

## PILE HOLDING SYSTEM

This invention relates generally to a pile holding system for installing offshore foundation piles. More specifically, although not exclusively, this invention relates to a pile holding  
5 system for installing offshore monopiles.

Offshore foundation piles, such as monopiles, are generally installed by suspending the pile from the side of a marine vessel, in a vertical configuration, to be driven into ground below water. The pile is typically lowered through the water and to the ground using a crane and  
10 is generally held against a side of the vessel by a pile holding system. The pile holding system maintains the pile in a vertical orientation during driving of the pile into the ground. In some cases, the pile holding system supports the pile during deployment, and is therefore rotated with the pile as the pile is upended by the crane.

15 The pile holding system typically has a pile gripper assembly with jaws, which surround the pile. The inner surface of the jaws may have rollers to allow the pile to move in a vertical direction through the jaws as it is driven into the ground. The pile holding system typically has a mounting assembly for mounting the pile holding system to the vessel. In some known systems, the mounting assembly has a translation assembly for dynamically adjusting the  
20 lateral position of the pile holding system, normal to the axis of the pile, relative to the vessel, to account for movement of the vessel during pile driving.

Clearly, due to the large size of offshore foundation piles, the pile holding system is large and occupies a significant amount of space on the vessel. It is preferable to bring the pile  
25 gripper assembly inboard when not in use, and so this significant occupation of vessel space is exacerbated. Bringing the pile gripper assembly inboard is sometimes achieved by rotating the pile gripper assembly relative to the mounting assembly such that a plane of the pile gripper assembly, which is normal to the pile when the pile is located in the pile gripper assembly, is upright. However, with such a large size this means that the mounting  
30 assembly occupies a lot of space in the horizontal direction of the vessel, and the pile gripper assembly occupies a lot of space in the vertical direction of the vessel. This hinders operations which are performed on the vessel, such as maintenance of the pile gripper assembly due to the height of the pile gripper assembly and due to the inboard orientation of the pile gripper assembly. The inboard orientation of the pile gripper assembly also  
35 increases the complexity of attaching auxiliary equipment thereto, such as noise mitigation systems.

It would therefore be advantageous to overcome at least some of these limitations.

Accordingly, a first aspect of the invention there is provided a pile holding system for installing offshore foundation piles into ground, the pile holding system comprising:

- 5 a pile gripper assembly;
- a mounting assembly for attachment of the pile holding system to a marine vessel;
- a connection assembly comprising a connection member; and
- actuation means connected to at least one of the pile gripper assembly, the
- 10 mounting assembly or the connection member;
- wherein the connection member is pivotally connected to the pile gripper assembly, the connection member being pivotable relative to the pile gripper assembly about a first pivot axis,
- wherein the connection member is pivotally connected to the mounting assembly,
- 15 wherein the connection member is pivotable relative to the mounting assembly about a second pivot axis, wherein the first pivot axis and the second pivot axis are substantially parallel, and
- wherein the actuation means is configured to pivot the connection member about the first pivot axis and the second pivot axis to move the pile gripper assembly
- 20 relative to the mounting assembly between a first extreme position and a second extreme position.

With this system there are two points of relative rotation between the pile gripper assembly and the mounting assembly, enabling easy manoeuvring of the system. That is, the pile gripper assembly can rotate about both the first pivot axis and the second pivot axis when

25 moving between the first extreme position and the second extreme position. As such, the pile gripper assembly remains in a substantially horizontal orientation, during operation and parking time, as it is brought from an outboard position to an inboard position. The pile gripper assembly can substantially overlie the mounting assembly in the inboard position.

30 The result is a more compact solution that consumes less deck space than conventional holding systems. This increases operational flexibility in that additional space is available for other equipment, for example noise mitigation systems suspended below the pile gripper assembly. In addition, the pile gripper assembly is more easily accessible for maintenance. Moreover, the operational times are substantially reduced.

In certain embodiments the first pivot axis extends through the pivotable connection point between the connection member and the pile gripper assembly and the second pivot axis extends through the pivotable connection point between the connection member and the mounting assembly. This enables a very compact system that can provide service for large  
5 amount of operations.

In certain embodiments in the first extreme position and the second extreme position an angle between a gripping plane of the pile gripper assembly and a plane of the mounting assembly is less than  $90^\circ$ , preferably less than  $45^\circ$ , and more preferably less than  $10^\circ$ . The  
10 gripping plane may be defined as a plane which is normal to a longitudinal axis of a gripped offshore foundation pile, in use.

As the pile gripper assembly is able to rotate about both the first pivot axis and the second pivot axis when moving between the first extreme position and the second extreme position, rotation between the gripping plane of the pile gripper assembly and the plane of the  
15 mounting assembly can be limited. That is, the pile gripper assembly is not brought inboard by rotating the pile gripper assembly relative to the mounting assembly such that the gripping plane is vertical. Instead the pile gripper assembly can remain in a substantially horizontal orientation as it is brought from an outboard position to an inboard position. As a  
20 result, the pile gripper assembly remains more accessible from the deck of the marine vessel.

In certain embodiments the plane of the mounting assembly is substantially parallel to the deck of the marine vessel. This permits to have a less complex configuration of the whole  
25 system, wherein the stresses on critical parts of the system are better managed and/or limited, in both extreme positions.

