US 20230203774A1

(19) United States

(12) Patent Application Publication

(10) Pub. No.: US 2023/0203774 A1

HUISMAN et al.

(43) Pub. Date: Jun. 29, 2023

(54) **DEVICES AND METHODS FOR INSTALLING PILES INTO THE GROUND OR SEABED**

(71) Applicant: **Heerema Marine Contractors Nederland SE**, Leiden (NL)

(72) Inventors: **Marco HUISMAN**, Leiden (NL); **Marius Gabriël OTTOLINI**, Leiden (NL); **Paul Antonius Alphonsus GEENE**, Leiden (NL); **Michael John BROWN**, Leiden (NL); **Benjamin Pierre Jacques CERFONTAINE**, Leiden (NL); **Yaseen Umar SHARIF**, Leiden (NL)

(21) Appl. No.: **17/917,590**

(22) PCT Filed: **Apr. 8, 2021**

(86) PCT No.: **PCT/EP2021/059219**

§ 371 (c)(1),
(2) Date: **Oct. 7, 2022**

(30) **Foreign Application Priority Data**

Apr. 8, 2020 (NL) 2025306

Publication Classification

(51) **Int. Cl.**

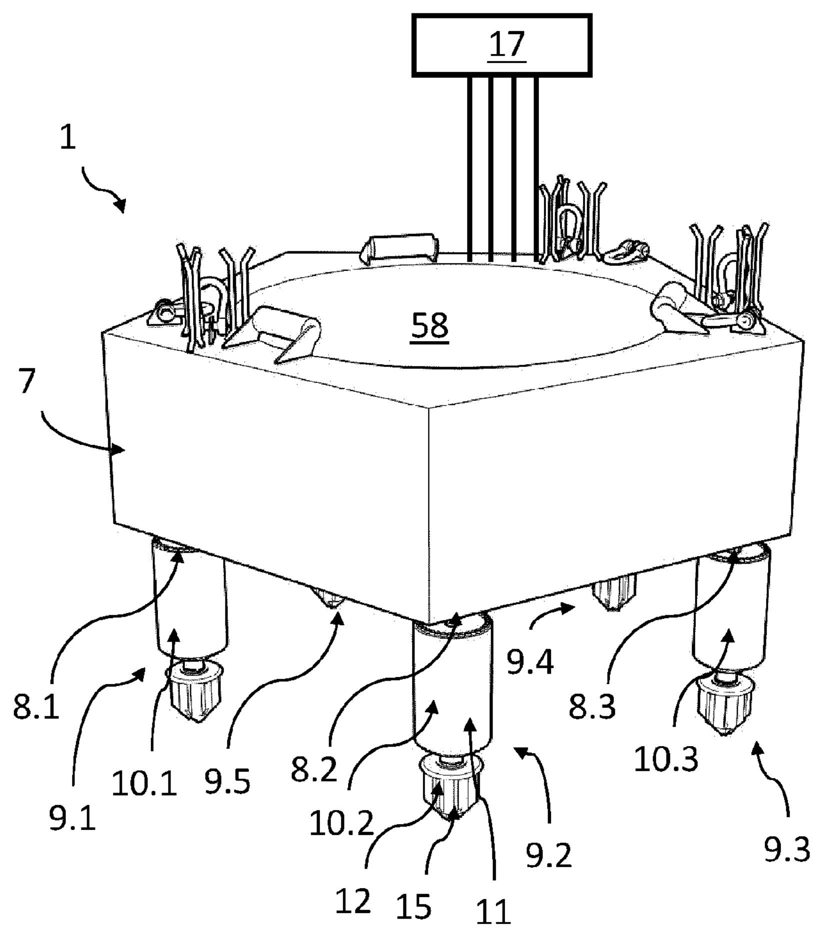
E02D 11/00 (2006.01)
E02D 13/04 (2006.01)
E02D 15/08 (2006.01)
E02D 27/52 (2006.01)

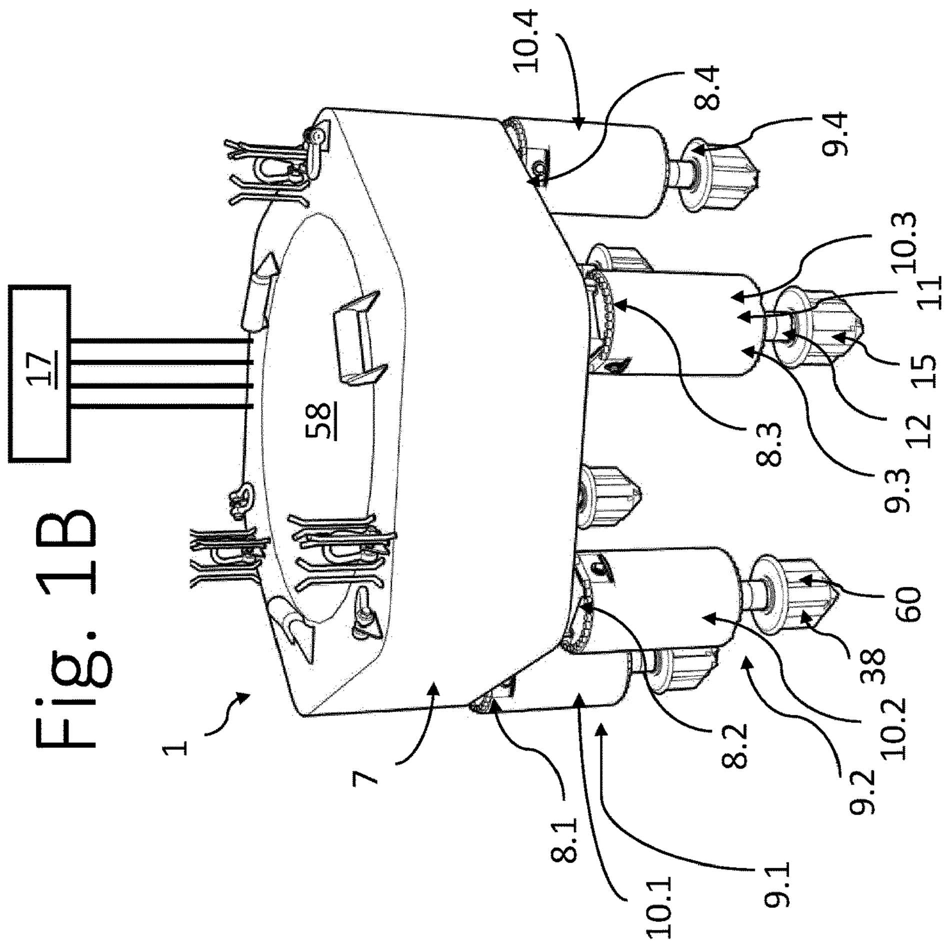
(52) **U.S. Cl.**

CPC *E02D 11/00* (2013.01); *E02D 13/04* (2013.01); *E02D 15/08* (2013.01); *E02D 27/525* (2013.01)

(57) **ABSTRACT**

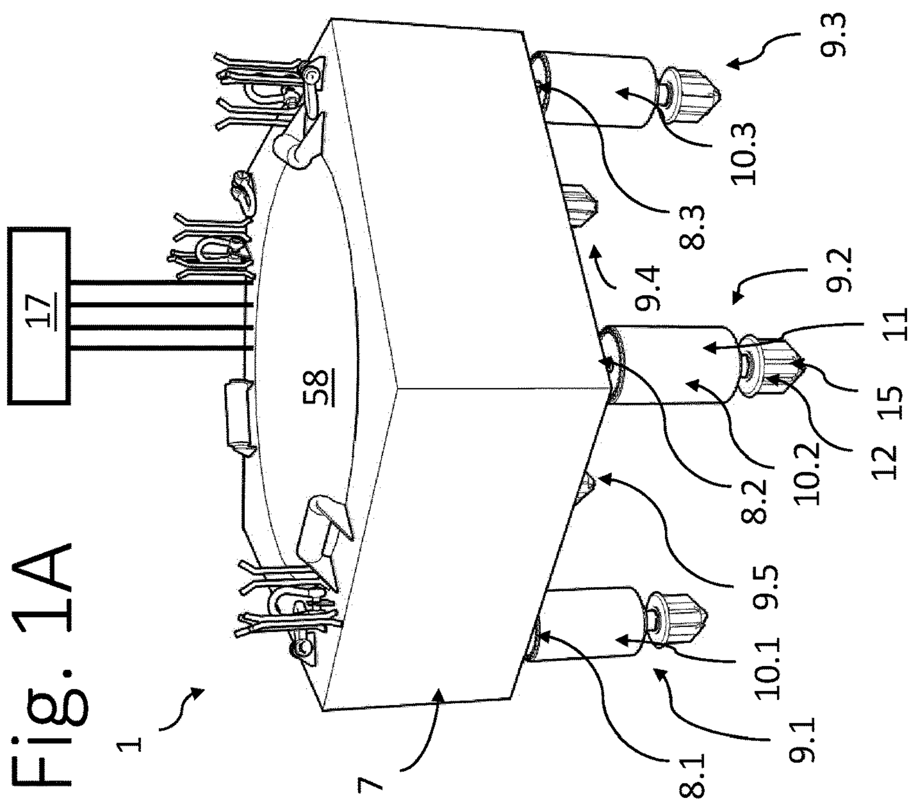
The present invention relates to a support structure for supporting a top structure, in particular a wind turbine, above the ground or a seabed, the support structure comprising: one single support pile having a length and a first outer diameter, the one single support pile comprising an upper part configured and intended to extend above the ground or the seabed, wherein the upper part of the support pile is configured to be connected to the top structure; a lower part configured to be in contact with the ground or seabed, wherein the support pile is configured to exert an upward vertical force on the top structure in order to carry the top structure; a plurality of foundation guides connected to the lower part of the single support pile, each foundation guide having an opening extending in a direction of the support pile.





