at an equal vertical height as the external support structure and arranged such that the external support structure and the end support are aligned along the pile's longitudinal axis *L*, and wherein steps B to E are repeated until a pile end of the pile located nearest the pile upending tool abuts the end support. The external support structure is hence in this exemplary configuration arranged between the end support and the first subsystem of the pile displacement system.

According to a second aspect of the present invention, there is provided a computer-readable medium having stored thereon a computer program comprising instructions to at least partly execute any of the method steps defined in the first aspect. For example, the computer program may control at least the movements B-E by communicating with motors controlling the various movements, and where the extents of the movements / alignments are set due to measurements of one or more installed sensors such as accelerometers.

According to a third aspect of the present invention, there is provided a pile displacement system suitable for displacing a monopile for an off-shore wind turbine towards an upper support of an upending tool aligned along a principal direction C transverse of the vessels deck. A pile is herein defined as any elongated object such as steel construction beams or monopiles for wind turbines.

The pile displacement system comprises a first subsystem and a second subsystem arranged adjacent to each other along a principal direction *C*, wherein each of the first and the second subsystems comprises a height adjustable support and a pile support unit movably coupled on top of the height adjustable support such that the pile support unit is movable along the principal direction *C,* and wherein the pile support unit of the first subsystem is aligned along *C* with the pile support unit of the second subsystem and the upper support.

During use, the pile displacement system may be arranged such that an external support structure as described above is situated next to the first subsystems with its vertical center plane aligned along the principal direction *C*.

Each pile support unit may comprise a concave pile receiving face in order to ensure sufficient horizontal stability of the pile. Such a concave pile receiving face preferably has a radius of curvature equal or near equal to a radius of curvature of the pile to be handled / displaced, for example a radius of curvature between 1 to 3 meters.

Moreover, each of the first and the second subsystems may comprise height adjusting means such as hydraulic cylinders and/or linear actuators for adjusting the height of the height adjustable support relative to a base floor during use. Such height adjusting means are fixed between the height adjustable supports and the base floor / deck.

The pile displacement system may further comprise one or more a pile displacement system bases onto which the height adjustable supports of the first and second subsystems are connected via the height adjusting means. Preferably, a single pile displacement base is used for both the first and the second subsystems. However, one system base for each subsystem may also be envisaged.

The pile displacement system base may be configured such that it is movable sideways along a base floor onto which the system base is supported during use. The direction of the sideways movement is perpendicular to the principal direction *C*.

The side of the pile displacement system base facing towards the base floor during use may comprise a recess and/or a protrusion for allowing restricted / guided movement on one or more base floor tracks/rails oriented perpendicular to the principal direction *C* on or within the base floor. Said protrusions may be wheels configured to move on linear rails. Use of low friction sliding bars may also be envisaged.

In addition, or alternatively, the pile displacement system may be moved by use of a rack-and-pinion system comprising circular gears (pinions) connected to linear gear (rack) arranged along the base floor. The circular gears, and the corresponding drive motor driving the circular gears, may be a separate unit located at on the side of the up-ending tool (i.e. along the aft-bow-direction) opposite the locations of the piles.

In particular during displacement of monopiles for wind turbines a preferred embodiment is the use of *both* a wheel / rail system and a rack-and-pinion- system in order to handle the excessive weights with sufficient accuracy and safety.

CLAIMS

1. A method for displacing a horizontally oriented monopile for an off-shore wind turbine parallel to a base floor by use of a pile displacement system comprising
- a first subsystem and
- a second subsystem arranged adjacent to the first subsystem along a longitudinal axis of the monopile,
wherein each of the first and the second subsystems comprises
- a height adjustable support and
- a pile support unit arranged on the height adjustable support such that the pile support unit is movable along the monopile's longitudinal axis,
wherein the method comprises the steps:

A. arranging the monopile onto the monopile support units of the first and second subsystems,
B. lowering the height adjustable support of at least the first subsystem towards the base floor until the weight of the monopile is transferred from at least the first subsystem to an external support structure aligned along the monopile's longitudinal axis, adjacent to the first subsystem,
C. moving the pile support unit of the first subsystem a distance in direction away from the external support structure,
D. raising the height adjustable support of the first subsystem away from the base floor until the weight of the monopile is transferred from the external support structure to the first subsystem and
E. moving the pile support units of the first and the second subsystems a distance in direction towards the external support structure.