In certain embodiments in the first extreme position, the second extreme position and all positions therebetween, an angle between the gripping plane of the pile gripper assembly  
30 and a plane of the mounting assembly is less  $45^\circ$ , and preferably less than  $10^\circ$ .

In certain embodiments the pile holding system is configured such that the planes of the pile gripper assembly and of the mounting assembly are substantially horizontal during installation of the offshore pile into the ground. This allows normal operations of the system  
35 during installation of the offshore pile into the ground, while the force capacity of the system is better controlled when the system is used on a floating vessel.

In certain embodiments in the first and second extreme positions, the gripping plane of the pile gripper assembly is substantially parallel with the plane of the mounting assembly.

5 In certain embodiments in all intermediate positions of the pile gripper assembly between the first and second extreme positions, the gripping plane of the pile gripper assembly is substantially parallel with the plane of the mounting assembly.

10 In certain embodiments in the first extreme position and the second extreme position the pile gripper assembly is in a spaced arrangement with the mounting assembly.

In this manner, auxiliary components, for example noise mitigation systems, can be suspended beneath the pile gripper assembly. These remain accessible from the deck of the vessel for maintenance in the inboard position.

15 In certain embodiments in the first extreme position, the second extreme position and all positions therebetween the pile gripper assembly is in a spaced arrangement with the mounting assembly.

20 In certain embodiments the connection member is a primary connection member, wherein the connection assembly further comprises a secondary connection member pivotally connected to at least one of the pile gripper assembly and the mounting assembly. Advantageously, this provides the possibility to use the secondary connection member for controlling either the pile gripper assembly and the mounting assembly for a motion compensated system when the pile installation is performed in a floating vessel, due to  
25 having two connection members to support the pile gripper assembly during motion compensation.

30 In certain embodiments the secondary connection member is pivotally connected to the pile gripper assembly, the secondary connection member being pivotable relative to the pile gripper assembly about a third pivot axis, the third pivot axis being substantially parallel to the first and second axes.

35 With this arrangement the pile gripper assembly can pivot relative to the connection assembly about two separate axis – the first pivot axis and the third pivot axis. This helps support the pile gripper assembly so as to remain substantially horizontal during retraction from the outboard position to the inboard position.

In certain embodiments the secondary connection member is pivotally connected to the mounting assembly, wherein the connection member is pivotable relative to the mounting assembly about a fourth pivot axis, the fourth pivot axis being substantially parallel to the first and second axes. This provides a very robust, while agile, system that can withstand  
5 large forces and therefore, can be easily used for large pile installation routines.

In certain embodiments the secondary connection member may be a first secondary connection member, and the pile holding system may comprise a second secondary connection member. The second secondary connection member may be pivotally  
10 connected to the pile gripper assembly. The second secondary connection member may be pivotable relative to the pile gripper assembly about the third pivot axis. The second secondary connection member may be spaced from the pivotal connection between the first secondary connection member and the pile gripper assembly. The second secondary connection member may be pivotable relative to the mounting assembly about the fourth  
15 pivot axis. The second secondary connection member may be spaced from the pivotal connection between the first secondary connection member and the mounting assembly.

In certain embodiments the primary connection member may be a first primary connection member, and the pile holding system may comprise a second primary connection member.  
20 The second primary connection member may be pivotally connected to the pile gripper assembly. The second primary connection member may be pivotable relative to the pile gripper assembly about the first pivot axis. The second primary connection member may be spaced from the pivotal connection between the first primary connection member and the pile gripper assembly. The second primary connection member may be pivotable  
25 relative to the mounting assembly about the second pivot axis. The second primary connection member may be spaced from the pivotal connection between the first primary connection member and the mounting assembly.

In certain embodiments the pile holding system may comprise a cross-member which  
30 connects the first and second primary connection members together.

In certain embodiments any or all of the primary or secondary connection members may be solid bodies. The primary or secondary connection members may be solid bodies in that any one part of each of the primary or secondary members does not move relative to any  
35 other part of the same primary or secondary connection member. This provides a robust assembly with little or minimal movement complications.

In certain embodiments the first extreme position is an outboard, or deployed, position and the second extreme position is an inboard, or retracted, position.

In certain embodiments the actuation means comprises at least one actuation assembly.

- 5 Each actuation assembly may comprise a linear actuator.

In certain embodiments each of the at least one actuation assembly is pivotally connected, at one end, to the mounting assembly, and is pivotally connected, at another end, to the connection member.

- 10 In certain embodiments the actuation assembly is pivotable relative to the connection member about another, or a fifth pivot axis, the another or fifth pivot axis being substantially parallel to the first and second axes.

- 15 In certain embodiments each of the at least one actuation assembly comprises an articulating arm with a first end pivotally connected to the mounting assembly and a second end pivotally connected to the connection member, and wherein a first end of the respective linear actuator is pivotally connected to the mounting assembly, and a second end of the respective linear actuator is pivotally mounted to the articulating arm.

- 20 In certain embodiments each articulating arm may comprise two parts pivotally connected together. A first of the two parts may be pivotally connected to the, or to a respective one of the, primary connection members. A second of the two parts may be pivotally connected to the mounting assembly. The respective linear actuator may be pivotally connected to the second part of the articulating arm at a position spaced from the pivotal connection between  
25 the two parts.