17
58
1
7
8.1
10.1
9.1
8.2
9.2
10.2
38
60
8.3
9.3
12
15
11
10.3
9.4
8.4
10.4

Fig. 1B



17
58
1
7
8.1
9.1
10.1
9.5
8.2
10.2
12
15
11
9.2
9.4
8.3
10.3
9.3

Fig. 1A

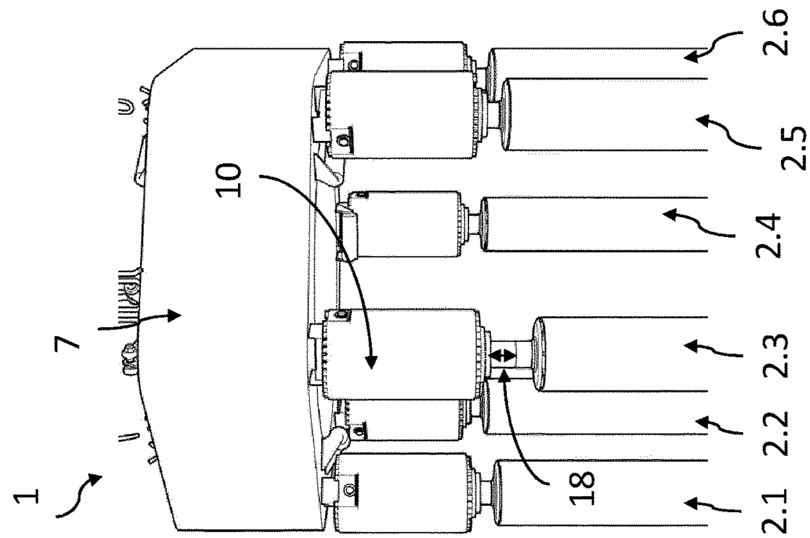


Fig. 2C

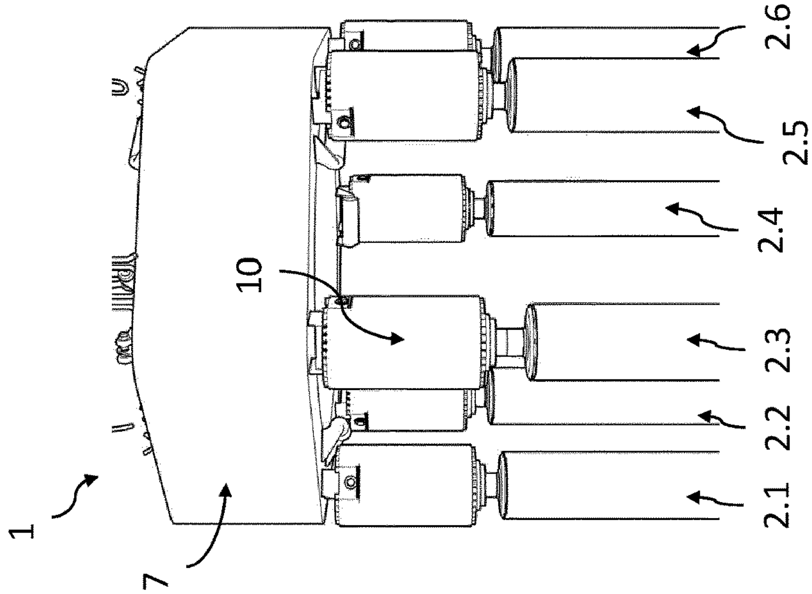


Fig. 2B

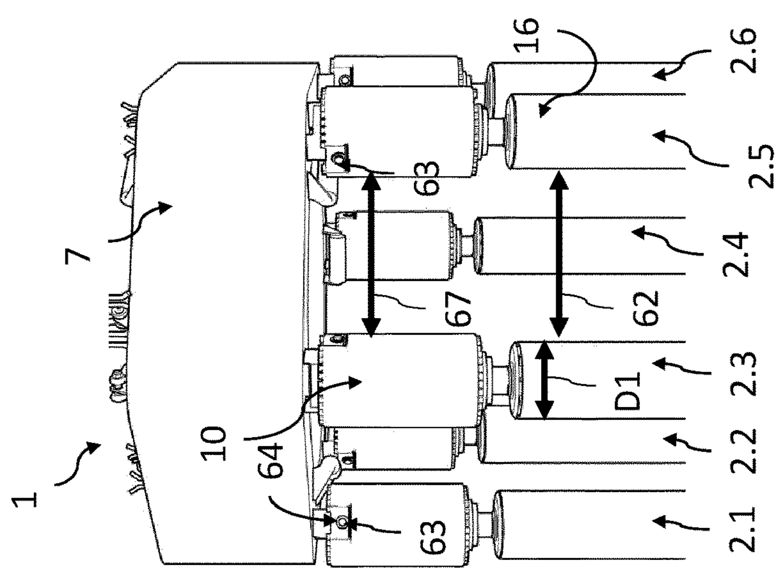


Fig. 2A

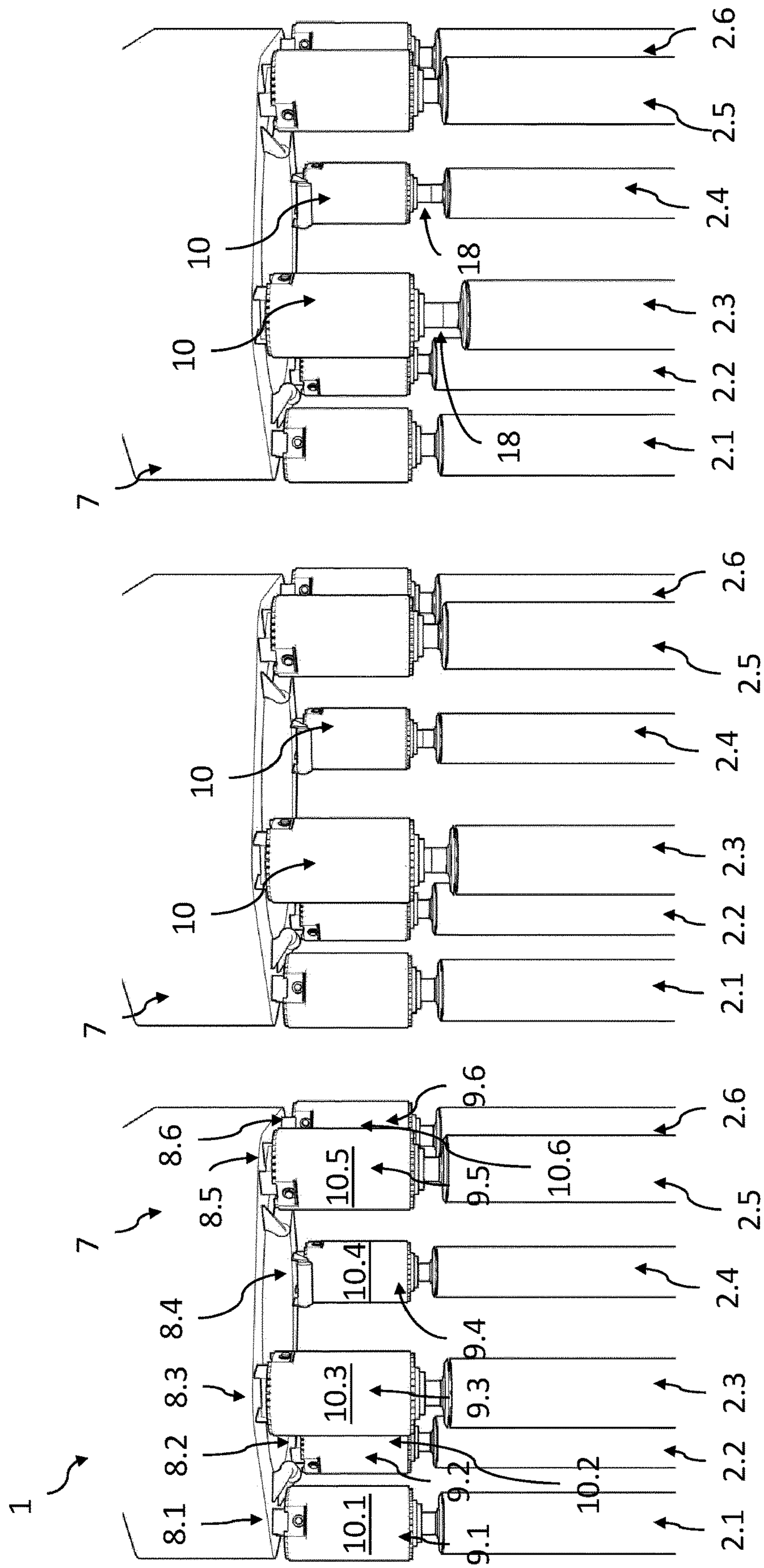


Fig. 3A

Fig. 3B

Fig. 3C

Fig. 4C

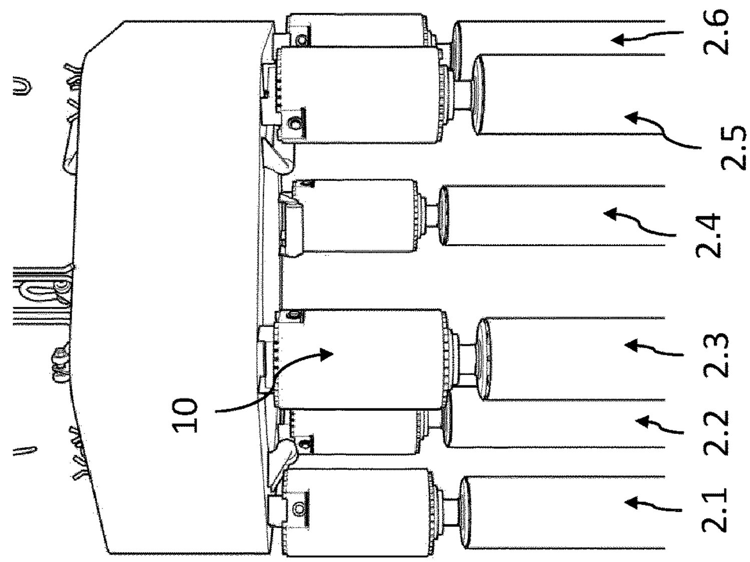


Fig. 4B

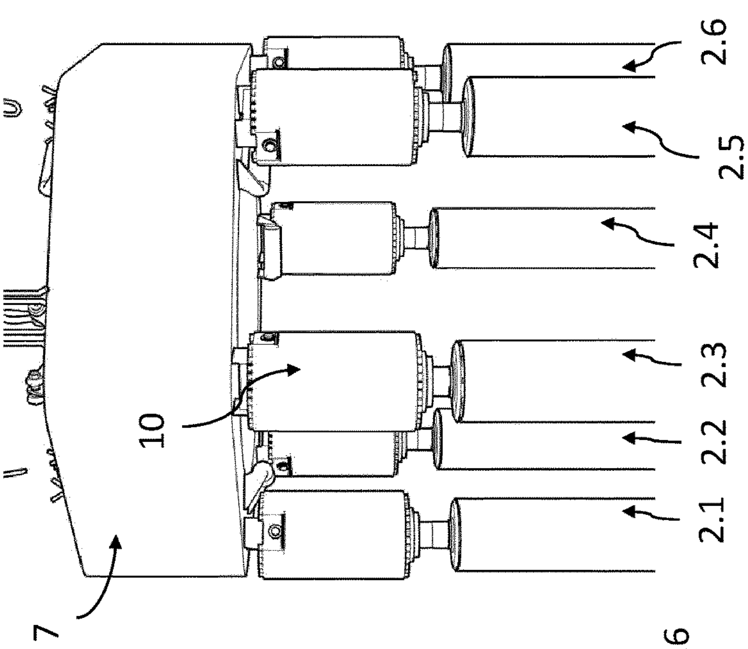
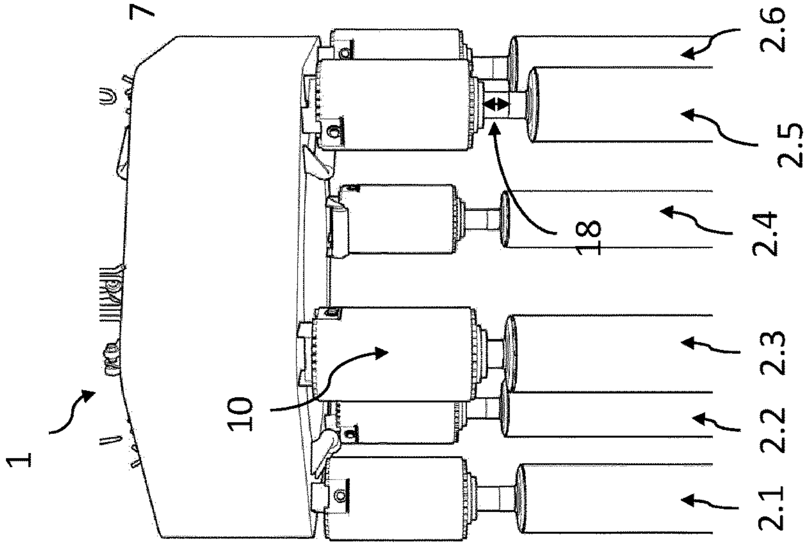


Fig. 4A



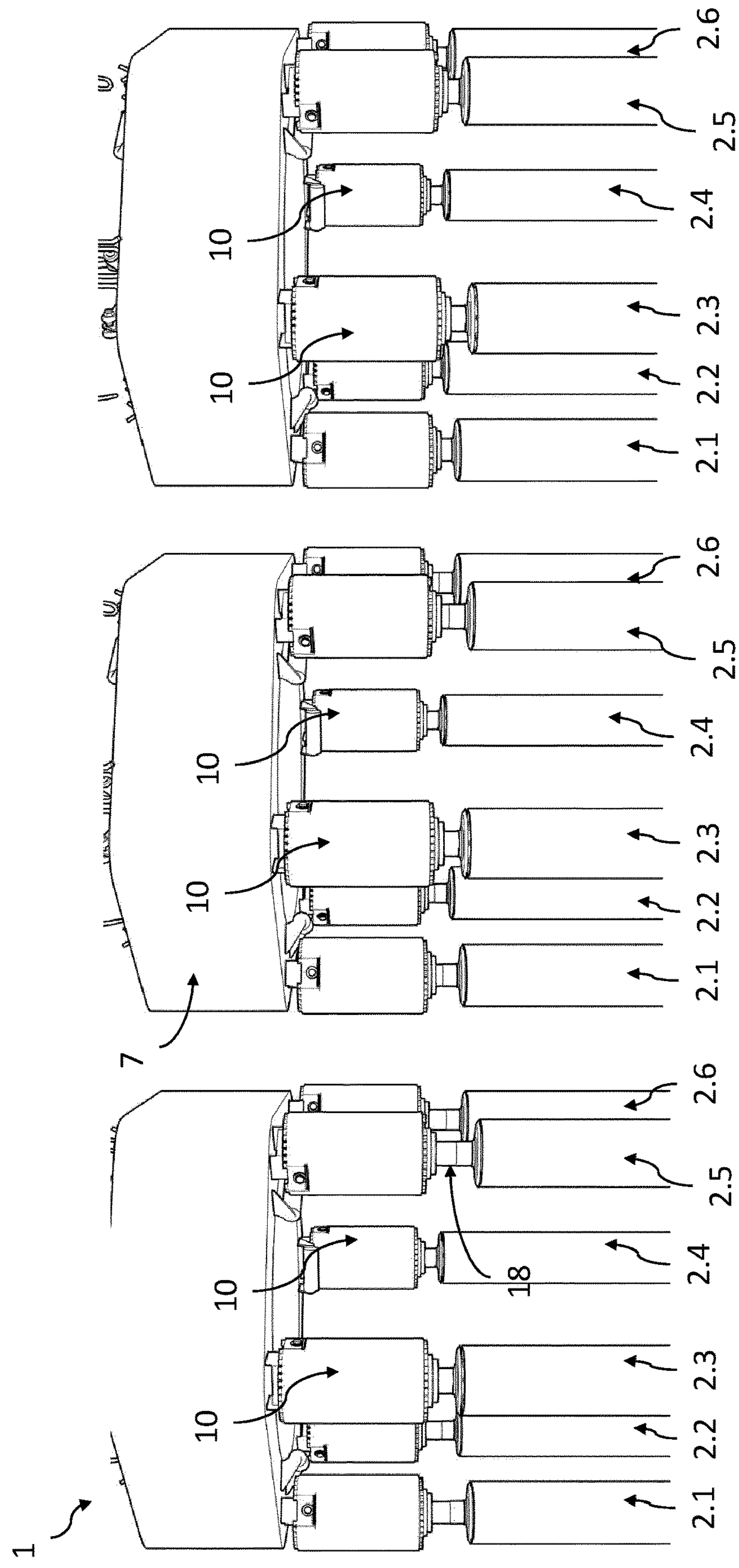


Fig. 5A

Fig. 5B

Fig. 5C

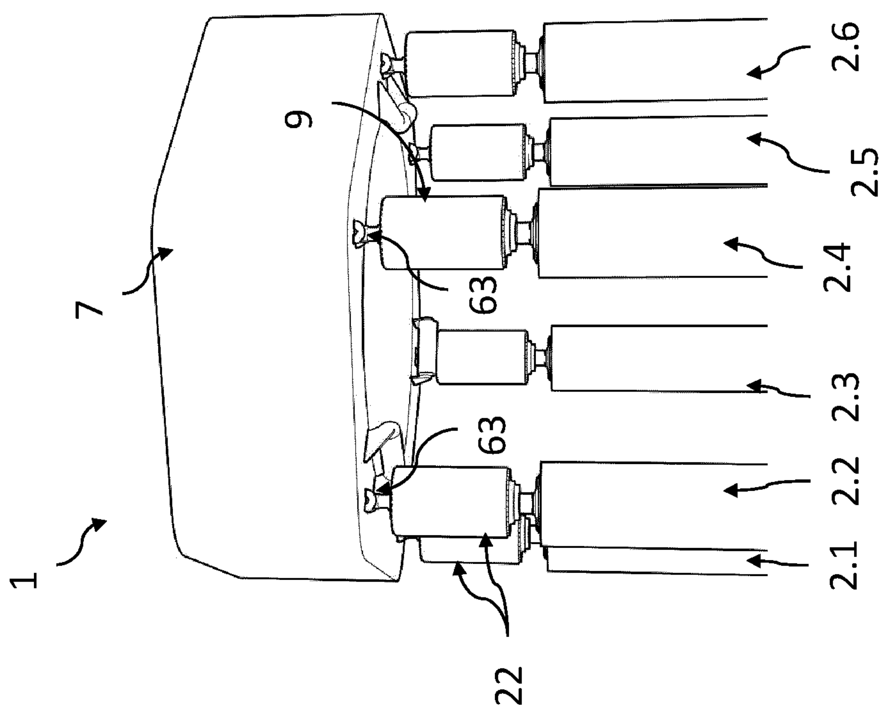


Fig. 6

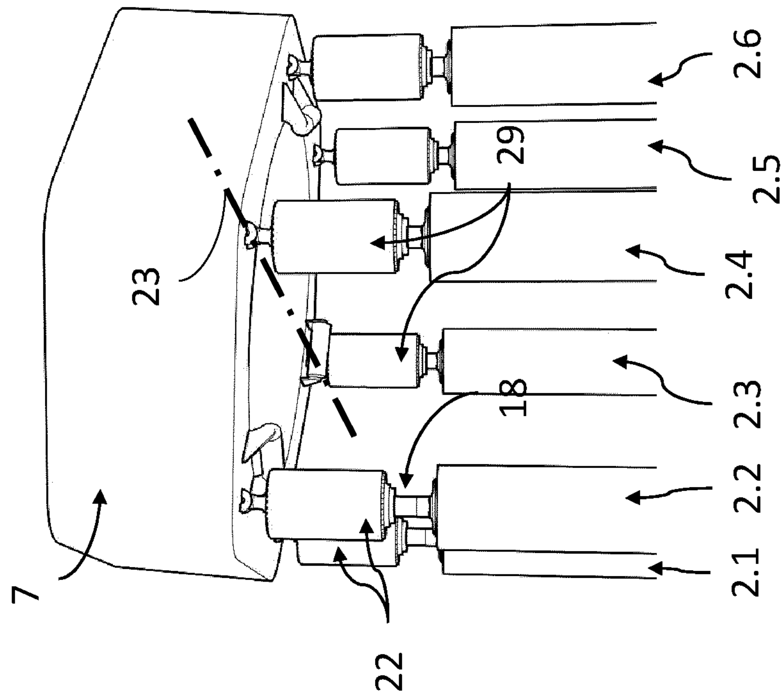


Fig. 7

Fig. 8

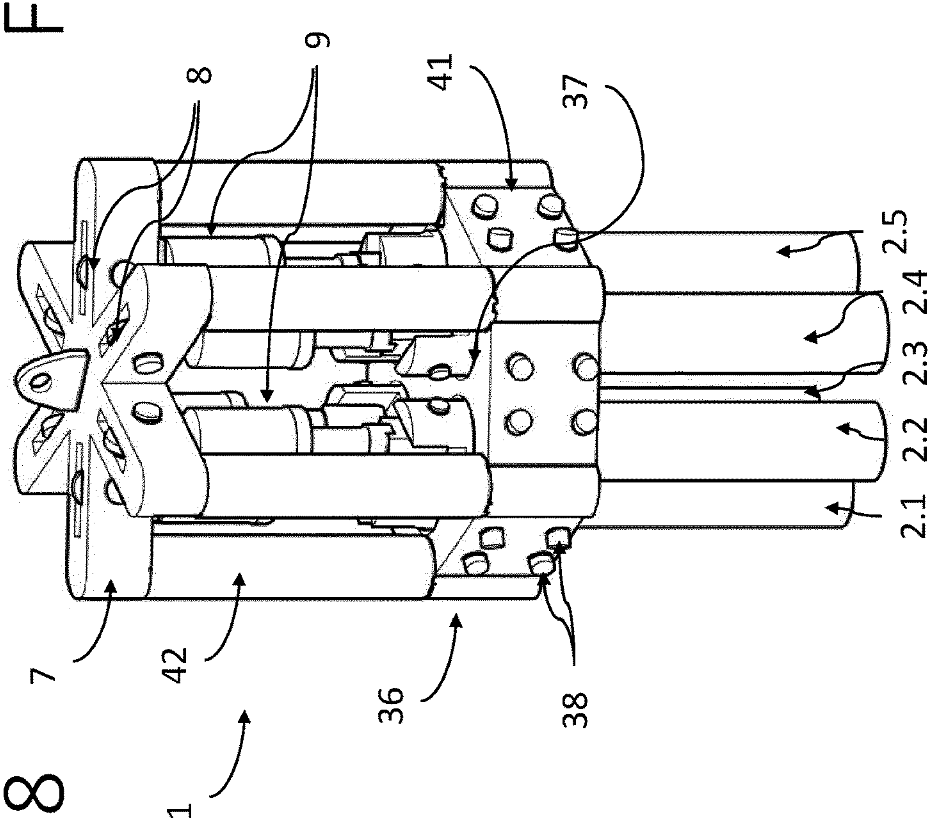


Fig.9

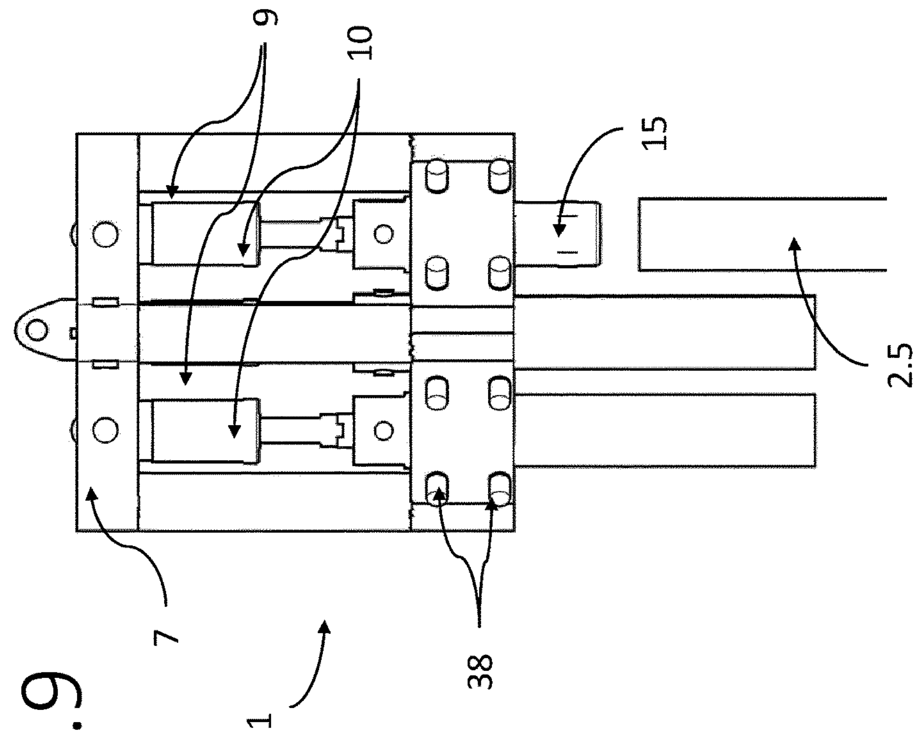
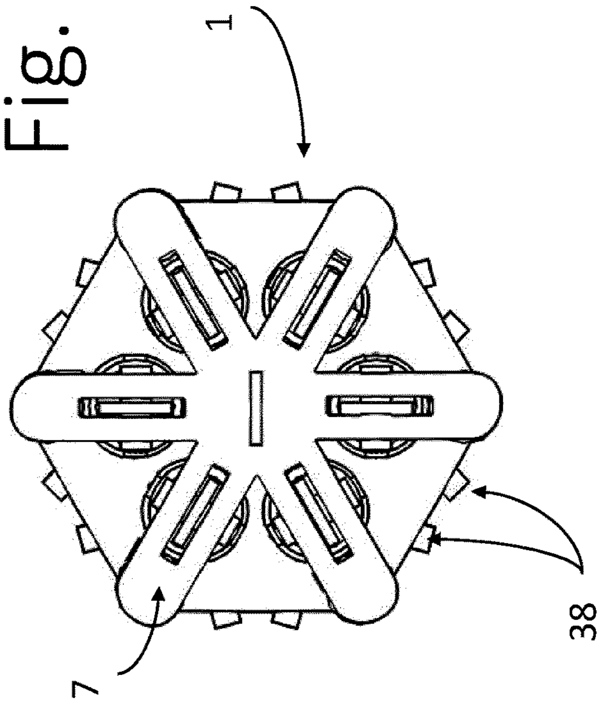
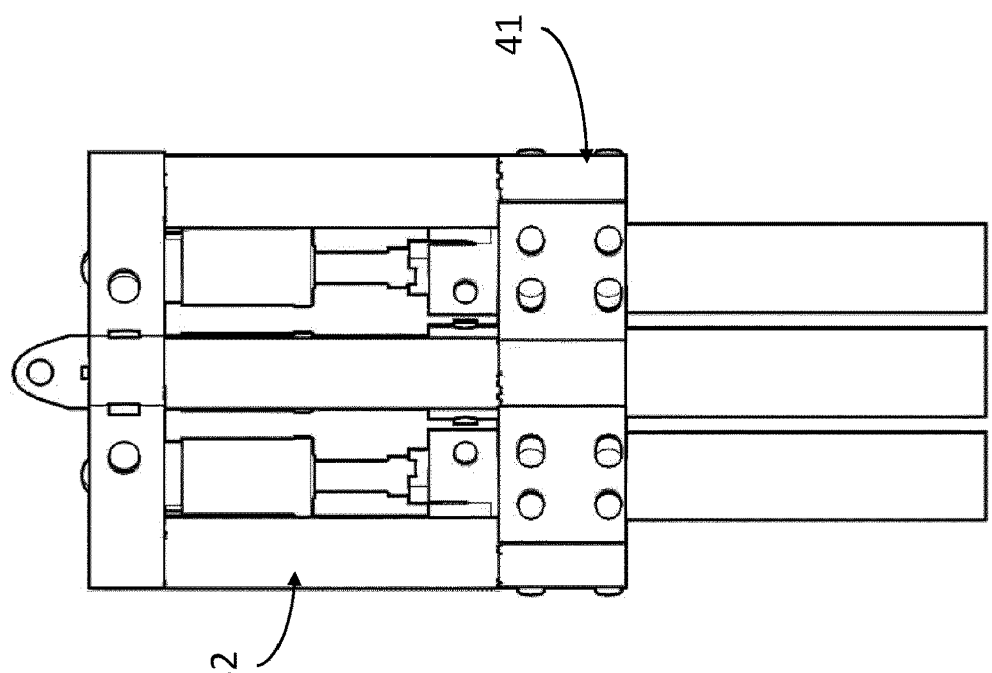