2. The method in accordance with claim 1, wherein the method further comprises the step of
- moving the pile displacement system sideways along the base floor in direction perpendicular to the monopile's longitudinal axis.

3. The method in accordance with claim 2, wherein, prior to step A, the method further comprises the steps:
- lowering the height adjustable supports towards the base floor such that the highest point of the pile displacement system is lower than a minimum vertical distance from the base floor to the horizontal monopile stored on the base floor within a pile parking support,
- moving the pile displacement system sideways along the base floor towards the horizontal monopile and
- aligning the pile displacement system with the monopile's longitudinal axis such that the pile supporting units are located directly below the monopile.

4. The method in accordance with claim 3, wherein the method further comprises the steps of
- raising the height adjustable supports until step A is completed and
- continue raising the height adjustable supports until the lowest point of the pile relative to the base floor is higher than the highest point of the pile parking support.

5. The method in accordance with claim 4, wherein, between step A and step B, the method further comprises the step of
- moving the pile displacement system with the monopile sideways towards the external support structure and,
- if needed, raising the height adjustable supports until the lowest point of the monopile relative to the base floor is higher than the highest point of the external support structure.

6. The method in accordance with any one of the preceding claims, wherein, between step A and step B, the method further comprises the step:
- moving the pile displacement system sideways until the monopile's longitudinal axis is aligned with a vertical center plane of the external support structure.

7. The method in accordance with any one of the preceding claims, wherein
- the base floor is a deck constituting part of a vessel suitable for transporting a plurality of wind turbine monopiles between a port and an installation site and
- the external support structure constitutes part of a pile upending tool configured to tilt one of the plurality of monopiles between

a horizontal orientation parallel to the deck and located at least partly within the deck boundaries and

a vertical orientation outside the deck boundaries.

8. The method in accordance with claim 7, wherein the pile upending tool further comprises
- an end support at an equal vertical height as the external support structure and arranged such that the external support structure and the end support are aligned along the monopile's longitudinal axis, and
wherein steps B to E are repeated until a pile end of the monopile located nearest the pile upending tool abuts the end support.

9. A computer-readable medium having stored thereon a computer program comprising instructions to execute the method steps of any one of claims 1-8.

10. A pile displacement system for displacing a monopile for an off-shore wind turbine towards an upper support of an upending tool aligned along a principal direction transverse of the vessels deck, wherein the pile displacement system comprises

- a first subsystem and a second subsystem arranged adjacent to each other along the principal direction,
wherein each of the first and the second subsystems comprises
- a height adjustable support and
- a pile support unit movably coupled on top of the height adjustable support such that the pile support unit is movable along the principal direction, and
wherein the pile support unit of the first subsystem is aligned with the pile support unit of the second subsystem and the upper support.

11. The pile displacement system in accordance with claim 10, wherein each pile support unit comprises a concave pile receiving face.

12. The pile displacement system in accordance with claim 11, wherein the concave pile receiving face has a radius of curvature equal or near equal to a radius of curvature of the monopile to be displaced.

13. The pile displacement system in accordance with any one of claims 10 to 12, wherein each of the first and the second subsystems comprises height adjusting means for adjusting the height of the height adjustable support relative to a base floor during use.

14. The pile displacement system in accordance with claim 13, wherein the pile displacement system further comprises
- a pile displacement system base onto which the height adjustable supports of the first and second subsystems are connected via the height adjusting means.

15. The pile displacement system in accordance with claim 14, wherein the pile displacement system base is configured movable along a base floor onto which the pile displacement system base is supported during use, in direction perpendicular to the principal direction.

16. The pile displacement system in accordance with claim 14 or 15, wherein the side of the pile displacement system base facing towards the base floor during use comprises at least one of a recess and a protrusion for allowing movement on one or more base floor tracks oriented perpendicular to the principal direction on or within the base floor.

17. The pile displacement system in accordance with any one of claims 10-16, wherein
each height adjustable support comprises a pile supporting unit guiding track oriented in the principal direction and
each pile supporting unit comprises at least one of a recess and a protrusion for allowing movement along the pile supporting unit guiding tracks.