- In certain embodiments the actuation means comprises a winch with an elongate element, for example a wire rope. The elongate element may be connected or connectable to the pile gripper assembly and/or the connection assembly. The elongate element may be  
30 retractable or releasable to pivot the connection member about the first pivot axis and the second pivot axis to move the pile gripper assembly relative to the mounting assembly between a first extreme position and a second extreme position.

- In certain embodiments the mounting assembly comprises a translation assembly  
35 comprising two, parallel, first rails and two, parallel, second rails, the first and second rails being substantially perpendicular to one another, and the translation assembly comprising

driving means configured to move the pile gripper assembly and the linkage assembly along the first and second rails, to provide dynamic position control of the pile gripper assembly, in use.

- 5 In certain embodiments the pile gripper assembly comprises articulating jaws configured to surround the circumference of a pile, in use.

In certain embodiments, the pile holding system comprises a motion control system configured to compensate motion of the vessel to which the offshore foundation pile is  
10 mounted, via the pile gripper assembly, in use. to the motion control system may maintain the orientation of the pile gripper assembly, relative to the mounting assembly, at all times. This enables the pile to be kept substantially vertical and in the optimal position, while being driven into the seabed.

- 15 In certain embodiments, the translation assembly is controlled by the motion control system, such that the movement of the two, parallel, first rails and two, parallel, second rails is perpendicular to one another.

In certain embodiments, the linear actuators are controllable by the motion control system.  
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In certain embodiments, the motion control system comprises at least one sensor to determine the inclination angle of the pile with respect to the vertical axis of the pile. The at least one sensor might enable measurements of the pile inclination before and during the pile driving operation. Advantageously, this causes the pile  
25 holding system to actively adapt to the vessel motion and enable a secure and agile pile driving operation on a floating vessel. Moreover, the simultaneous and active control of the linear actuators as well as of the pile gripper assembly enables the fine use of thrusters on a floating vessel.

According to a second aspect of the invention there is provided a marine vessel comprising  
30 a pile holding system according to the first aspect of the invention, the mounting assembly of the pile holding system being mounted to the marine vessel. The mounting assembly may be mounted to a deck of the marine vessel. The mounting assembly may be mounted above or below a deck of the marine vessel. The mounting assembly may be mounted substantially parallel to a deck of the marine vessel.

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According to a third aspect of the invention there is provided a method of moving a pile gripper assembly of a pile holding system between a first extreme position and a second extreme position, the method comprising:

actuating actuation means of the pile holding system to pivot a connection member of a  
5 connection assembly relative to the pile gripper assembly about a first pivot axis and to  
pivot the connection member relative to a mounting assembly of the pile holding system  
about a second pivot axes, to move the pile gripper assembly relative to the mounting  
assembly, wherein the first and second pivot axes are substantially parallel to one another  
and wherein the mounting assembly is for attachment of the pile holding system to a marine  
10 vessel.

In certain embodiments, in the first extreme position and the second extreme position an  
angle between a gripping plane of the pile gripper assembly and a plane of the mounting  
assembly is less than  $45^\circ$ , and preferably less than  $10^\circ$ . The gripping plane of the pile  
15 gripper assembly may be normal to a longitudinal axis of a gripped offshore foundation pile,  
in use.

In certain embodiments in the first and second extreme positions, the gripping plane of the  
pile gripper assembly is substantially parallel with the plane of the mounting assembly.

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In certain embodiments during movement between the first and second extreme positions,  
the plane of the pile gripper assembly is substantially parallel with the plane of the mounting  
assembly.

25 In certain embodiments, during movement between the first and second extreme positions,  
the pile gripper assembly is maintained in a spaced arrangement with the mounting  
assembly.

In certain embodiments the first extreme position is an outboard, or deployed, position and  
30 the second extreme position is an inboard, or retracted, position.

In certain embodiments the actuation means comprises at least one actuation assembly  
which comprises a linear actuator, and wherein actuation of the actuation means comprises  
extending or retracting the linear actuator of the at least one actuation assembly.

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In certain embodiments the actuation means comprises a winch with an elongate element, for example a wire rope. The elongate element may be connected or connectable to the pile gripper assembly and/or the connection assembly. Actuation of the actuation means may comprise retracting or releasing the elongate element  
5 form the winch to pivot the connection member about the first pivot axis and the second pivot axis to move the pile gripper assembly relative to the mounting assembly between a first extreme position and a second extreme position.

In certain embodiments the pile holding system of the third aspect of the invention is that of the first aspect of the invention.

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According to a fourth aspect of the present invention there is provided a method of installing an offshore pile using a pile holding system mounted to a marine vessel, the method comprising:

gripping the offshore pile in a pile gripper assembly;  
15 moving the pile holding system from a second extreme position to a first extreme position according to a previous aspect of the invention, the second extreme position being a retracted position, the first extreme position being a deployed position; and performing a piling operation to drive the offshore pile into ground.