Fig. 11





1

Fig. 10

Fig. 12

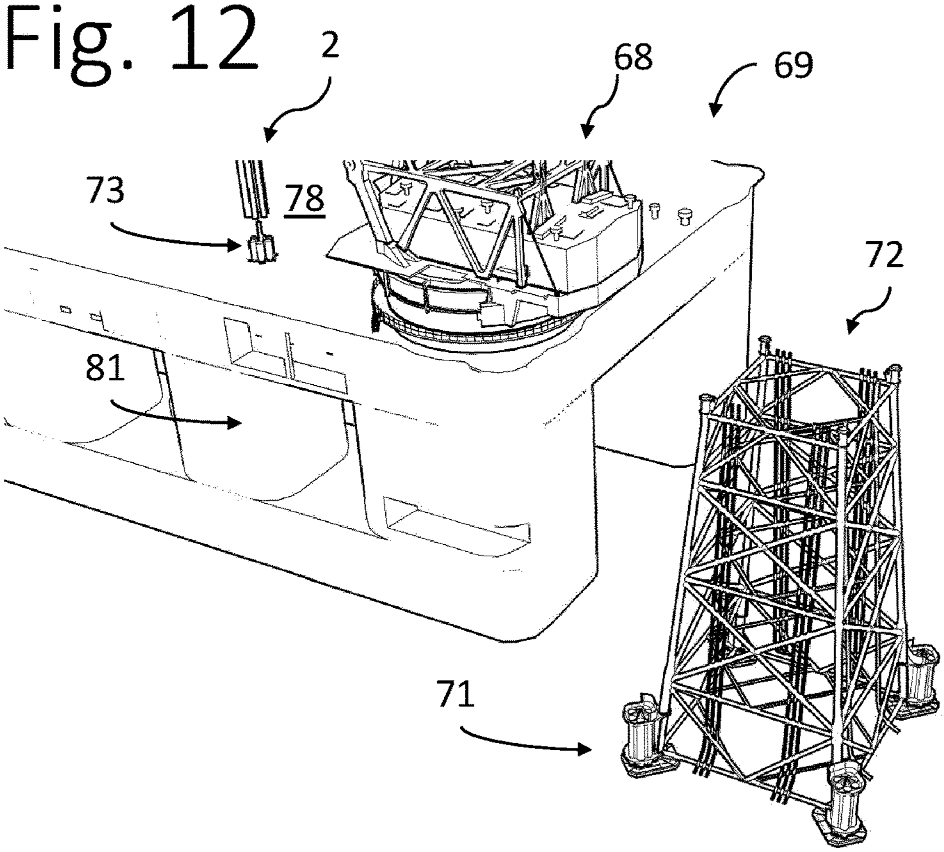


Fig. 13

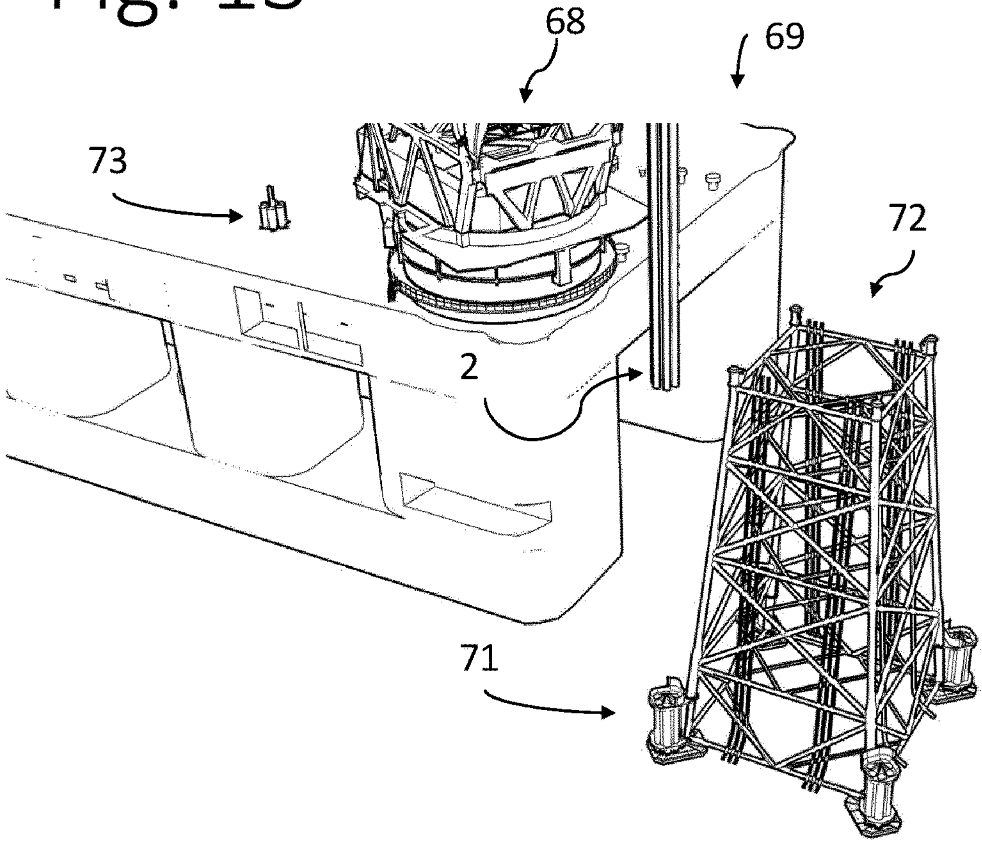


Fig. 14

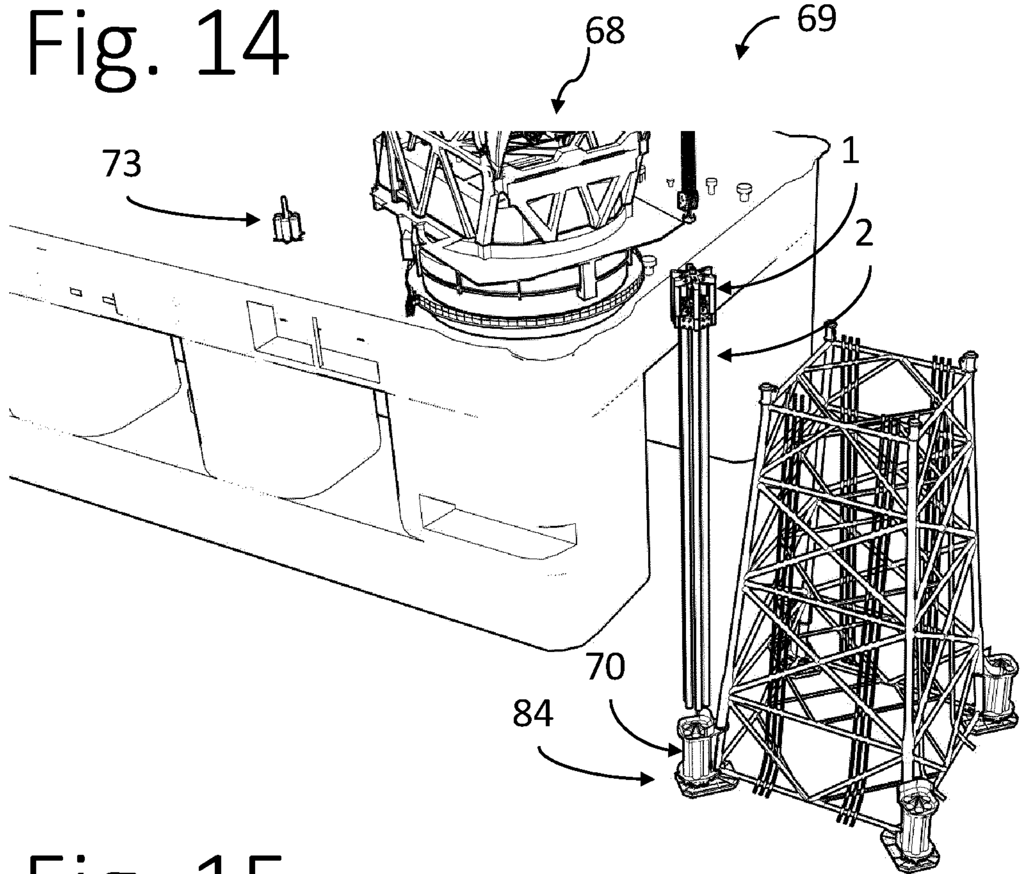
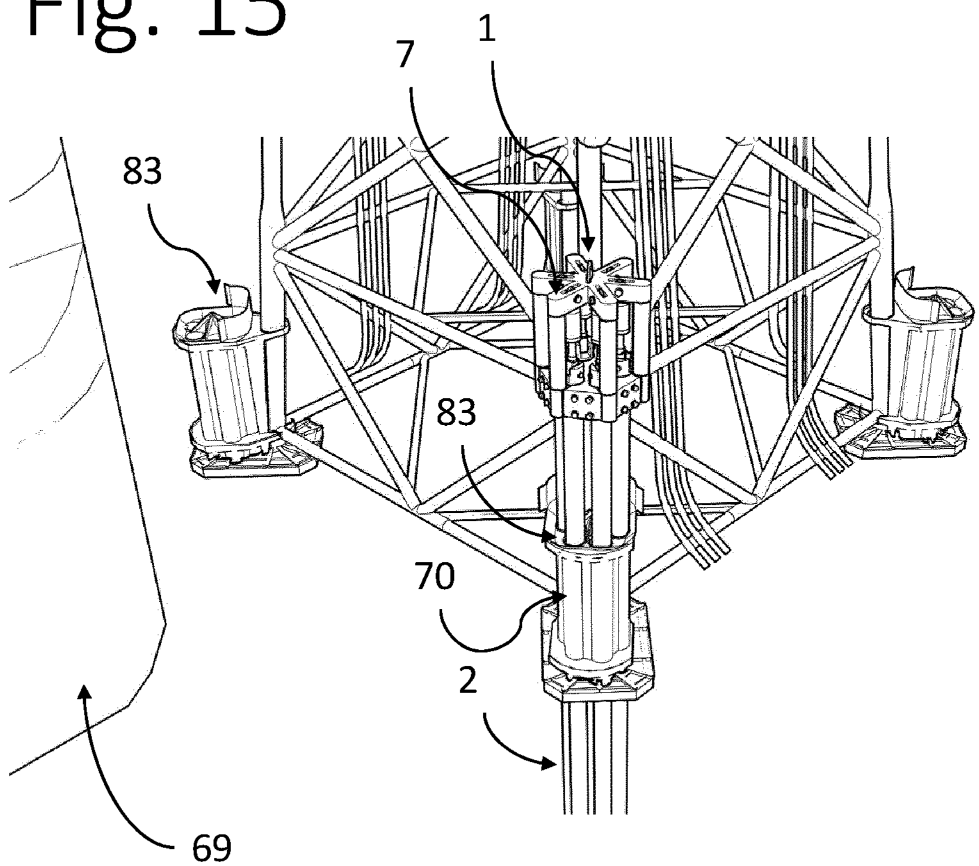
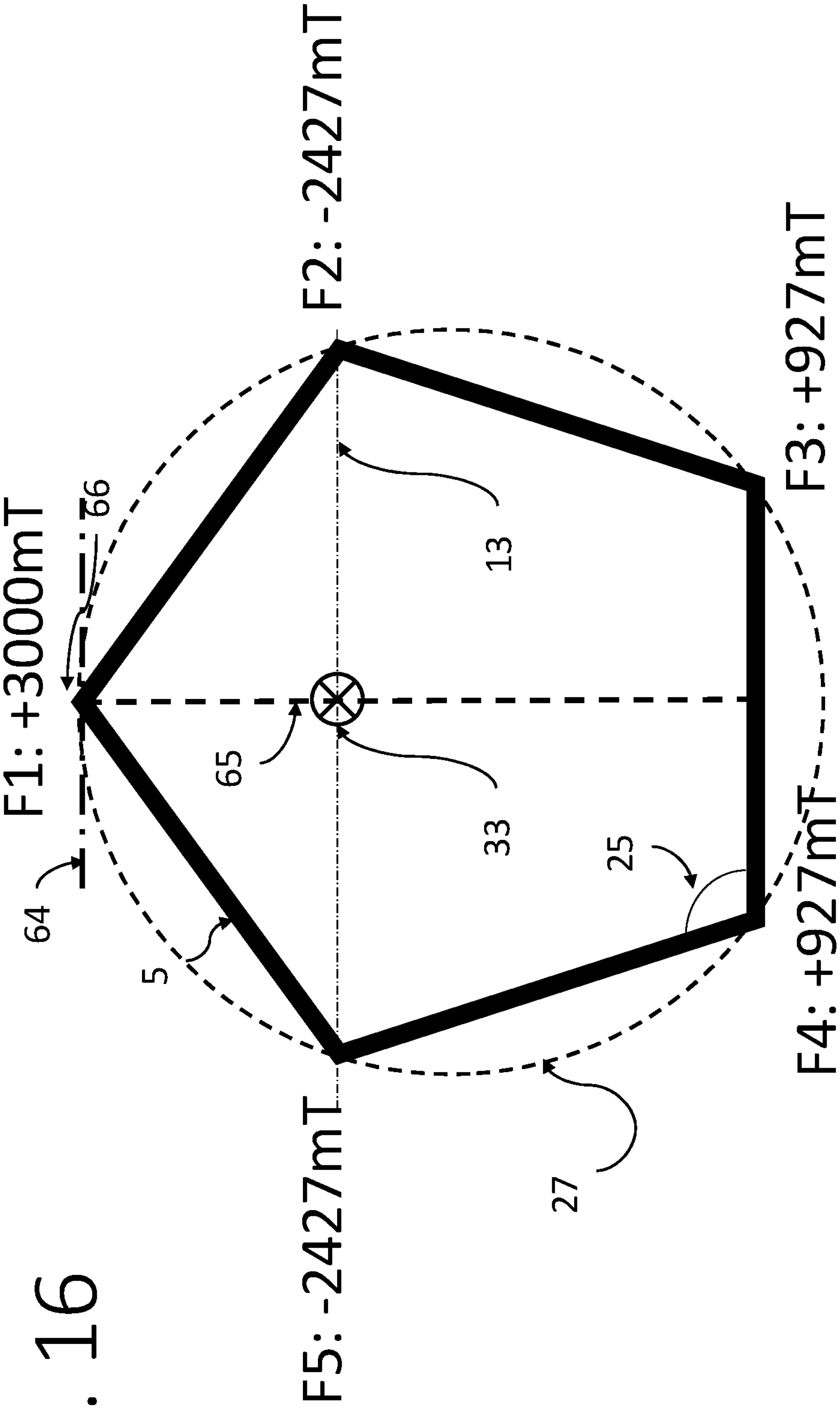


Fig. 15





F1: +3000mT
F2: -2427mT
F3: +927mT
F4: +927mT
F5: -2427mT
5
13
25
27
33
64
65
66

Fig. 16

Fig. 17

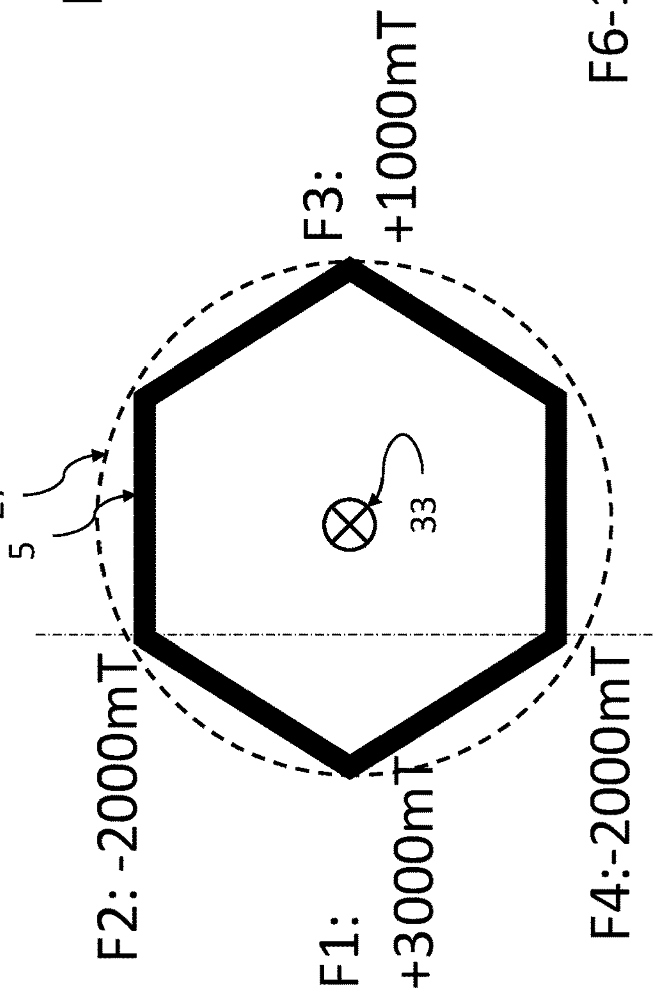
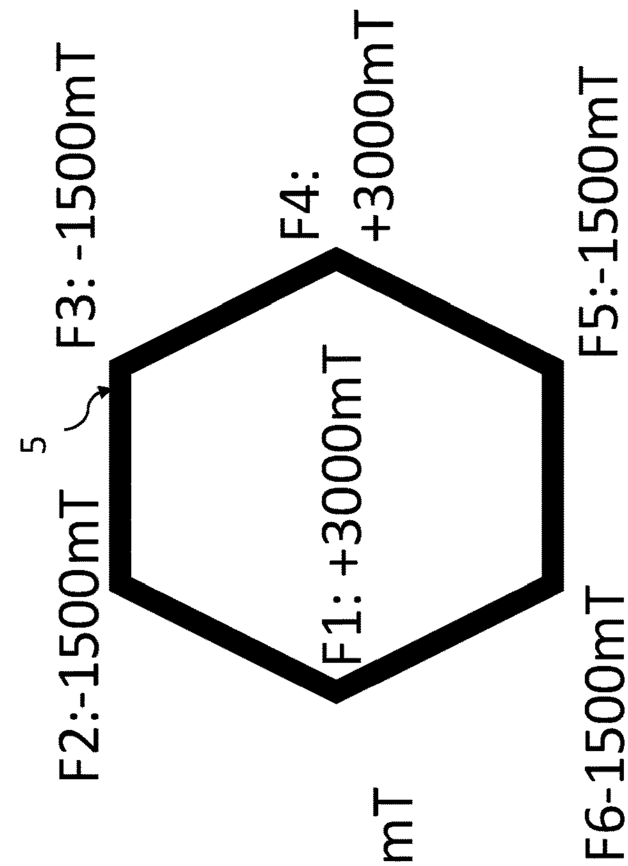

F2: -2000mT
F1: +3000mT
F4:-2000mT
F3: +1000mT
27
5
33

Fig. 18


F2:-1500mT
F3: -1500mT
F1: +3000mT
F4: +3000mT
F5:-1500mT
F6-1500mT
5

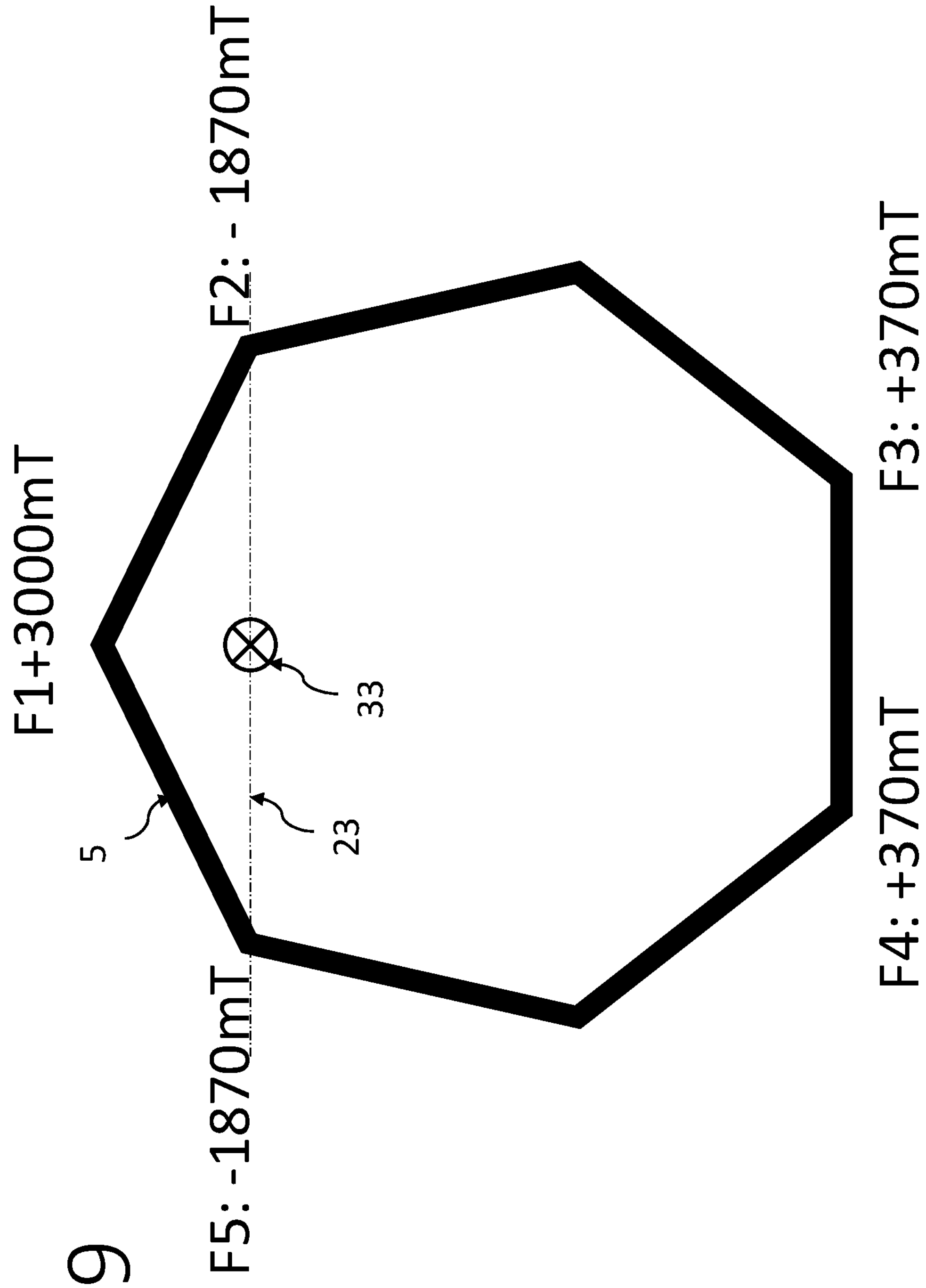


Fig. 19

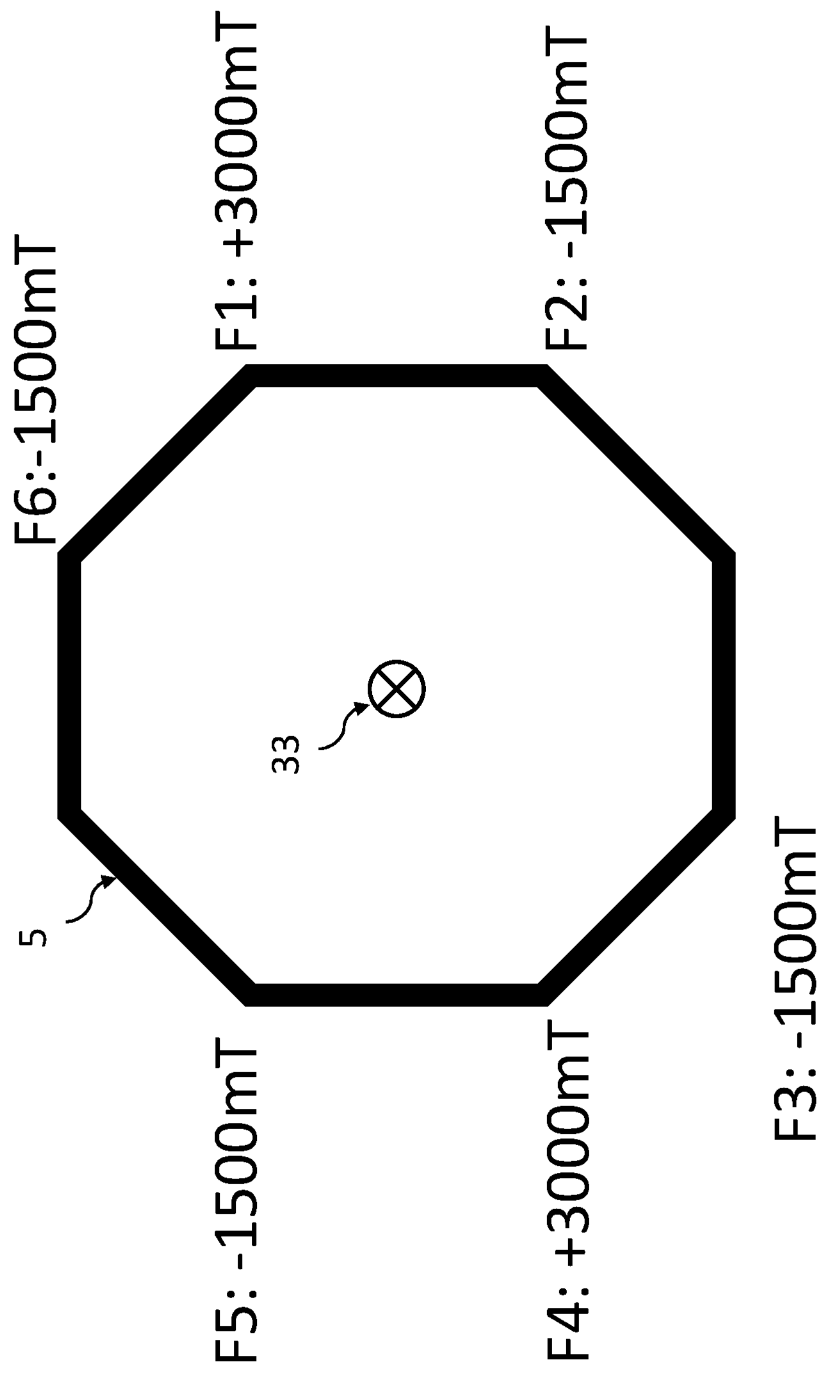
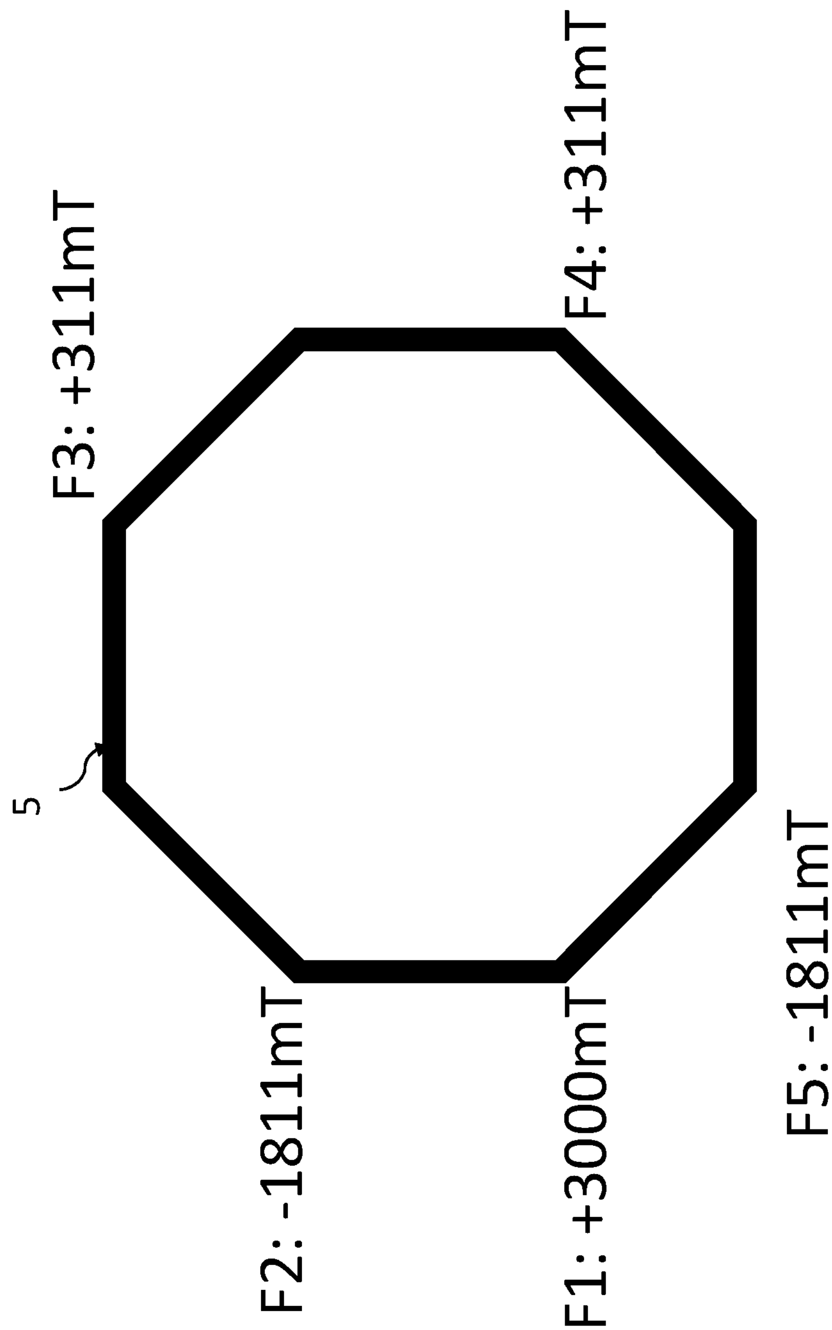

F1: +3000mT
F2: -1500mT
F3: -1500mT
F4: +3000mT
F5: -1500mT
F6:-1500mT
33
5

Fig. 20

Fig. 21



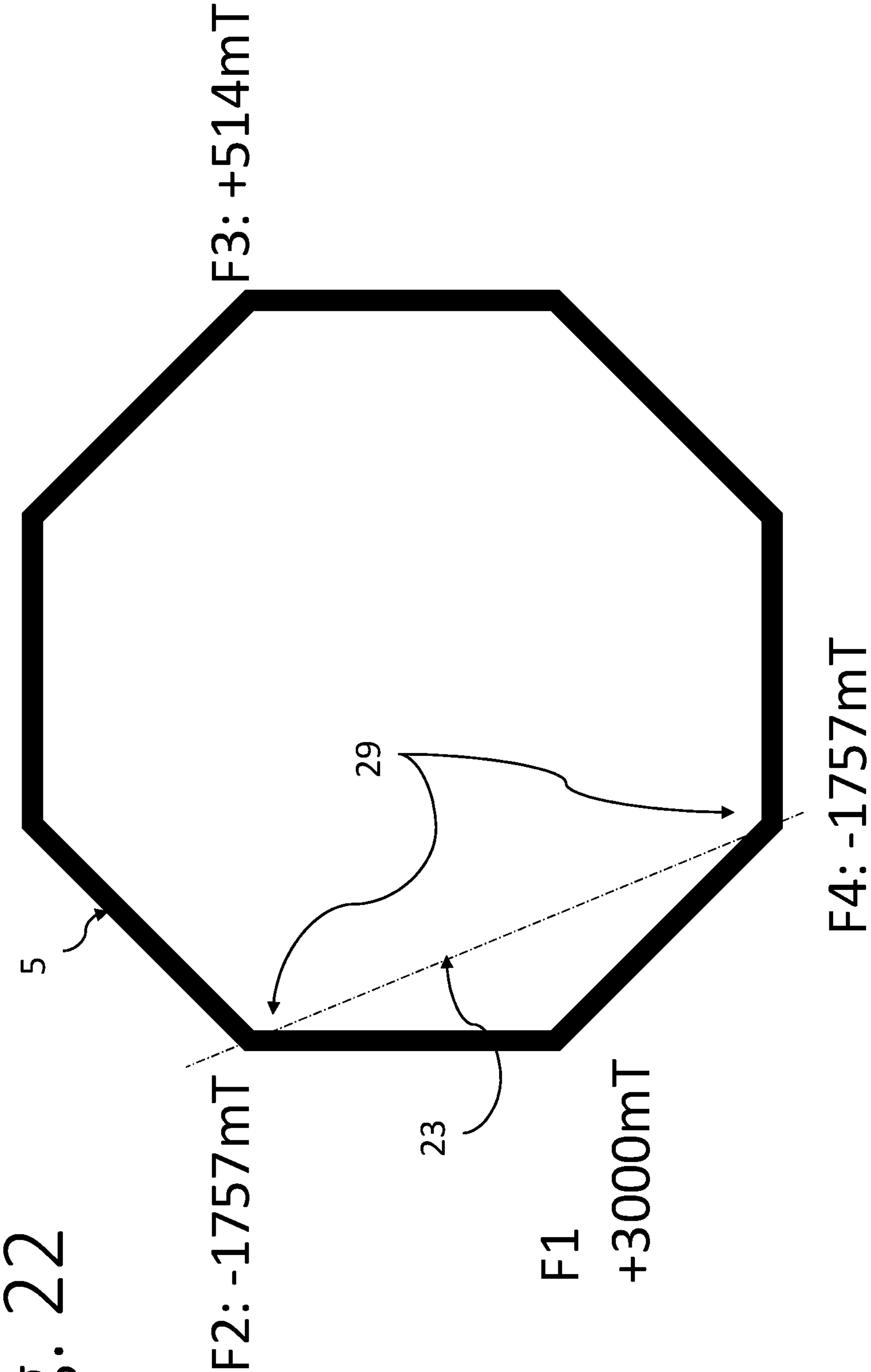


Fig. 22

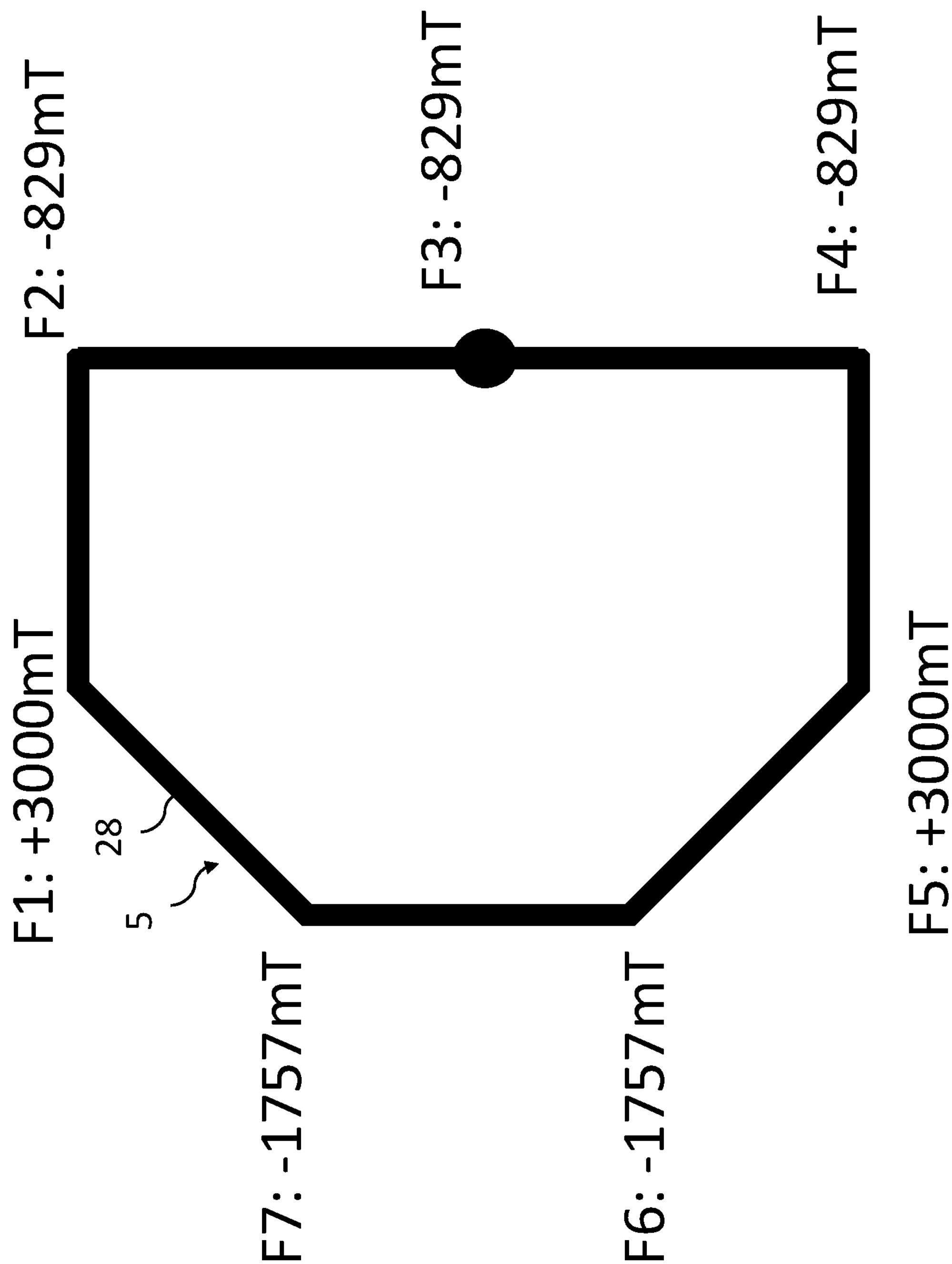

F2: -829mT
F3: -829mT
F4: -829mT
F1: +3000mT
F5: +3000mT
28
5
F7: -1757mT
F6: -1757mT