20 In certain embodiments, the method comprises actuating driving means to move the pile gripper assembly and connection assembly along substantially perpendicular first and second rails of a translation assembly which is comprised in the mounting assembly, the translation assembly also comprising the driving means, to provide dynamic position control of the pile gripper assembly relative to the marine vessel, when installing the pile.  
25 Advantageously, this may be used to account for movement of the vessel, for example when the vessel is floating and so waves, and currents, move the vessel. Additionally, or alternatively, this may be used to account for wave and current loads on the foundation pile, to maintain the foundation pile within inclination tolerances.

30 In certain embodiments gripping the offshore pile comprises gripping the offshore pile between articulating jaws of the pile gripper assembly which surround the circumference of the offshore pile.

For the avoidance of doubt, any of the features described herein apply equally to any aspect  
35 of the invention. For example, the method may comprise any one or more features or steps relevant to one or more features of the pile holding system.

Within the scope of this application it is expressly intended that the various aspects, embodiments, examples and alternatives set out in the preceding paragraphs, in the claims and/or in the following description and drawings, and in particular the individual features thereof, may be taken independently or in any combination. That is, all embodiments and/or  
5 features of any embodiment can be combined in any way and/or combination, unless such features are incompatible. For the avoidance of doubt, the terms “may”, “and/or”, “e.g.”, “for example” and any similar term as used herein should be interpreted as non-limiting such that any feature so-described need not be present. Indeed, any combination of optional features is expressly envisaged without departing from the scope of the invention, whether  
10 or not these are expressly claimed. The applicant reserves the right to change any originally filed claim or file any new claim accordingly, including the right to amend any originally filed claim to depend from and/or incorporate any feature of any other claim although not originally claimed in that manner.

15 Embodiments of the invention will now be described by way of example only with reference to the accompanying drawings in which:

**Figures 1a to 1d** are schematics of a pile holding system;

**Figure 2a to 2d** are schematics of the pile holding system of Figures 1a to 1d, with  
20 the addition of a noise mitigation system; and

**Figures 3a and 3b** are schematics of another pile holding system.

Referring first to Figure 1a-d, there is shown a pile holding system 1 for installing offshore foundation piles (not shown) into ground (not shown). The pile holding system 1 has a pile gripper assembly 2 and a mounting assembly 3. In this example the mounting assembly 3  
25 is attached to the deck D of a marine vessel, however, the mounting assembly may be mounted above or below the deck D. Preferably, the mounting assembly 3 is mounted substantially parallel to the deck D. The pile holding system 1 is attached to a side of the marine vessel so that the pile holding system 1 can extend beyond the boundary of the  
30 marine vessel.

The pile gripper assembly 2 is connected to the mounting assembly 3 via a connection assembly. In this example the connection assembly has first and second primary connection members 41 which are spaced from one another. In this example there is a  
35 cross member 41a connecting the two primary connection members 41 together. However, the cross-member 41a is optional. In this example each primary connection member 41 is

a solid body, for example a rod, beam or bar. It will be appreciated that any number of primary connection members may be provided, for example there may be one primary connection member.

- 5 The primary connection members 41 are pivotally connected, at first ends, to the pile gripper assembly 2. The primary connection members 41 are pivotally connected, at second ends, to the mounting assembly 3. The primary connection members 41 are pivotable relative to the pile gripper assembly 2 about a first pivot axis A1. The primary connection members 41 are pivotable relative to the mounting assembly 3 about a second pivot axis A2. The first  
10 pivot axis A1 and the second pivot axis A2 are substantially parallel to one another.

In this example the connection assembly has first and second secondary connection members 42. Each secondary connection member 42 is a solid body, for example a rod, beam or bar. The secondary connection members 42 are pivotally connected, at first ends,  
15 to the pile gripper assembly 2. The secondary connection members 42 are pivotally connected, at second ends, to the mounting assembly 3.

In this example, the two secondary connection members 42 have a common pivotable connection to the pile gripper assembly 2, and separate pivotable connections to the mounting assembly 3. In this way, the secondary connection members 42 diverge from one another in a direction away from their first ends to their second ends. In this example the  
20 two secondary connection members 42 are connected to one another by a cross member 42a proximal the pivotable connections to the mounting assembly 3. It will be appreciated that either or both of the common pivotable connection to the pile gripper assembly 2, and the cross-member 42a, may be omitted. For example, the two secondary connection  
25 members 42 may be spaced apart in their entirety in a substantially parallel manner. It will also be appreciated that the secondary connection members 42 may be omitted entirely, such that the pile gripper assembly 2 merely pivots relative to the primary connection members 41.

30 The secondary connection members 42 are pivotable relative to the pile gripper assembly 2 about a third pivot axis A3. The secondary connection members 42 are pivotable relative to the mounting assembly about a fourth pivot axis A4. The third pivot axis A3 and the fourth pivot axis A4 are substantially parallel to one another and are substantially parallel to the  
35 first and second pivot axes A1, A2.

The pile holding system 1 includes actuation means. In this example, the actuation means includes two actuation assemblies. Each actuation assembly has a linear actuator 51 and an articulating arm which is formed of a first part 52a and a second part 52b.