Fig. 23

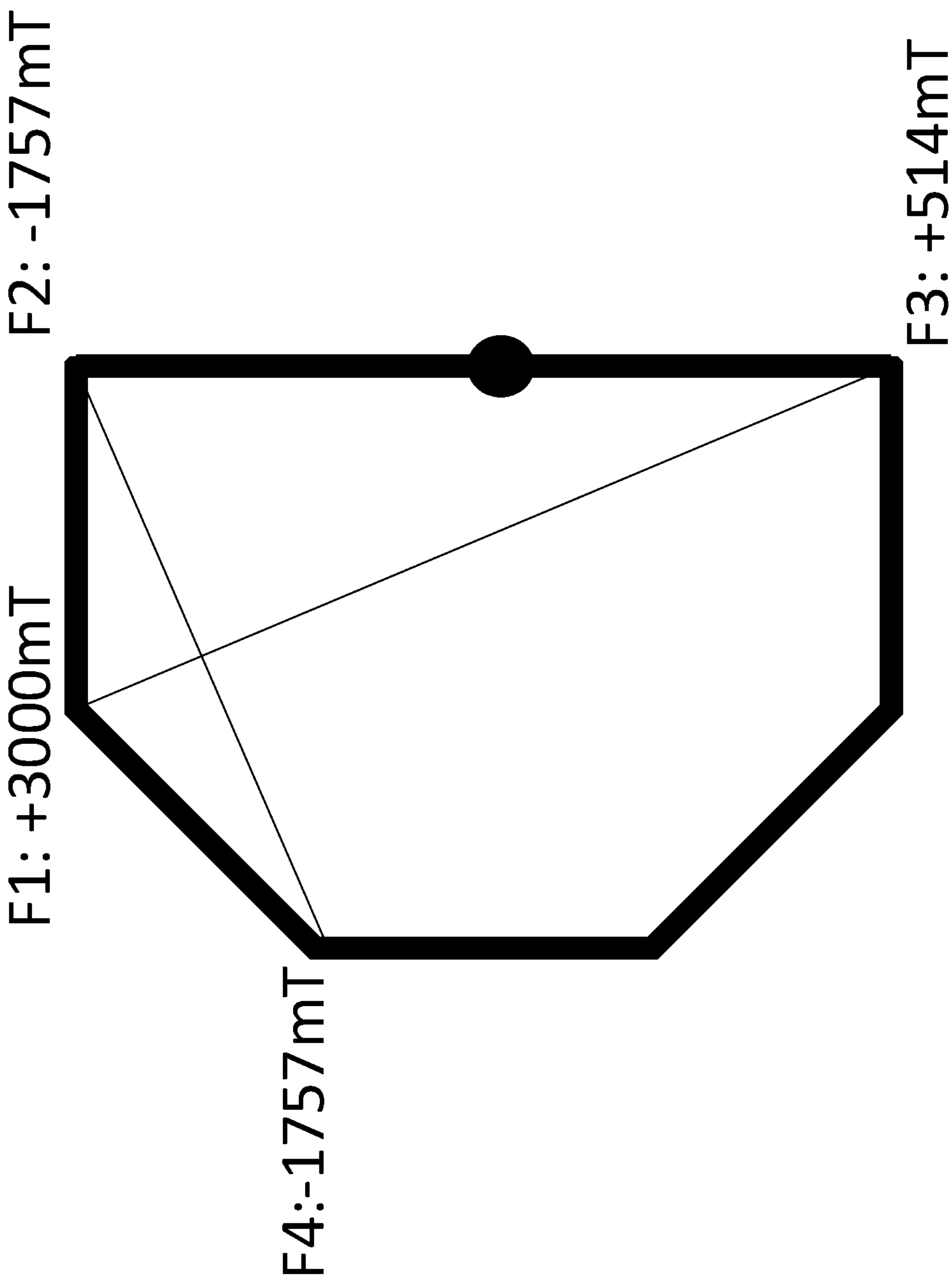


Fig. 24

Fig. 25

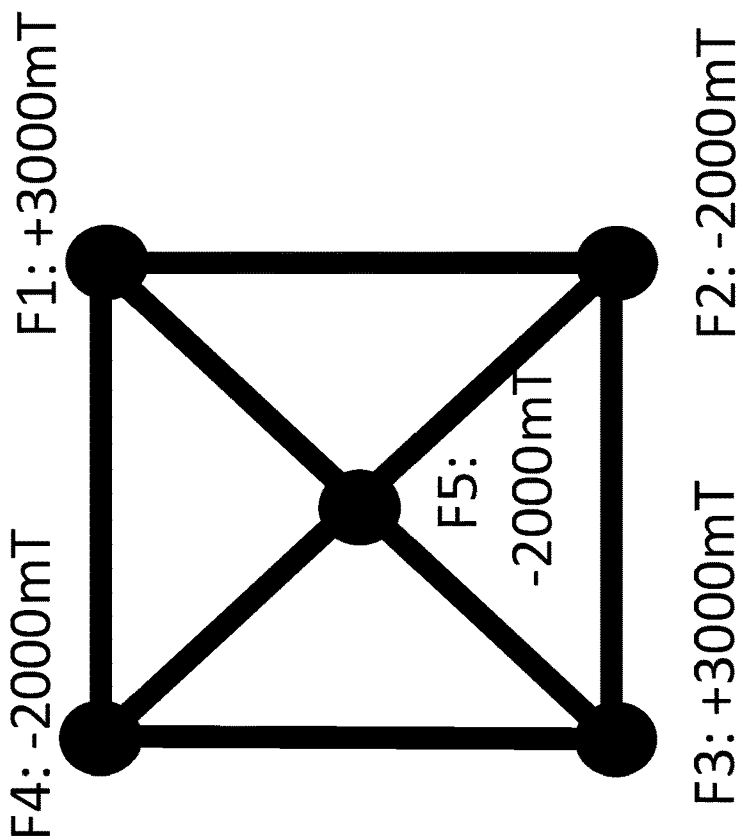

F1: +3000mT
F2: -2000mT
F3: +3000mT
F4: -2000mT
F5:
-2000mT

Fig. 26

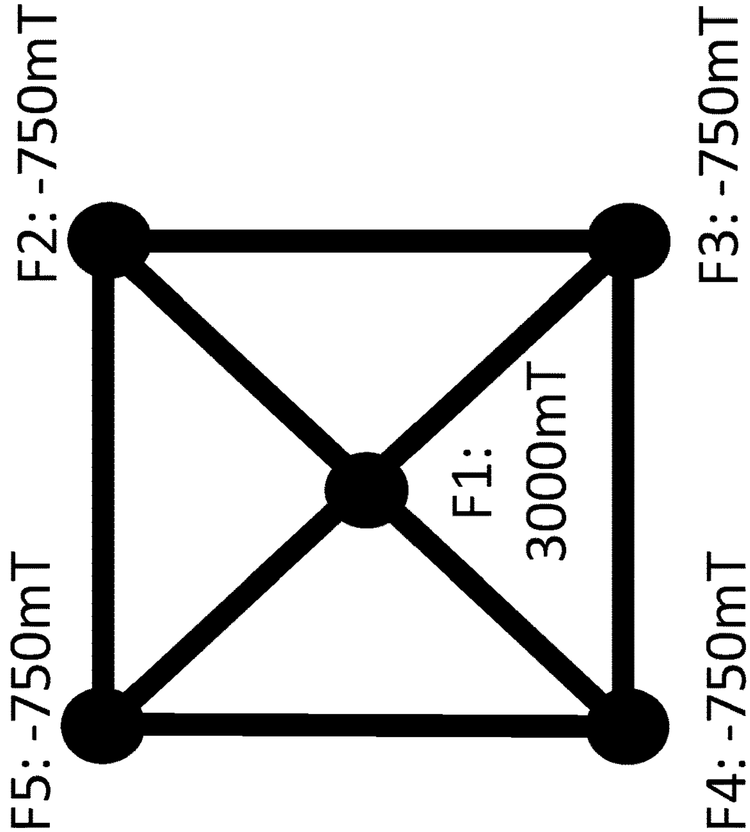

F2: -750mT
F3: -750mT
F4: -750mT
F5: -750mT
F1:
3000mT

Fig. 27

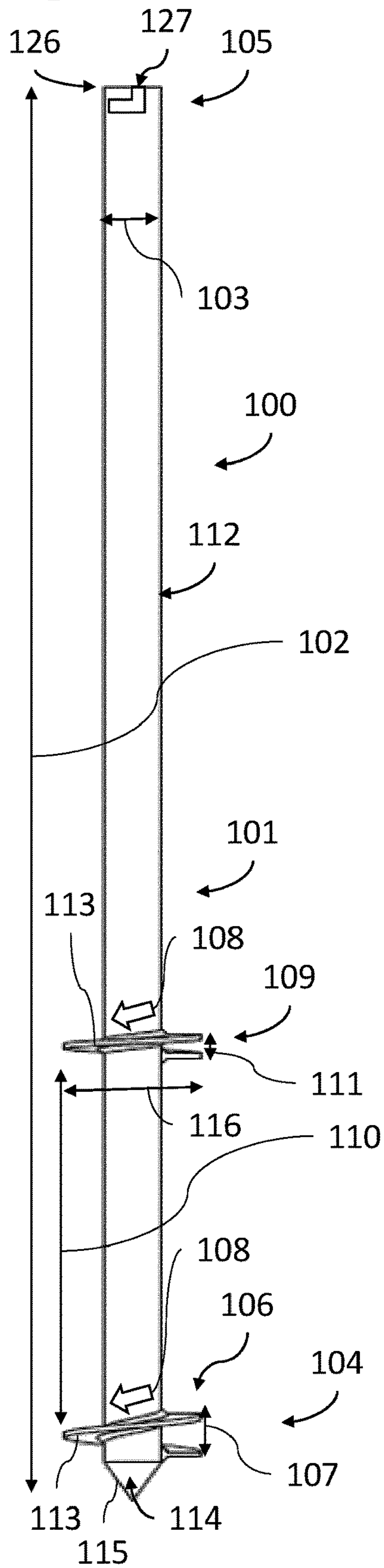

127
126
105
103
100
112
102
101
113
108
109
111
116
110
108
106
104
107
113
114
115

Fig. 28

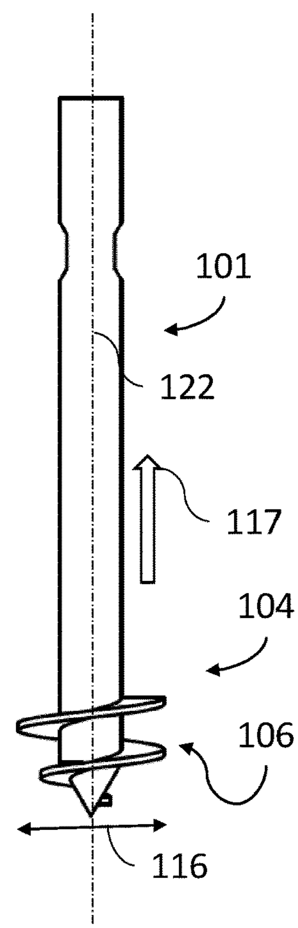
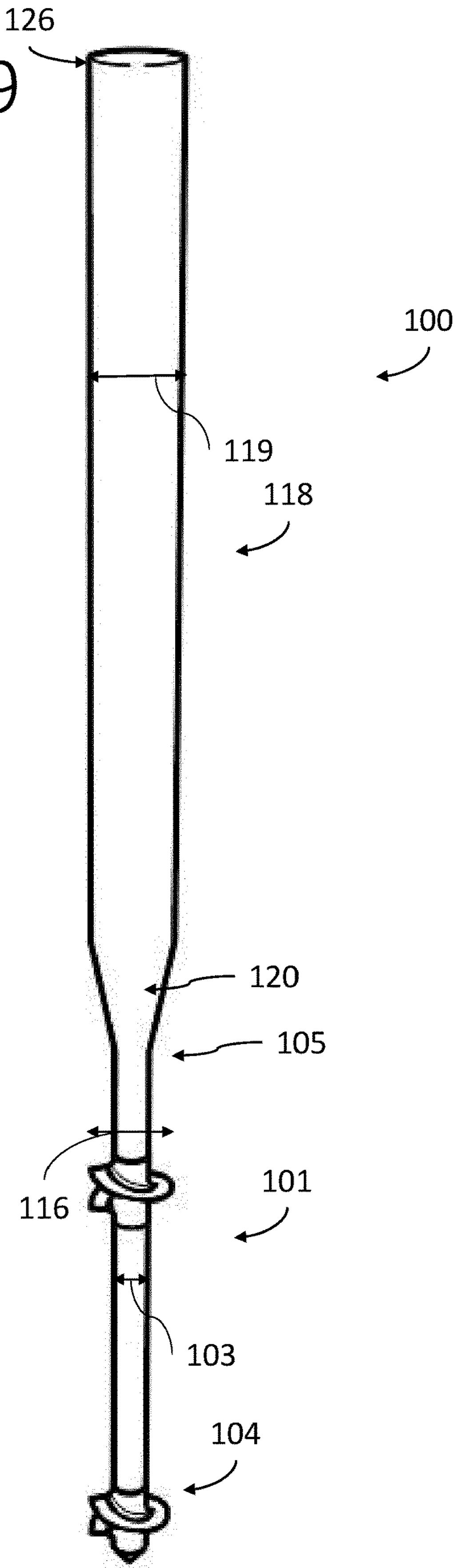