5 Each linear actuator 51 is pivotally connected to the mounting assembly 3 at one end and to the respective articulating arm at another end. In each articulating arm, ends of the first and second parts 52a, 52b are pivotally connected to one another. Another end of the first part 52a of each articulating arm is pivotally connected to the mounting assembly 3 at a separate position to the pivotable connection between the respective linear actuator 51 and  
10 the mounting assembly 3. Another end of the second part 52b of each articulating arm is pivotally connected to a respective one of the primary connection members 41 such that the second part 52b of each articulating arm is pivotable relative to the respective primary connection member 41 about a fifth pivot axis A5. The fifth pivot axis A5 is spaced from and parallel to the first, second, third and fourth pivot axes A1, A2, A3, A4. Each linear actuator  
15 51 is pivotally connected to the first part 52a of the respective articulating arm at a distance along the length of the first part 52a. In this example the first parts 52a of the two actuation arms are connected together via a cross-member 52c. However, the cross member 52c is optional.

20 The actuation means may instead be provided by a winch (not shown). An elongate element, such as a wire rope, or the winch is connected to connectable to the pile gripper assembly 2, such that retracting or releasing the wire rope moves the pile gripper assembly 2 relative to the mounting assembly.

25 The pile gripper assembly 2 has openable jaws 21 which define a substantially circular passage when closed. The jaws 21 are openable such that an offshore pile (not shown) can be located in, and gripped by, the jaws 21 of the pile gripper assembly 2. In this example, the pile gripper assembly 2 has a plurality of roller devices 22 located around the periphery of the circular passage. When the jaws 21 are closed about the pile, the pile is  
30 gripped by the roller devices 22 and is thus permitted to move in an axial direction but is prevented from movement in other directions. In this way, the pile gripper assembly 2 is usable to hold the pile in a vertical orientation while the pile is driven into the ground during a pile driving operation.

35 In certain embodiments the mounting assembly 3 includes a mounting frame for mounting the pile gripper assembly 2 and the connection assembly to the deck D. The mounting

frame may fix the pile holding system 1 with respect to the deck D. However, in other examples, the mounting frame may allow the pile holding system 1 to move relative to the deck D.

5 In this example the mounting assembly 3 includes a translation assembly having two, parallel, first rails 31 and two, parallel, second rails 32. The first rails 31 are substantially perpendicular to the second rails 32. The first rails 31 are mountable to the marine vessel. In this example, the first rails 31 are mounted to the deck D of the marine vessel, but, as mentioned previously, it will be appreciated that the first rails 31 might be mounted in  
10 another manner, such as to another structure which is present on the deck D, or mounted below deck D.

In this example the first and second rails 31, 32 are coupled together by movement devices, for example a moveable carriage or the like.

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In this example the movement devices permit the second rails 32 to move along the axial direction of the first rails 31. In this example the movement devices are biaxial couplings in that they also permit the second rails 32 to move in the axial direction of the second rails 32. That is, the second rails 32 are permitted to move, relative to the movement devices,  
20 along their longitudinal axis across the first rails 31. In this manner, the second rails 32 can move in a first direction (the axial direction of the first rails 31) and a second direction (the axial direction of the second rails 32).

In this example, the mounting assembly 3 includes driving means, which are operable to  
25 drive the movement of the second rails 32 and/or the movement devices along the axial direction of the first rails 31 and along the axial direction of the second rails 32. The driving means may include a motor or the like. The driving means may be coupled to the second rails 32 or the movement devices. In this example, the driving means are controlled by a motion control system (not shown). The motion control system drives the driving means in response to one or more sensors which measure the inclination or the foundation pile,  
30 during a pile driving application, to maintain the foundation pile in a substantially vertical orientation. Other sensors may also be present to measure the position and/or orientation of the vessel, and the motion control system may use these further measurements to control the driving means.

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In this example, the primary connection members 41, secondary connection members 42, linear actuators 51 and first parts 52a of the articulating arms are all pivotally connected to the second rails 32. It would be understood that this connection may be direct, as shown in the illustrated examples, or indirect, for example via an intermediate platform. In this way, movement of the second rails 32 relative to the first rails 31 moves the pile gripper assembly 2. This allows the position of the pile gripper assembly 2, relative to the marine vessel, to be adjusted, or dynamically controlled, to account for movement of the marine vessel during pile driving operations, to maintain the offshore pile in a vertical orientation despite movement of the marine vessel and/or loads on the foundation pile, for example caused by waves or currents. It would be understood that, in other more simplified examples, the mounting assembly may only allow movement of the pile gripper assembly 2 relative to the deck D in only a single direction or not at all.

Figures 1a and 1c show the pile holding system in a first extreme position. In this example the first extreme position is an outboard, or deployed, position. Figures 1b and 1d show the pile holding system 1 in a second extreme position. In this example the second extreme position is an inboard, or retracted, position. In the outboard position, the pile gripper assembly 2 is outboard of the vessel and is usable for pile driving applications, as described previously. When there are no pile driving operations occurring, the pile gripper assembly 2 is stored in the inboard position.

The pile gripper assembly 2 includes a plane, or gripper plane P1, which is normal to the axis of the circular passage of the pile gripper assembly 2, and so is normal to an axis of the pile during pile driving operations. The gripper plane P1 is visible in Figure 1b.