101
122
117
104
106
116

Fig. 29



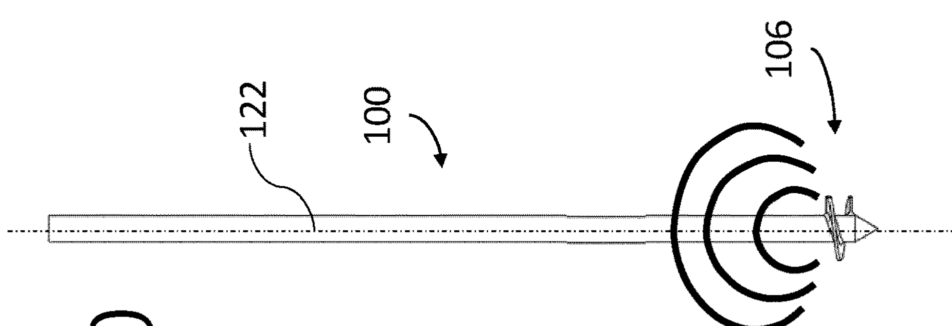


Fig.30

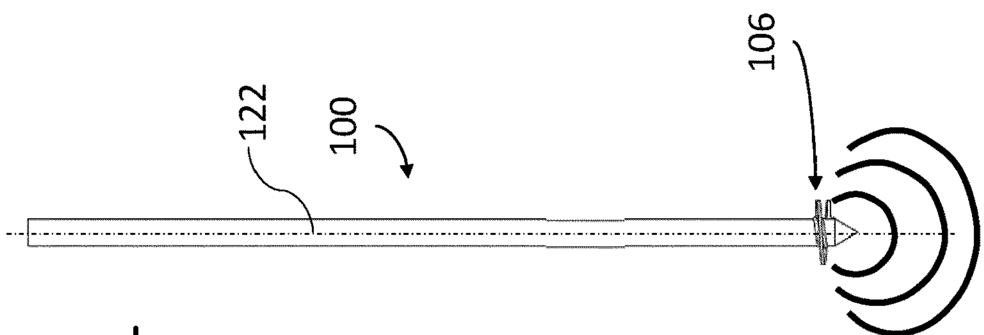


Fig.31

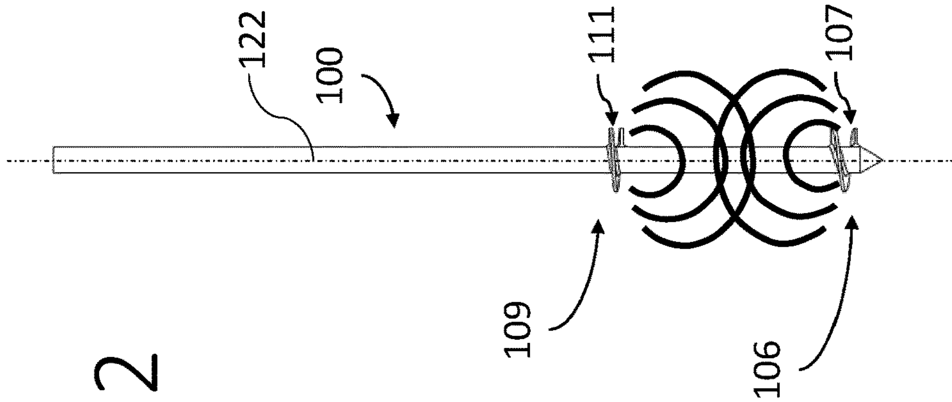


Fig.32

Fig.35

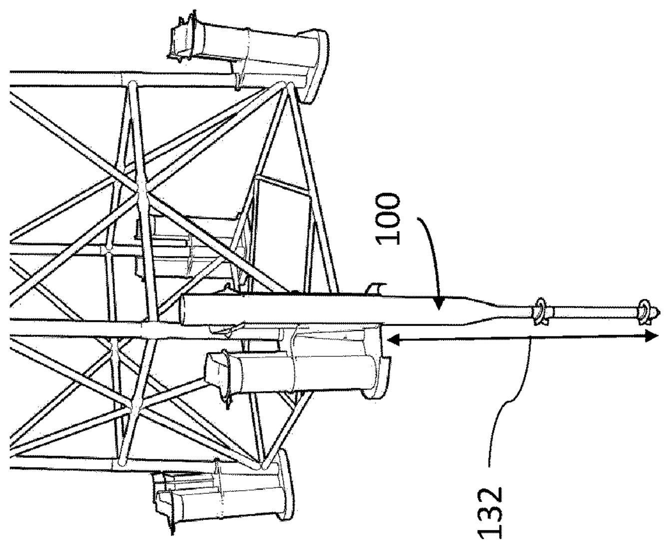


Fig.34

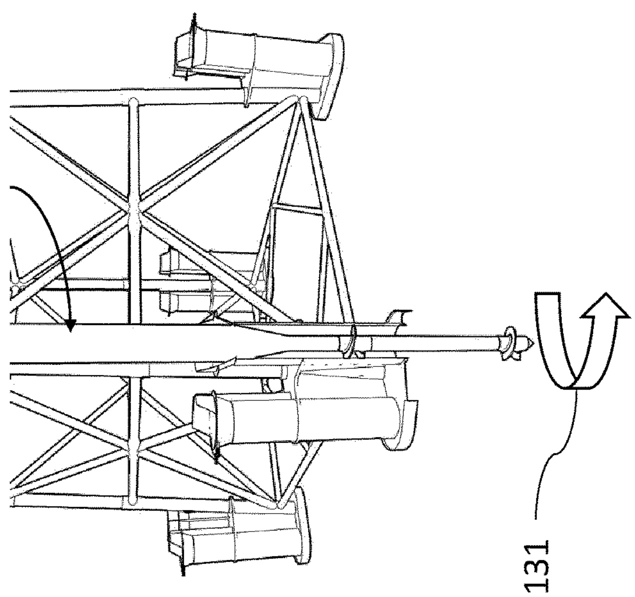


Fig.33

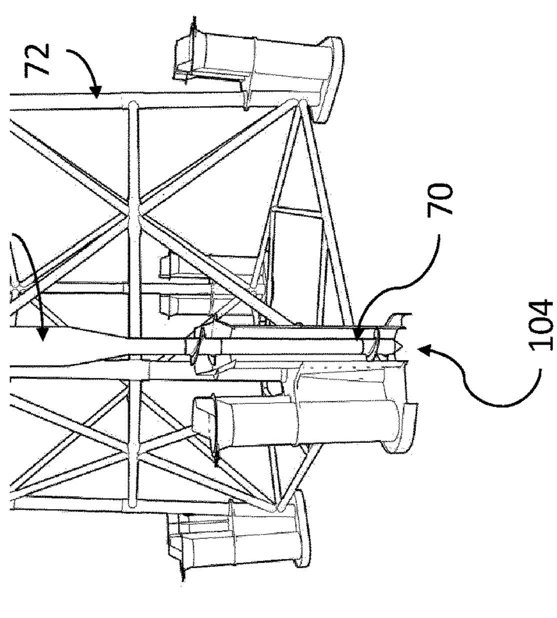


Fig.37

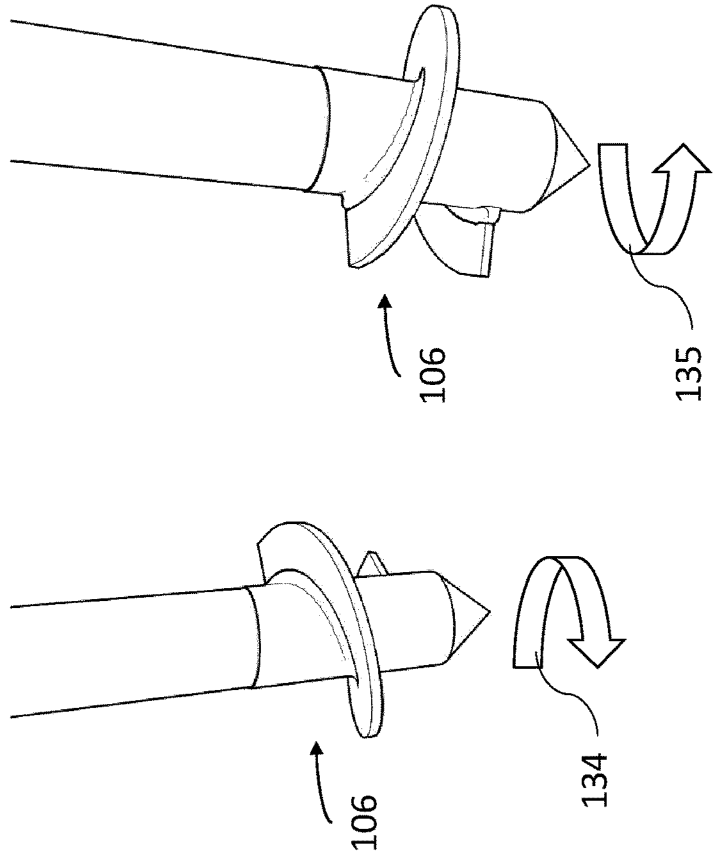


Fig.36

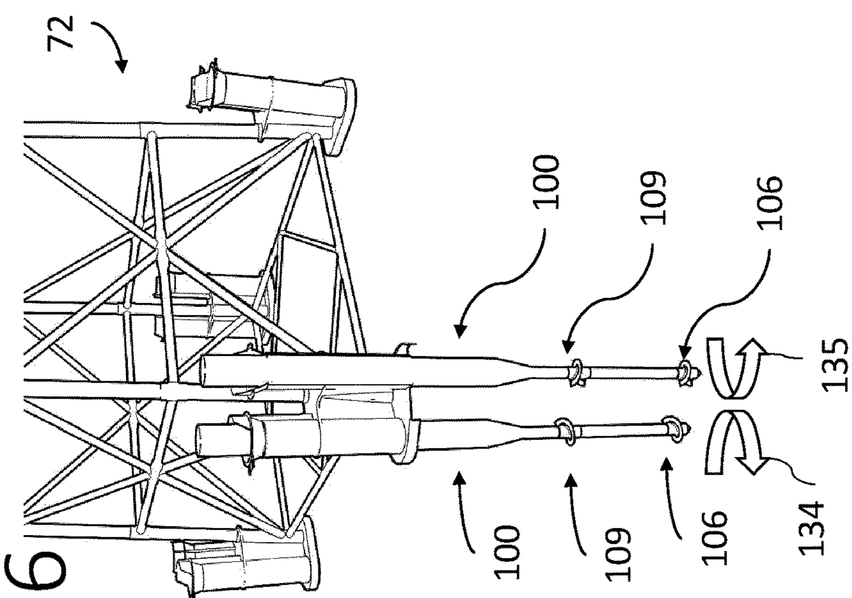
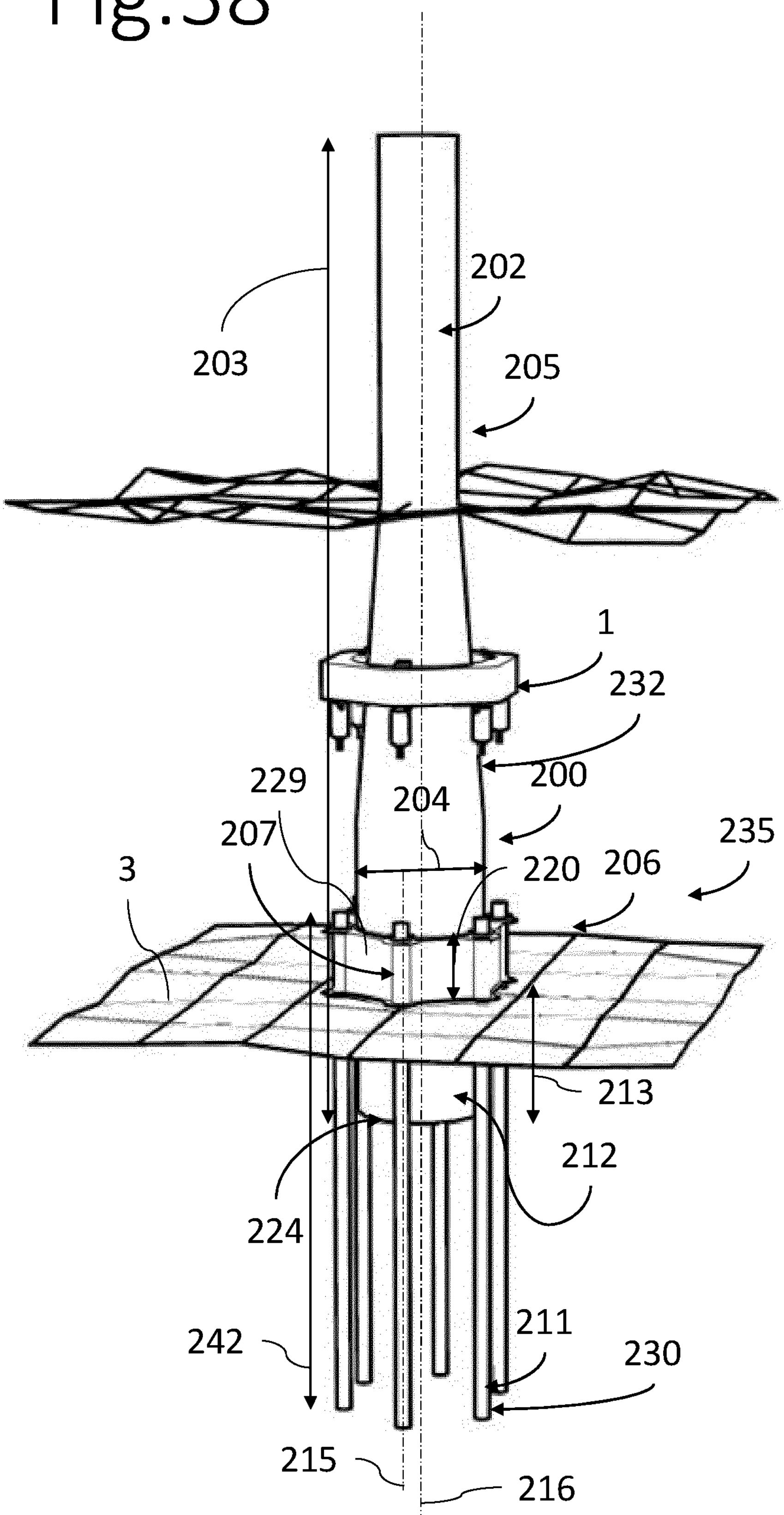


Fig.38


202
203
205
1
232
229
200
204
207
235
220
206
3
213
212
224
242
211
230
215
216

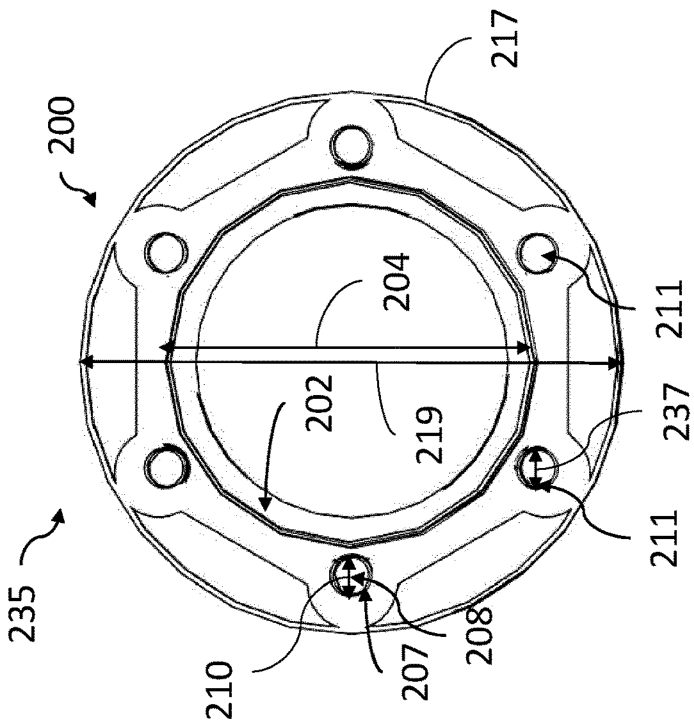


Fig. 39B

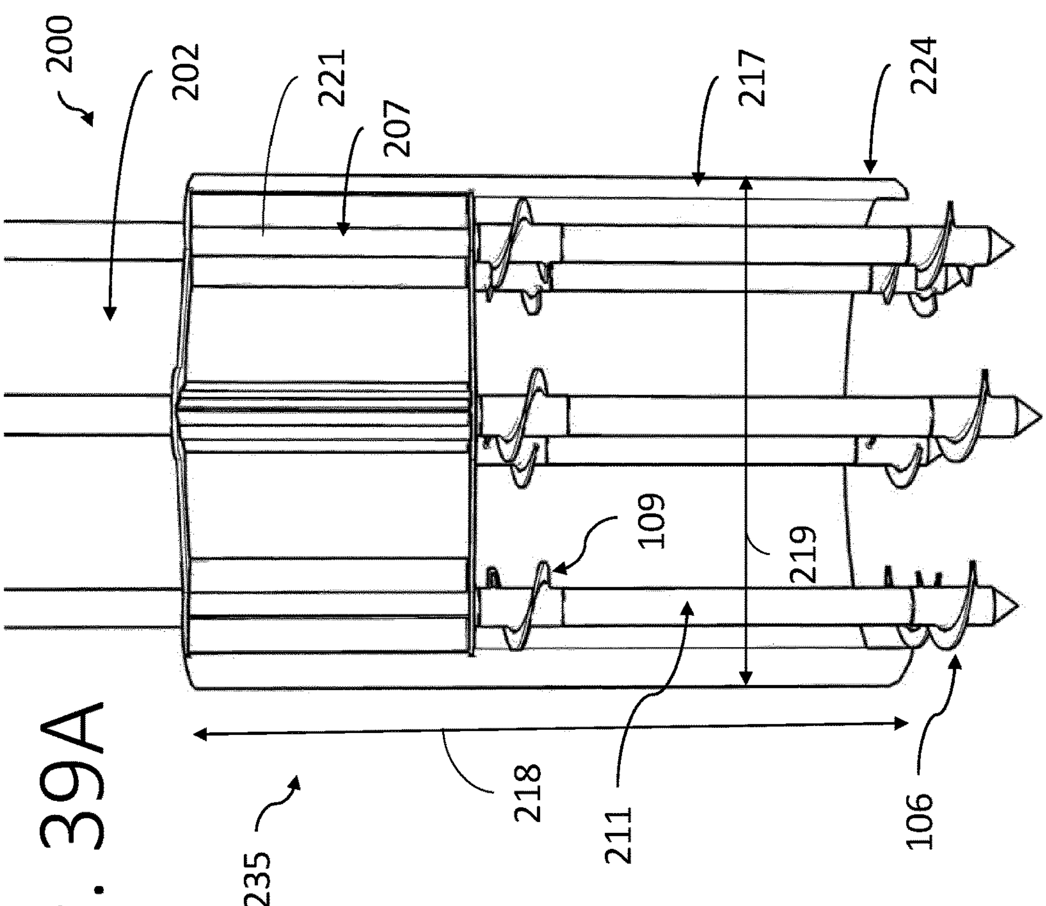


Fig. 39A

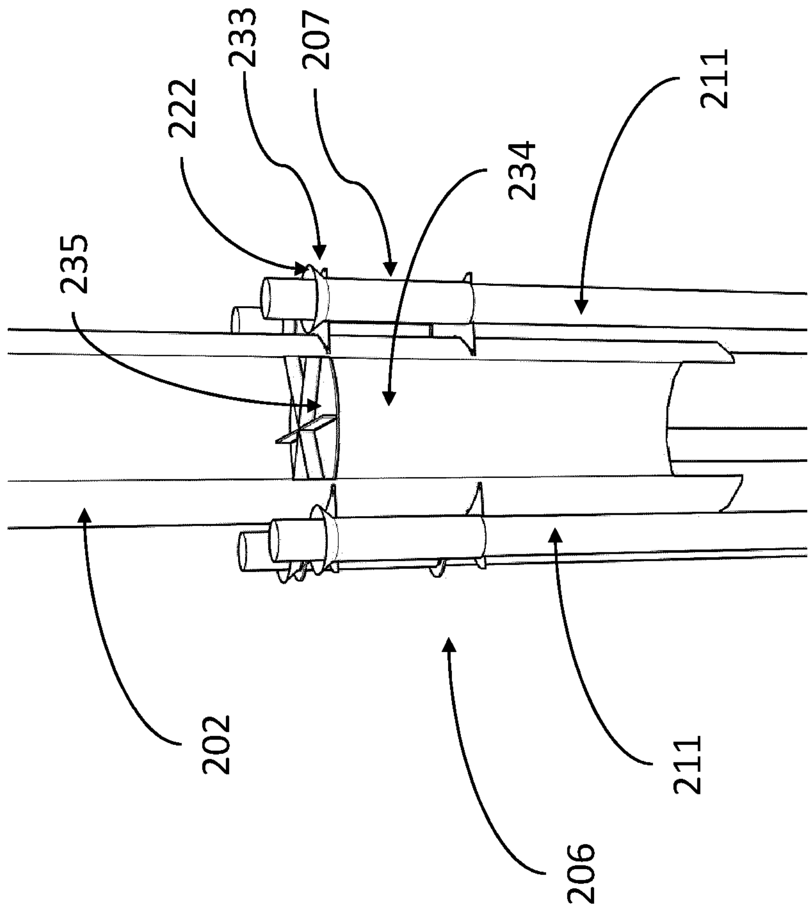


Fig. 40

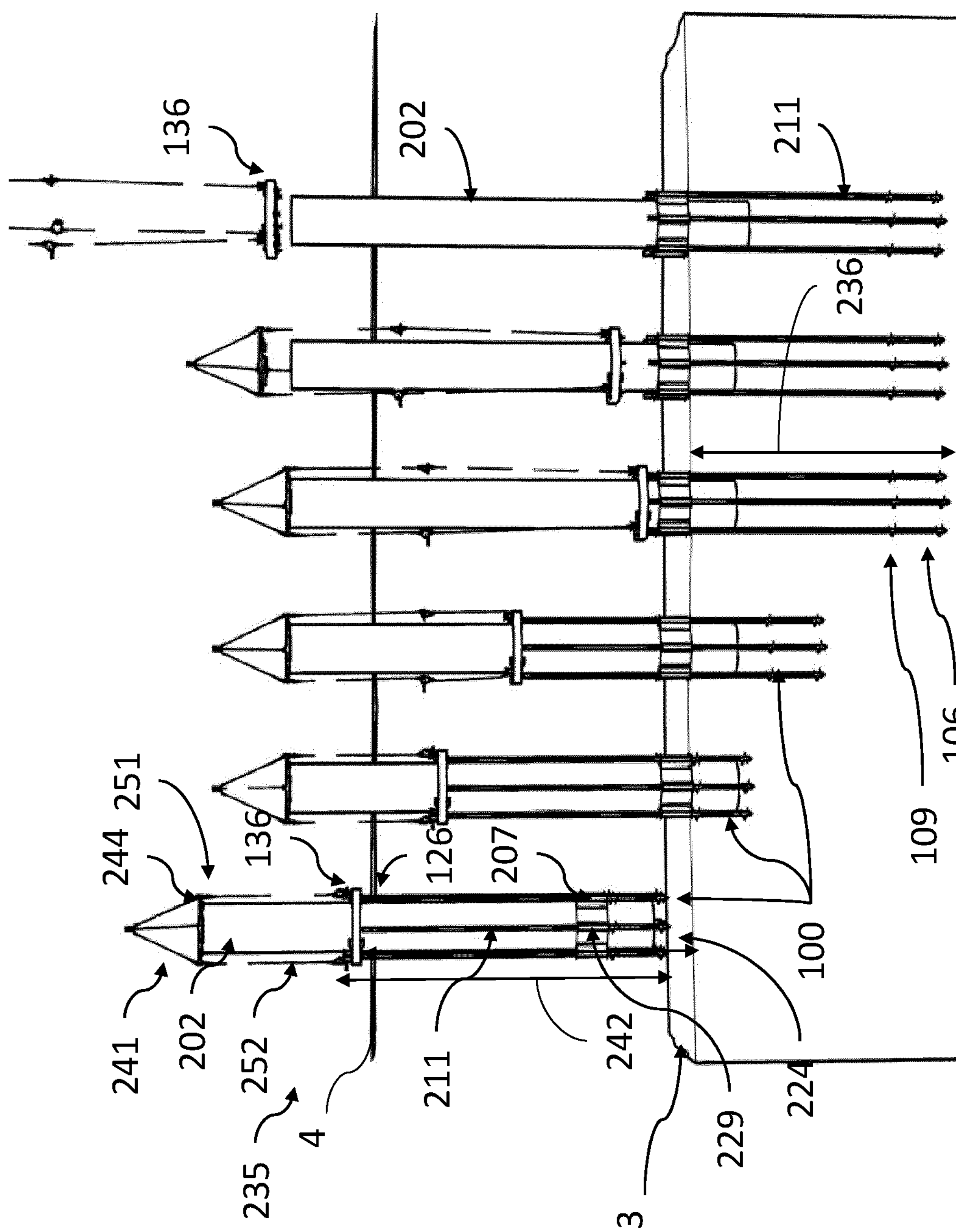

136
202
211
236
106
109
100
251
244
136
126
207
241
202
252
4
211
242
224
229
3
235