In the illustrated example, in both the inboard position and the outboard position the orientation of the gripper plane P1 of the pile gripper assembly 2 remains substantially constant with respect to fixed points of reference on the marine vessel. For example, in both the inboard position and the outboard position the gripper plane P1 of the pile gripper assembly 2 remains substantially parallel with the deck D of the marine vessel or a plane P2 of the mounting assembly, where the plane P2 of the mounting assembly is also normal to the axis of the pile during pile driving operations, and is also visible in Figure 1b

The parallel orientation of the pile gripper assembly 2 with respect to the deck D in the inboard position is beneficial as this simplifies access to the pile gripper assembly 2 for maintenance and for attaching auxiliary equipment, such as noise mitigation systems

(NMS). This orientation is also an efficient use of space, with the volume of space, above the deck D of the marine vessel, occupied by the pile holding system 1 not being significantly greater in the inboard position than in the outboard position. It will be appreciated that the planes P1, P2 of the pile gripper assembly 2 and the mounting assembly 3 need not be parallel to realise these advantages, and it will be appreciated that angles between the planes P1, P2 may be provided by changing relative lengths of the primary and secondary connection members 41, 42. It is nevertheless preferable that the angle between the planes P1, P2 be less than  $45^\circ$ , and more preferably less than  $10^\circ$ .

- Now described is movement of the pile holding system 1 between the inboard and outboard positions as shown in Figures 1b, 1d and Figures 1a, 1c, respectively, when the pile holding system 1 is mounted to a marine vessel.

When starting from the outboard position, the linear actuators 51 are actuated to extend linearly. This causes the respective first parts 52a of the articulating arms to pivot about the pivotable connections to the mounting assembly 3, which, in turn, moves the second parts 52b of the articulating arms in an inboard direction. Movement of the second parts 52b of the articulating arms causes the primary connection members 41 to pivot about the second axis A2, relative to the mounting assembly, such that the primary connection members 41 pivot in an inboard direction. The primary connection members 41 also pivot about the first pivot axis A1, relative to the pile gripper assembly. The movement of the primary connection members 41 first lifts the pile gripper assembly 2, and then lowers the pile gripper assembly 2 to the inboard position. Due to the pivotable connections at either end of the second part 52b of each articulating arm, the second parts 52b freely pivot to be loaded in tension to lift the primary connection members 41 away from the outboard position. Once the primary connection members 41 pass the point of rotation at which the line of supported weight passes through the second pivot axis A2, the second parts 52b of the articulating arms are loaded in compression to lower the pile gripper assembly 2 to the inboard position and to support the pile gripper assembly 2 in the inboard position.

When starting from the inboard position, the linear actuators 51 are actuated to retract linearly. This causes the respective first parts 52a of the articulating arms to pivot about the pivotable connections to the mounting assembly 3, which, in turn, moves the second parts 52b of the articulating arms in an outboard direction. Movement of the second parts 52b of the articulating arms causes the primary connection members 41 to pivot about the second axis A2, relative to the mounting assembly, such that the primary connection members 41

pivot in an outboard direction. The primary connection members 41 pivot about the first pivot axis A1, relative to the pile gripper assembly. The movement of the primary connection members 41 first lifts the pile gripper assembly 2, and then lowers the pile gripper assembly 2 to the outboard position. Due to the pivotable connections at either end of the second part 52b of each articulating arm, the second parts 52b freely pivot to be loaded in compression to lift the primary connection members 41 away from the inboard position. Once the primary connection members 41 pass the point of rotation at which the line of supported weight passes through the second pivot axis A2, the second parts 52b of the articulating arms are loaded in tension to lower the pile gripper assembly 2 to the outboard position and to support the weight of the pile gripper assembly 2 in the outboard position.

In both movement directions the rotation of the pile gripper assembly 2, relative to the mounting assembly 3, is controlled due to the pivotable connections, of the pile gripper assembly 2 and the mounting assembly 3, to the secondary connection member 42, about the third and fourth axes A3, A4, respectively.

A possible variation on this embodiment of the pile holding system is that the secondary connection member 42 may be an actuator, such that the angle of the plane of the pile gripper assembly 2 is adjustable. This may be beneficially for maintenance, or for maintaining a particular angle, between the planes of the pile gripper assembly and the mounting assembly, when moving between inboard and outboard positions. As mentioned previously, another variation is that the actuation assemblies are replaced by one or more winches, elongate elements of which are connectable to the pile gripper assembly 2. In this case the winch is operable to lift and lower the pile gripper assembly 2 between the inboard and outboard positions.

Referring now to Figures 2a-2d, the pile holding system 1 of Figure 1 is shown, with a noise mitigation system (NMS) 6 fitted to the pile gripper assembly 2. As is clear from Figures 2b and 2d, the orientation of the pile gripper assembly 2 in the inboard position makes the attachment and detachment of the NMS 6, to and from the pile gripper assembly 2, much easier. The NMS 6 might be a Hydro Sound Damper (HSD) system or a system of resonators tuned to specific frequencies.

The structure and operation of the pile holding system 1 with the NMS 6 attached is the same as that described with reference to Figure 1.

Referring now to Figures 3a-b, there is shown a pile holding system 11 according to another embodiment of the invention. This pile holding system 11 is similar to the pile holding system 1 of the previous embodiment, and similar features are denoted with like reference numerals with a preceding '1'.

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The pile holding system 11 of this embodiment differs from that of the previous embodiment in that the two linear actuators 151 are directly pivotally connected to the cross member 141a which connects the two primary connection members 141 together. Therefore, there is no articulation arm in the pile holding system 11 of this embodiment.

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The primary connection members 141 of this embodiment also differ from those of the previous embodiment in that each one is a generally triangular in shape, being formed by three elongate sections, each joined at either end to respective one of the other two elongate members. A first of the elongate members of each primary connection member 141 has, at one end, the pivotal connection to the mounting assembly 13, and, at the other end, the pivotal connection to the pile gripper assembly 2. A second one of the elongate members of each primary connection member 141 has, at one end, the pivotal connection to the mounting assembly 13, and at the other end, has the cross member 141a. The third one of the elongate members of each primary connection member 141 has, at one end, the pivotal connection to the pile gripper assembly 2, and at the other end, has the cross member 141a.

It would be appreciated that other variations on the geometry, configuration, or number of each of the primary connection members 41, 141, secondary connection members 42, 142, linear actuators 51, 151 are also possible.

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The mounting assembly 13 is substantially the same as in the previous embodiment, and the pivotal connections between the primary connection members 141, the secondary connection members 142 and the linear actuators 151, are with the second rail 132.

The pile gripper assembly 22 and secondary connection members 142 are substantially the same as in the previous embodiment and are not described further. The operation of the pile gripper assembly 22 and the mounting assembly 13 is also the same as that described previously and will not be described further. As visible from Figures 3a-b, an NMS 16 is present on the pile gripper assembly 22, as was the case in Figures 2a-d. However, the NMS 16 could be omitted, as in the embodiment of Figures 1a-d.

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The movement of the pile gripper assembly 22 between the outboard position and the inboard position is now described.

When starting from the outboard position, the linear actuators 151 are actuated to extend  
5 linearly. This pushes the cross member 141a, which connects the primary connection  
members 141 together, in the inboard direction, thereby pivoting the primary connection  
members 141 about the second pivot axis A12 relative to the mounting assembly 13. This,  
in turn, lifts the pile gripper assembly 22, and the primary connection members 141 pivot  
about the first pivot axis A11, relative to the pile gripper assembly 22. Continued extension  
10 of the linear actuators 151 lowers the pile gripper assembly 22 into the inboard position.

When starting from the inboard position, the linear actuators 151 are actuated to retract  
linearly. This pulls the cross member 141a, which connects the primary connection  
members 141 together, in an outboard direction, thereby pivoting the primary connection  
15 members 141 about the second pivot axis A12 relative to the mounting assembly 13. This,  
in turn, lifts the pile gripper assembly 22, and the primary connection members 141 pivot  
about the first pivot axis A11, relative to the pile gripper assembly 22. Continued extension  
of the linear actuators 151 lowers the pile gripper assembly 22 into the outboard position.

20 As in the previous embodiment, in both movement directions rotation of the pile gripper  
assembly 22 relative to the mounting assembly 13, is maintained due to the pivotable  
connections of the pile gripper assembly 22 and the mounting assembly 13 to the secondary  
connection member 142, about the third and fourth axes A13, A14, respectively.

25 As in the previous embodiment, a possible alteration is that the secondary connection  
members 142 may be actuators, such that the angle of the plane of the pile gripper  
assembly 22 is adjustable. This may be beneficially for maintenance, or for maintaining a  
particular angle when moving between inboard and outboard positions.

## CLAIMS

1. A pile holding system for installing offshore foundation piles into ground, the pile holding system comprising:
  - 5 a pile gripper assembly;
  - a mounting assembly for attachment of the pile holding system to a marine vessel;
  - a connection assembly comprising a connection member; and
  - actuation means connected to at least one of the pile gripper assembly, the mounting assembly or the connection member;
  - 10 wherein the connection member is pivotally connected to the pile gripper assembly, the connection member being pivotable relative to the pile gripper assembly about a first pivot axis,
  - wherein the connection member is pivotally connected to the mounting assembly,
  - 15 wherein the connection member is pivotable relative to the mounting assembly about a second pivot axis, wherein the first pivot axis and the second pivot axis are substantially parallel, and
  - wherein the actuation means is configured to pivot the connection member about the first pivot axis and the second pivot axis to move the pile gripper assembly relative to the mounting assembly between a first extreme position and a second extreme position.
  - 20
2. A pile holding system according to claim 1, wherein in the first extreme position and the second extreme position an angle between a gripping plane of the pile gripper assembly and a plane of the mounting assembly is less than  $45^\circ$ , and preferably less than  $10^\circ$ .
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3. A pile holding system according to any preceding claim, wherein, in the first and second extreme positions, a gripping plane of the pile gripper assembly is substantially parallel with a plane of the mounting assembly.
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4. A pile holding system according to claim 3, wherein, in all intermediate positions of the pile gripper assembly between the first and second extreme positions, the gripping plane of the pile gripper assembly is substantially parallel with the plane of the mounting assembly.
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5. A pile holding system according to any preceding claim, wherein, in the first extreme position and the second extreme position the pile gripper assembly is in a spaced arrangement with the mounting assembly.
- 5 6. A pile holding system according to any preceding claim, wherein the connection member is a primary connection member, wherein the connection assembly further comprises a secondary connection member pivotally connected to at least one of the pile gripper assembly and the mounting assembly.
- 10 7. A pile holding system according to claim 6, wherein the secondary connection member is pivotally connected to the pile gripper assembly, the secondary connection member being pivotable relative to the pile gripper assembly about a third pivot axis, the third pivot axis being substantially parallel to the first and second axes.
- 15 8. A pile holding system according to claim 6 or claim 7, wherein the secondary connection member is pivotally connected to the mounting assembly, wherein the connection member is pivotable relative to the mounting assembly about a fourth pivot axis, the fourth pivot axis being substantially parallel to the first and second axes.
- 20 9. A pile holding system according to any preceding claim, wherein the first extreme position is an outboard, or deployed, position and the second extreme position is an inboard, or retracted, position.
- 25 10. A pile holding system according to any preceding claim, wherein the actuation means comprises at least one actuation assembly, each actuation assembly comprising a linear actuator.
- 30 11. A pile holding system according to claim 10, wherein each of the at least one actuation assembly is pivotally connected, at one end, to the mounting assembly, and is pivotally connected, at another end, to the connection member.
- 35 12. A pile holding system according to claim 11, wherein each of the at least one actuation assembly comprises an articulating arm with a first end pivotally connected to the mounting assembly and a second end pivotally connected to the