Fig. 41A

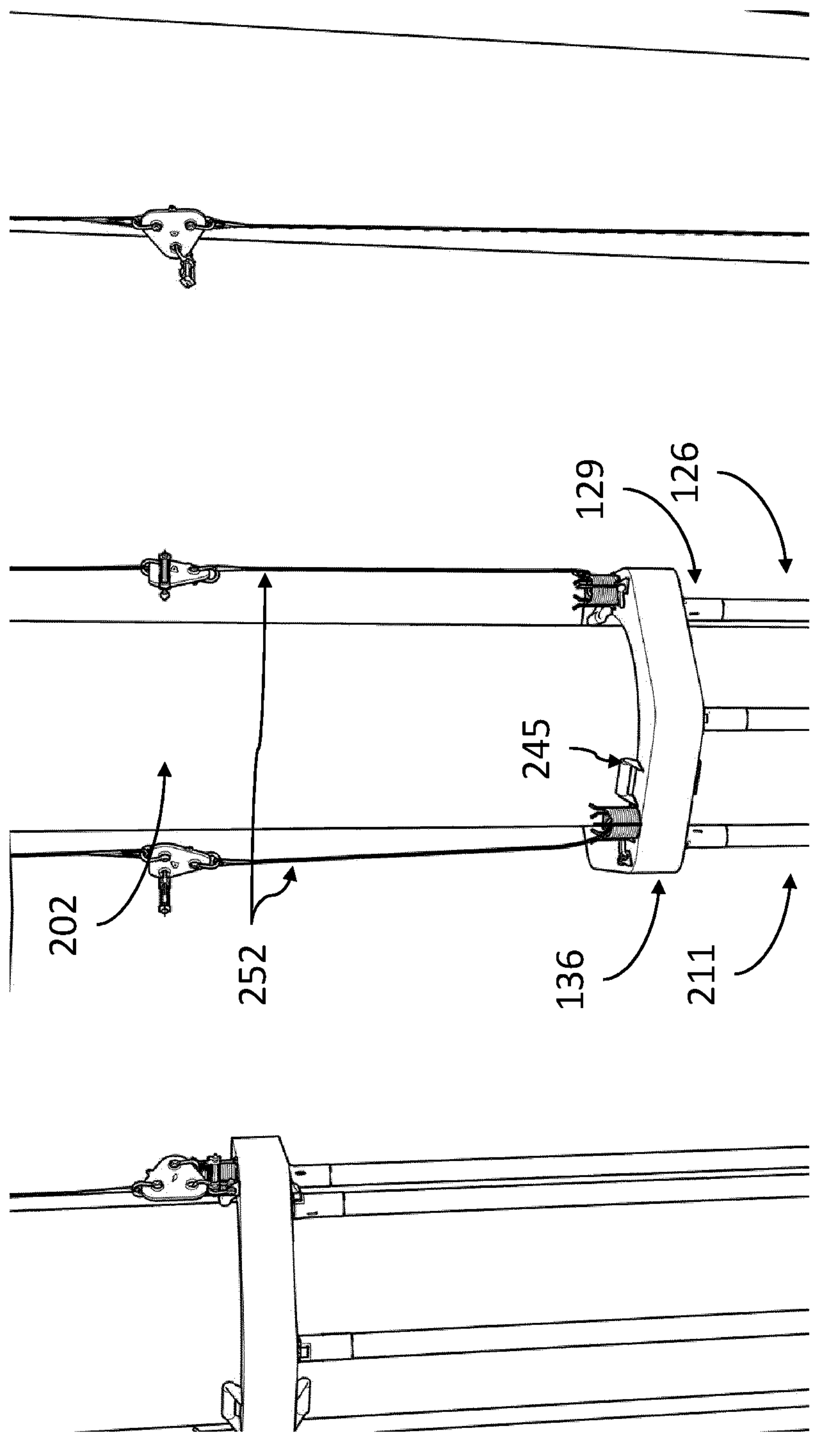


Fig. 41B

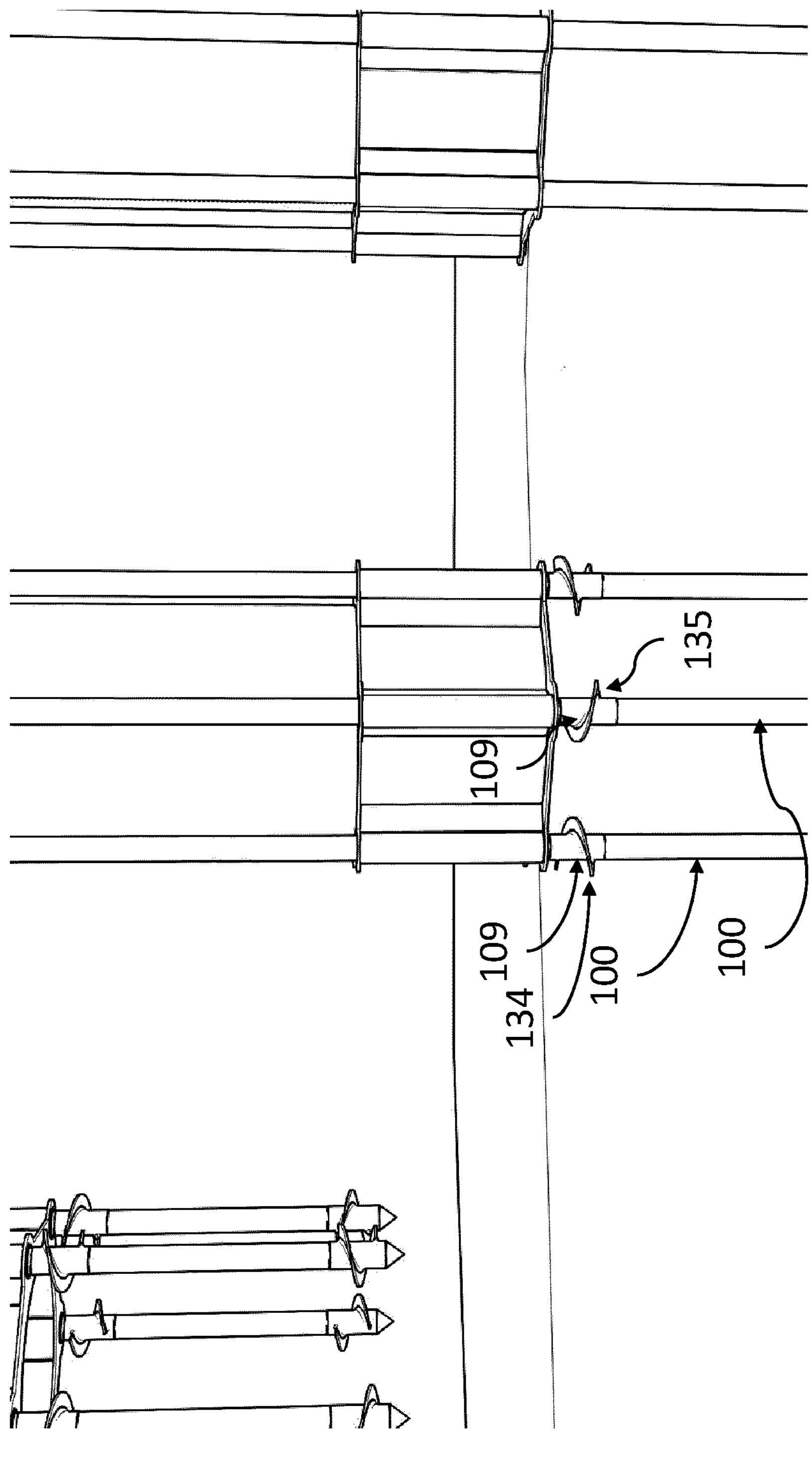
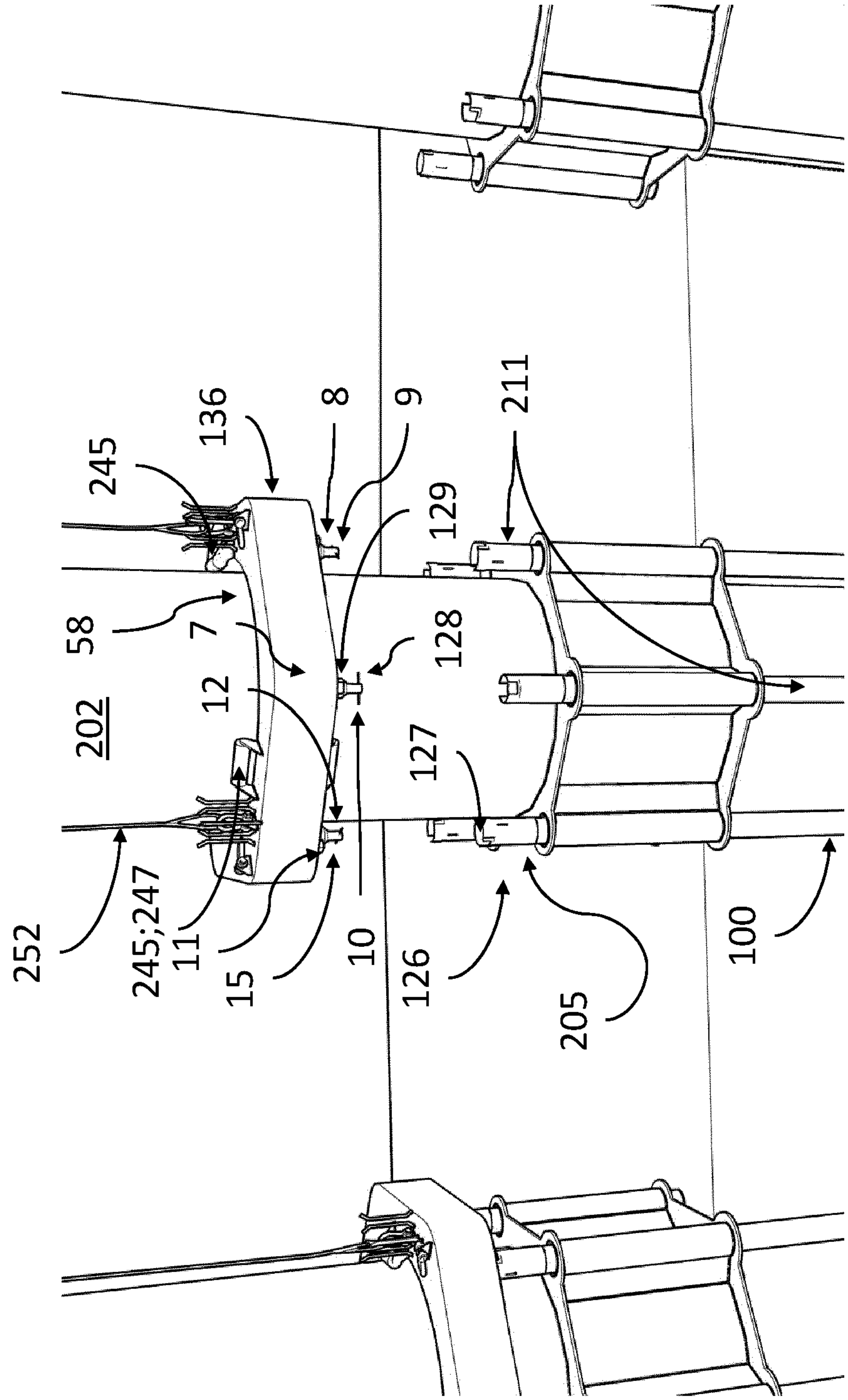