connection member, and wherein a first end of the respective linear actuator is pivotally connected to the mounting assembly, and a second end of the respective linear actuator is pivotally mounted to the articulating arm.

- 5 13. A pile holding system according to any preceding claim, wherein the mounting assembly comprises a translation assembly comprising two, parallel, first rails and two, parallel, second rails, the first and second rails being substantially perpendicular to one another, and the translation assembly comprising driving means configured to move the pile gripper assembly and the linkage assembly along the first and second rails, to provide dynamic position control of the pile gripper assembly, in use.
- 10 14. A pile holding system according to claim 13, further comprising a motion control system configured to compensate motion of the vessel to which the offshore foundation pile is mounted, via the pile gripper assembly, in use.
- 15 15. A pile holding system according to claim 14, wherein the translation assembly is controlled by the motion control system, such that the movement of the two, parallel, first rails and two, parallel, second rails is perpendicular to one another.
- 20 16. A pile holding system according to any preceding claim, wherein the pile gripper assembly comprises articulating jaws configured to surround the circumference of a pile, in use.
- 25 17. A marine vessel comprising a pile holding system according to any preceding claim, the mounting assembly of the pile holding system being mounted to the marine vessel.
- 30 18. A method of moving a pile gripper assembly of a pile holding system between a first extreme position and a second extreme position, the method comprising:  
actuating actuation means of the pile holding system to pivot a connection member of a connection assembly relative to the pile gripper assembly about a first pivot axis and to pivot the connection member relative to a mounting assembly of the pile holding system about a second pivot axes, to move the pile gripper assembly relative to the mounting assembly, wherein the first and second pivot axes are
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substantially parallel to one another and wherein the mounting assembly is for attachment of the pile holding system to a marine vessel.

- 5 19. A method according to claim 18 wherein the pile gripper assembly has a gripping plane, the gripping plane of the pile gripper assembly being normal to the longitudinal axis of a gripped offshore foundation pile in use, and wherein in the first extreme position and the second extreme position an angle between the gripping plane of the pile gripper assembly and a plane of the mounting assembly is less than 45°, and preferably less than 10°.
- 10 20. A method according to claim 19, wherein, in the first and second extreme positions, the gripping plane of the pile gripper assembly is substantially parallel with the plane of the mounting assembly.
- 15 21. A method according to claim 20 wherein during movement between the first and second extreme positions, the plane of the pile gripper assembly is substantially parallel with the plane of the mounting assembly.
- 20 22. A method according to any of claims 18 to 21, wherein, during movement between the first and second extreme positions, the pile gripper assembly is maintained in a spaced arrangement with the mounting assembly.
- 25 23. A method according to any of claims 18 to 22, wherein the first extreme position is an outboard, or deployed, position and the second extreme position is an inboard, or retracted, position.
- 30 24. A method according to any of claims 18 to 23, wherein the actuation means comprises at least one actuation assembly which comprises a linear actuator, and wherein actuation of the actuation means comprises extending or retracting the linear actuator of the at least one actuation assembly.
25. A method of installing an offshore pile using a pile holding system mounted to a marine vessel, the method comprising:  
gripping the offshore pile in a pile gripper assembly;

moving the pile holding system from a second extreme position to a first extreme position according to any of claims 16 to 22, the second extreme position being a retracted position, the first extreme position being a deployed position; and performing a piling operation to drive the offshore pile into ground.

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26. A method according to claim 25, the method comprising actuating driving means to move the pile gripper assembly and connection assembly along substantially perpendicular first and second rails of a translation assembly which is comprised in the mounting assembly, the translation assembly also comprising the driving means, to provide dynamic position control of the pile gripper assembly relative to the marine vessel, when installing the pile.

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27. The method of claim 25 or claim 26, wherein gripping the offshore pile comprises gripping the offshore pile between articulating jaws of the pile gripper assembly which surround the circumference of the offshore pile.

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