Fig. 41C



245
136
8
9
211
129
58
7
128
202
12
127
252
245;247
11
15
10
126
205
100

Fig. 41D

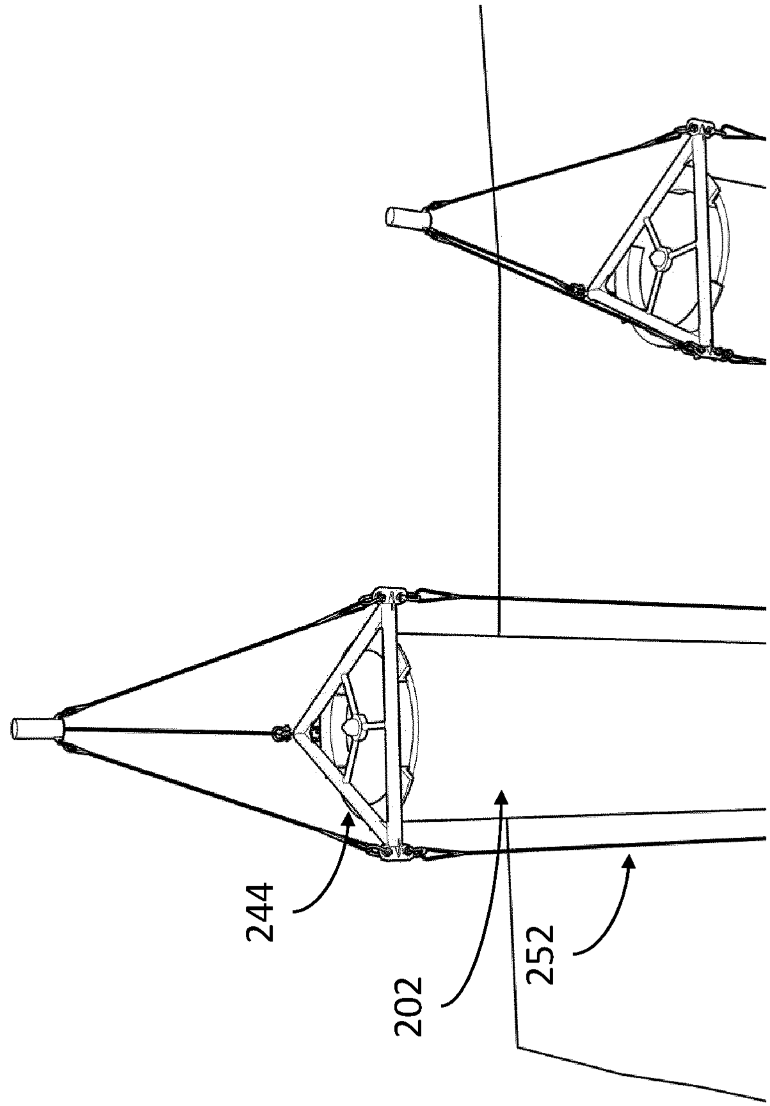


Fig. 41E

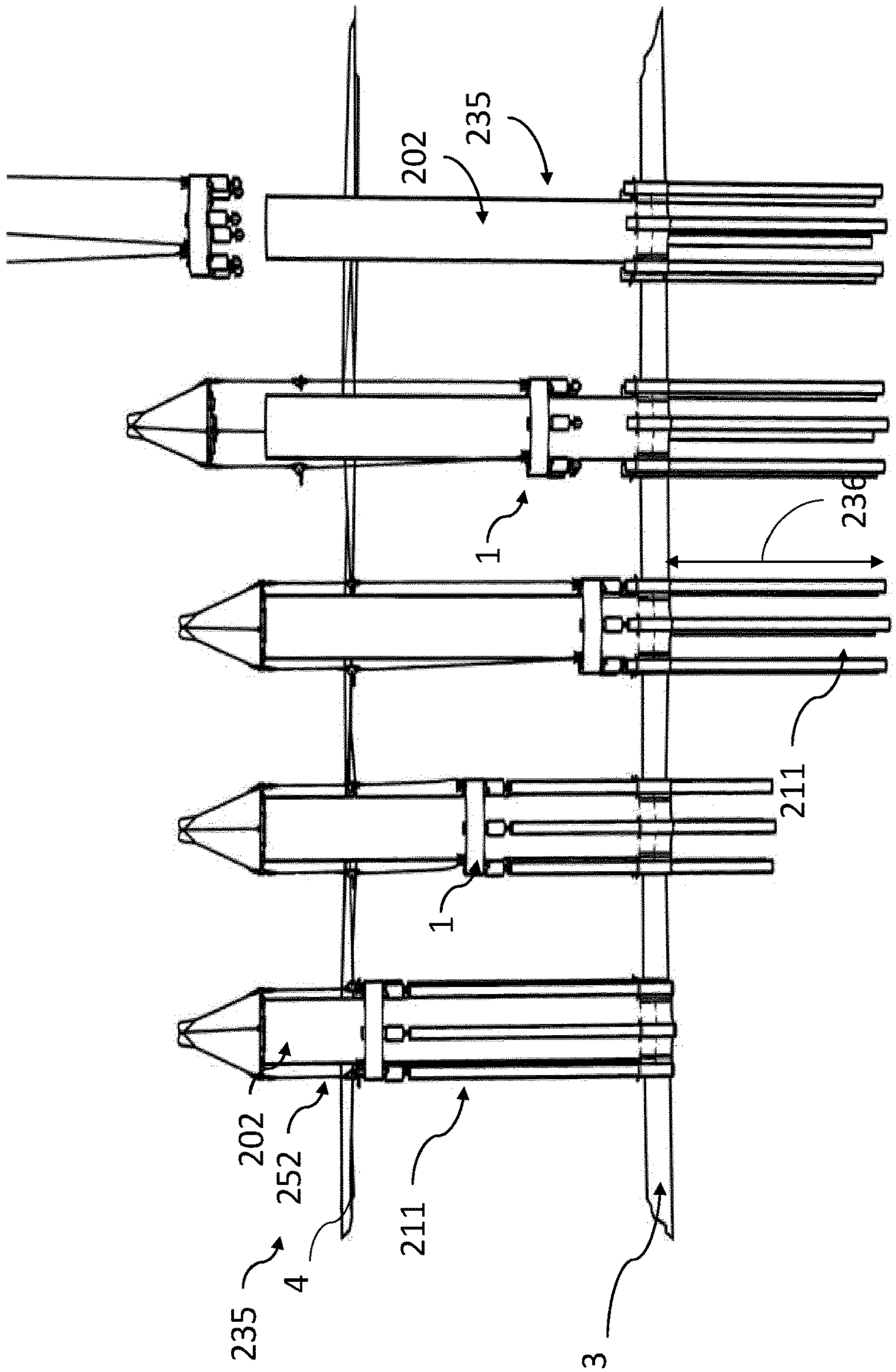


Fig.42

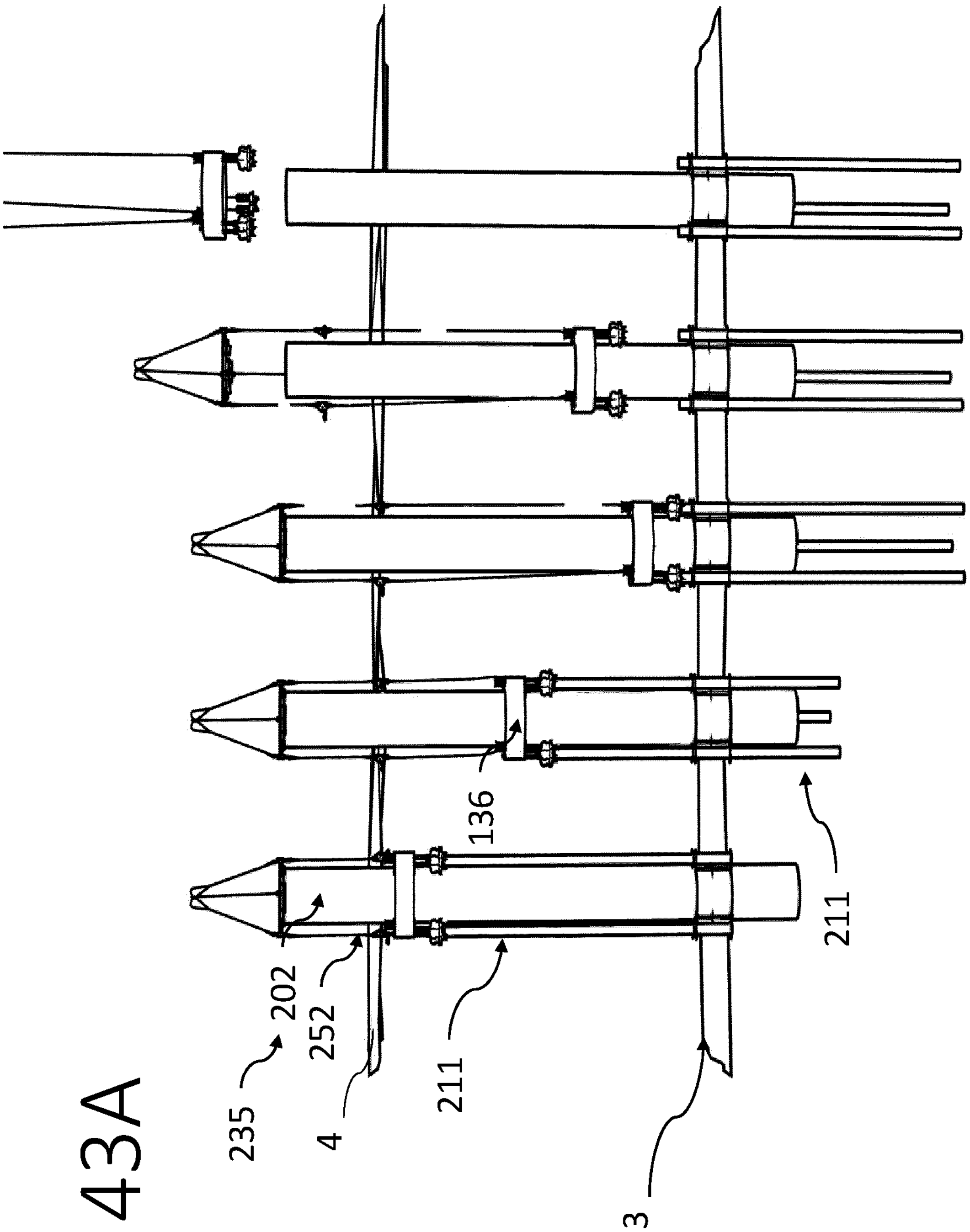


Fig. 43A

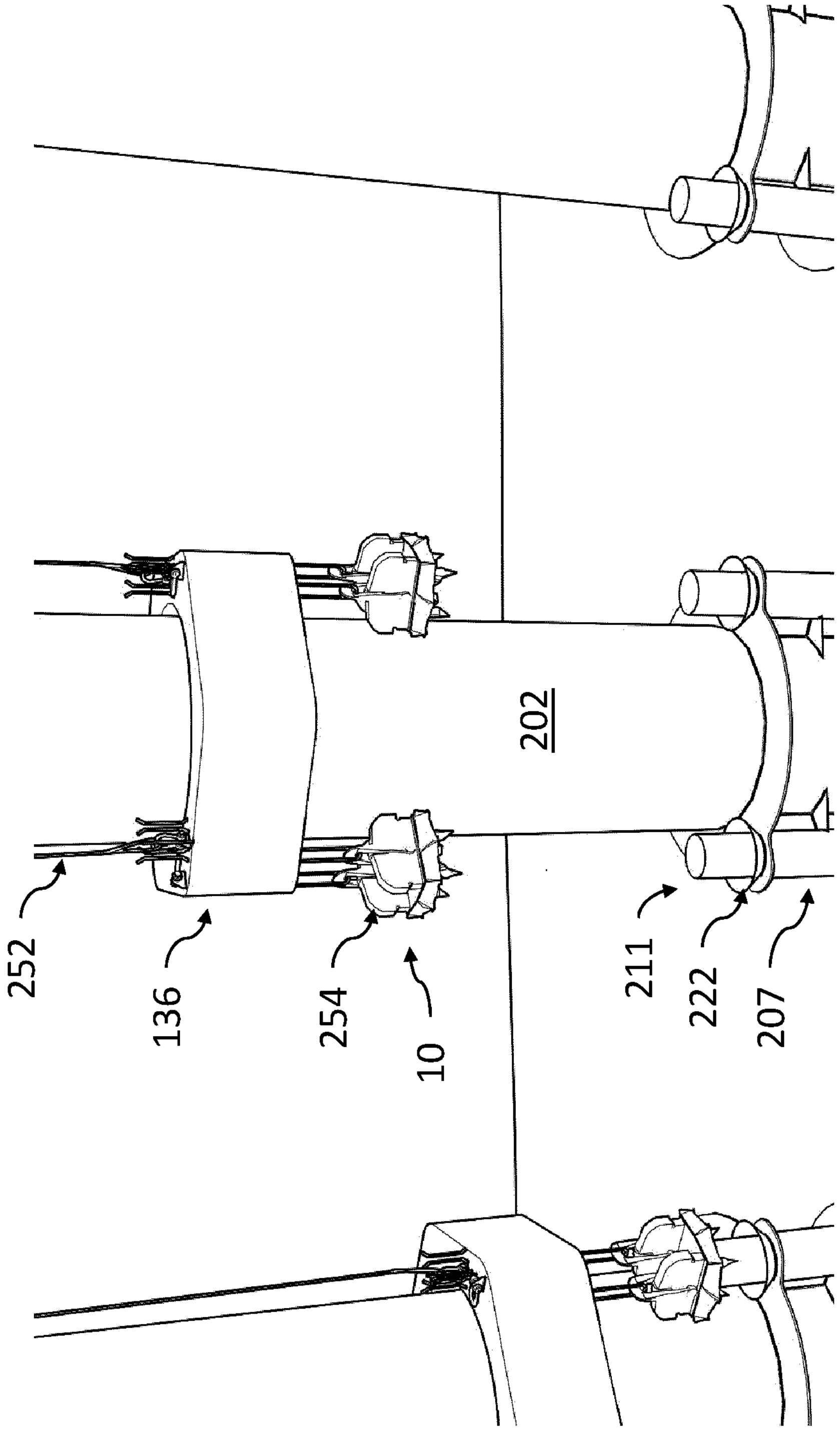


Fig. 43B

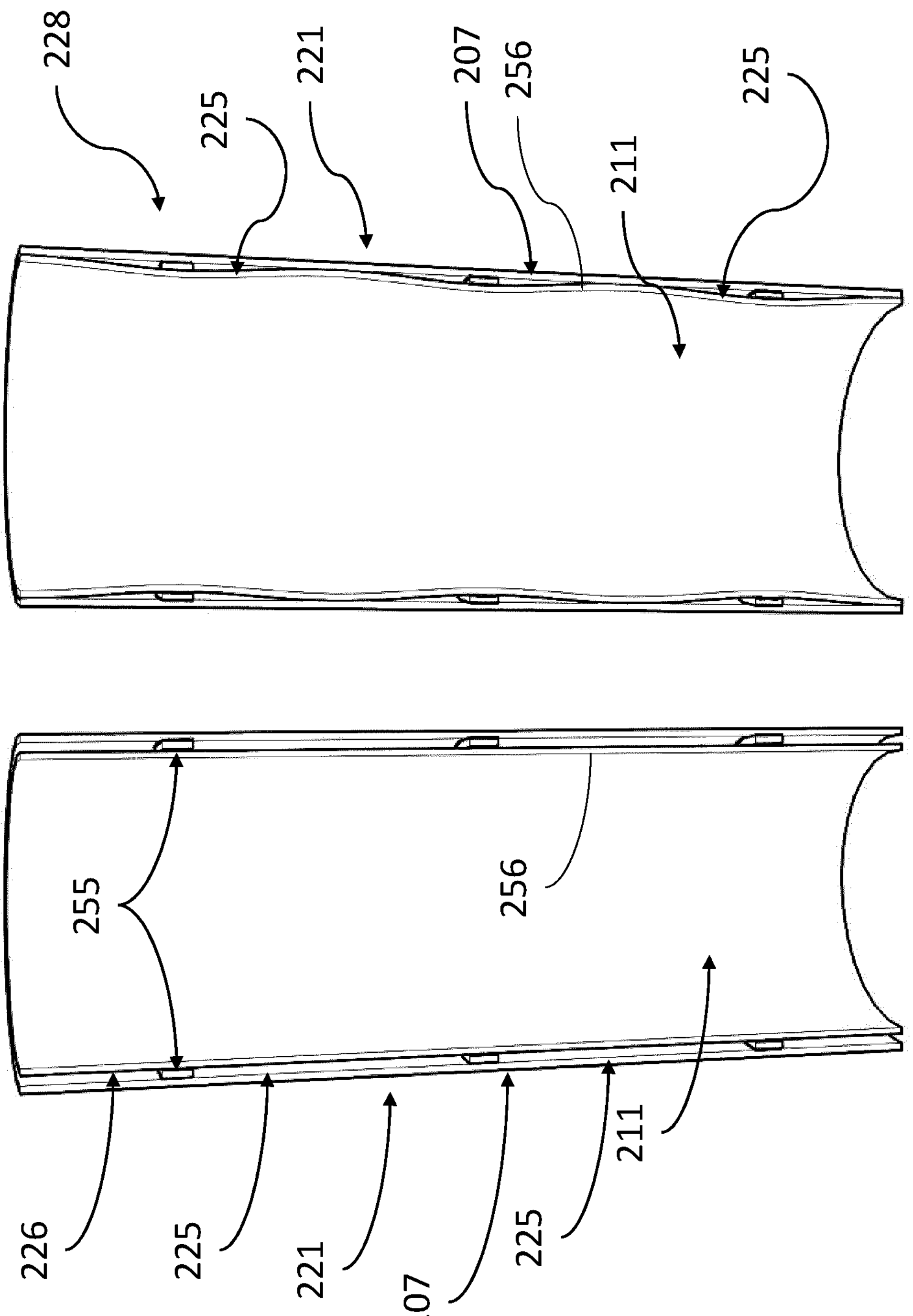


Fig. 44

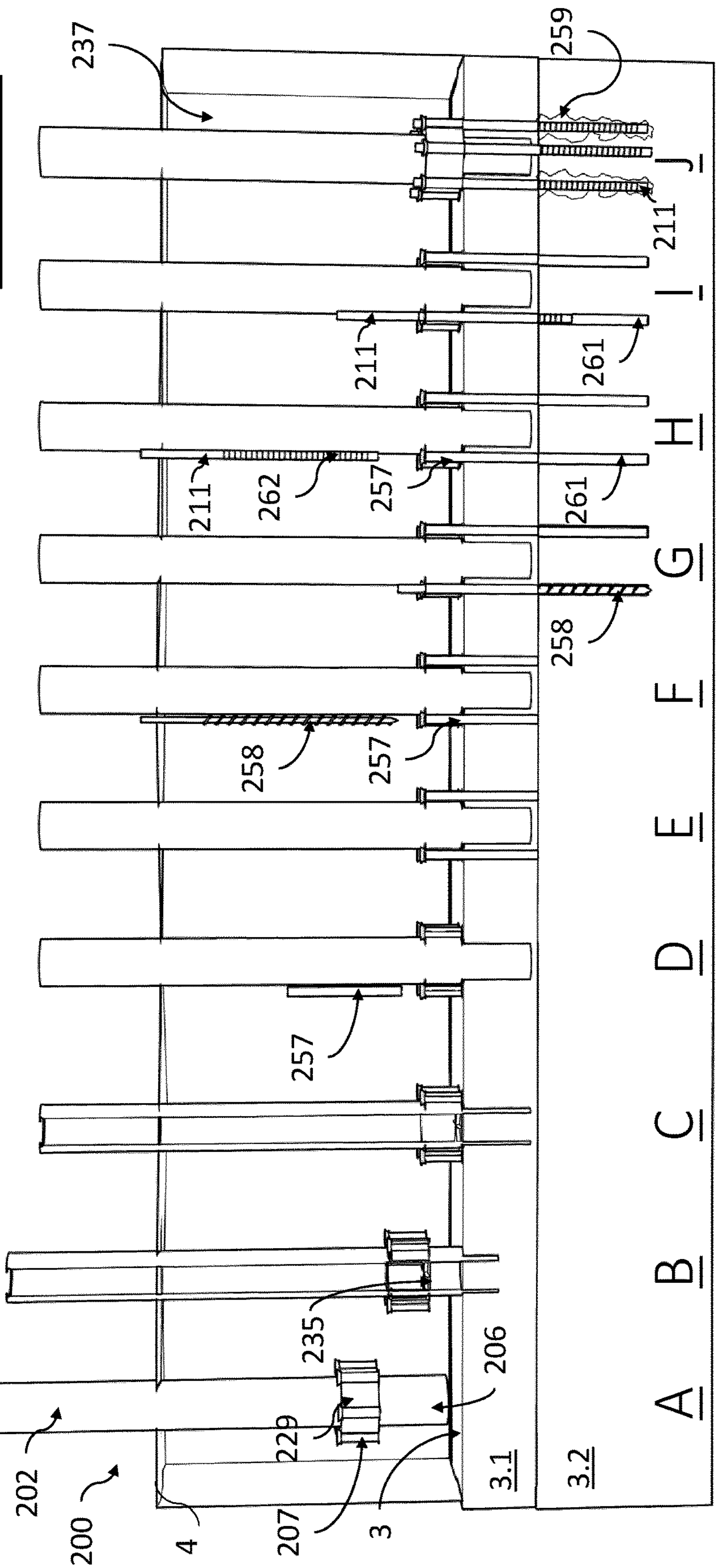

237
259
J
211
I
211
261
H
211
262
257
261
G
258
F
258
257
E
D
257
C
B
235
206
A
202
229
3.1
3.2
200
4
207
3

Fig. 45

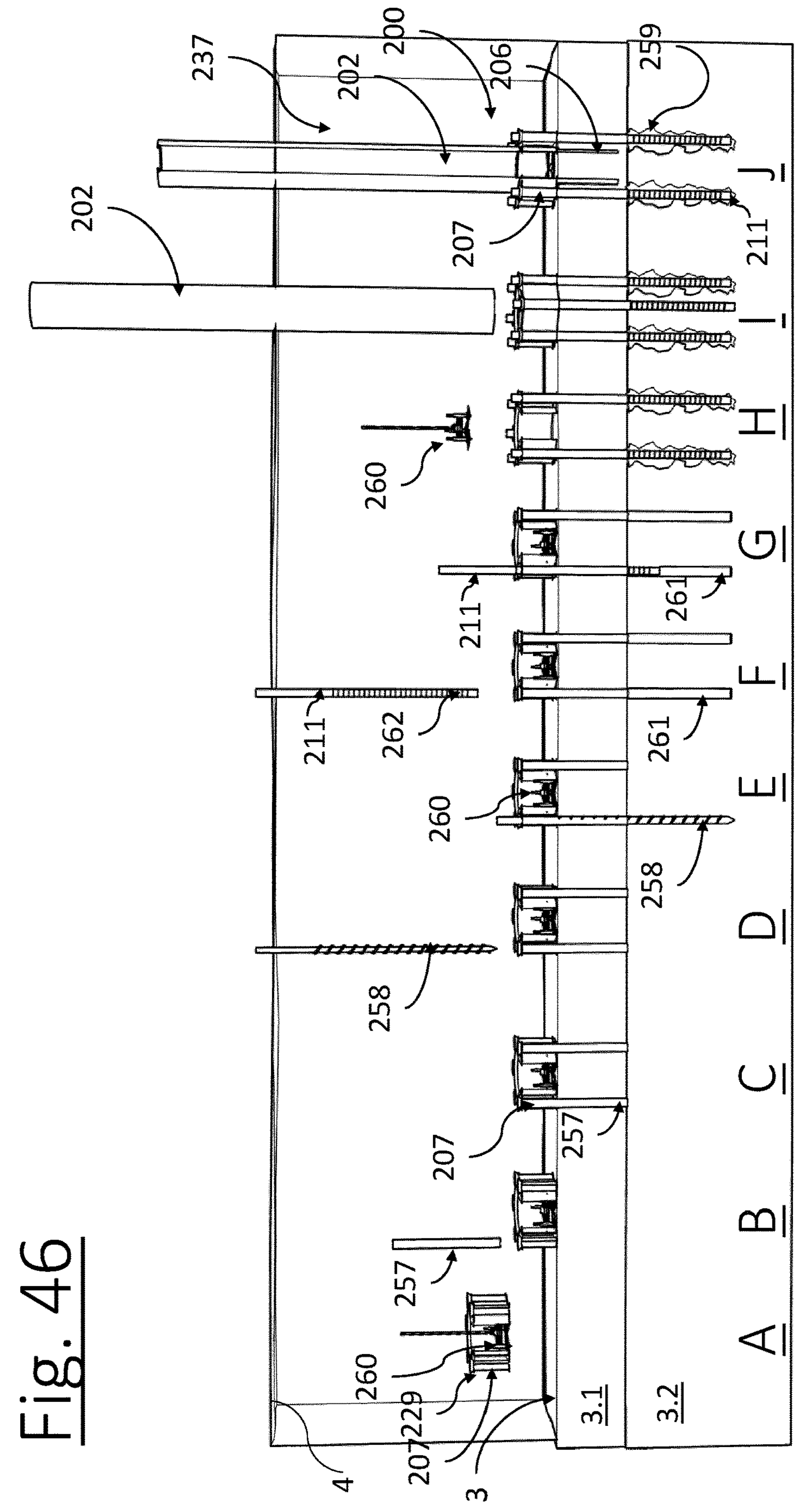


Fig. 46
200
237
202
206
259
207
211
260
261
262
258
257
229
3
3.1
3.2
4
A
B
C
D
E
F
G
H
I
J

DEVICES AND METHODS FOR INSTALLING PILES INTO THE GROUND OR SEABED

FIELD OF THE INVENTION

[0001] The present invention relates in a first aspect to a device for pushing at least five piles into or pulling at least five piles out of the ground or a seabed in a polygonal configuration. Devices for pushing piles into the ground are known in the field of the art.

[0002] In a second aspect the present invention relates to a helical pile for installation into the ground or seabed, and a method for installing said helical pile.

[0003] In a third aspect the present invention relates to a support structure and a support assembly for supporting a top structure above the ground or a seabed, and to a method for installing said support assembly.

BACKGROUND OF THE INVENTION

[0004] Offshore structures are generally grounded to the seabed with large diameter piles. The piles may be installed through the legs of the structure, so called main piles, or may be installed adjacent to the structure and connected with pile sleeves, so called skirt piles, to the structure. In order to insert these piles into the seabed, hydraulic impact hammers are typically used. The impact of the hydraulic hammer on the pile during a blow radially expands the pile. This expansion in turn results into a pressure wave in the water and soil column.

[0005] The noise generated by the pressure wave may be harmful for marine animals, in particular mammals. In some areas regulatory bodies limit the allowed sound levels. Such regions are for instance Germany, where the allowed sound levels are limited to 160 dB SEL5% at 750 m. In order to reduce the sound levels bubble curtains can be deployed prior to installation. These curtains are hoses with holes which lay on the seabed. Air is blown through these hoses, which escapes through the holes. Due to the difference in impedance between the air bubbles and the seawater part of the pressure wave is reflected and energy is dissipated reducing the noise levels significantly.

[0006] In order to blow enough air from the bubble curtain, many compressors are required. These are typically positioned on an auxiliary vessel. This is an expensive operation and has a large carbon footprint. Furthermore, the noise during pile driving is only reduced, never fully mitigated. Finally, these bubble curtains only work effectively in shallow water depths and become less efficient at larger depths. Therefore a silent alternative would be preferred both from a sustainability and technical perspective.

[0007] A further disadvantage of hammering piles into the ground or seabed is that the shockwaves typically are so strong that they damage electronic equipment which could be used to measure the position and orientation (inclination) of the piles.

[0008] There are several options to silently install piles. Typical examples are screw piles, or helical piles (hereafter helical piles) installed by torque or piles which are pushed into the ground. The push-in pile is often used on land where multiple piles are installed at the same time. One pile is pushed down while the other piles are used as a reaction force. These piles are installed in one line, to form a row. In the present invention, it was recognized that this is not economical for offshore piles, because the distance between the outermost pile and the jacket would become too large. Currently, there is no viable technology available to drive piles into the seabed in a silent manner.

[0009] On land, hammering piles into the ground is common technology and widely used for foundations of buildings and in general structures. However, similar issues apply with regard to noise. The hammering has a disadvantage in that a lot of noise is generated, which provides serious inconvenience to people in the surrounding. The hammering may also form a cause of damage to other buildings, in particular by causing cracks in other buildings.

[0010] As indicated above, systems for pushing piles into the ground in a silent matter exist. However, such systems generally have a limitation that the piles need to be positioned in a row. Furthermore, these systems generally require a separate reaction frame for the first few piles, because the system requires a support position in order to be able to start working. Only after a few piles are inserted into the ground, the reaction frame is no longer necessary.

[0011] Another system for silently driving piles into the ground exists. This system is applied by a British company called Dawson, called a Dawson system. With this system, at least five interlocked sheet piles can be driven into the ground. See the website of this company: http://www.dcpuk.com/products_press.html. This system is considered to form the closest prior art for the present invention.

[0012] It was recognized in the present invention that a disadvantage of this Dawson system is that the Dawson system is not capable of driving regular tubular piles into the ground. In the Dawson system, the piles needs to be interlocked, and for this reason need to have a specific design which allows for the interlocking of the piles. Such specially made piles are quite costly.

[0013] Other systems for driving piles into the ground in a silent manner also exist. For instance, systems exist for driving piles having a helical shape into the ground. This is essentially screwing a pile into the ground. Although these systems work, the piles need to be specifically designed and manufactured, and are quite costly.

[0014] Other systems exist which are based on vibrating piles into the ground. Such systems have a specific disadvantage that the vibrations may also cause inconvenience to people in the surroundings and may be a cause of damage to surrounding buildings. Furthermore, these systems do not work under all circumstances.

[0015] The above mentioned helical piles are beneficial from a sound point of view. The installation of helical piles causes less noise than hammering piles into the ground. A disadvantage of the presently available helical piles is that the tension capacity when installed is lower than desired.

[0016] The offshore structures usually comprise a support structure and a top structure. The support structure, or foundation, are generally of a monopile type or a jacket type. This is especially the case for wind turbines where monopiles are used as they are considerably easier to fabricate and cheaper to make than jacket type foundations.

[0017] With ever increasing water depths the use of monopiles is deemed less favourable for various reasons.

[0018] A first reason is that an increase in water depth also means an increase of the required length of the monopile. Secondly the increase in water depth drives the diameter and base requirements, as with an increase in distance between the seabed to the top of the wind turbine the overturning moment on the foundation increases. In general it can be concluded that with increasing turbine size together with increasing water depths, the diameter and length of monopiles will increase. Where some time ago diameters of 8 meter where considered large in size, currently diameters of 12 meters are considered.

[0019] Drawbacks of increasing monopile size are experienced in multiple stages before getting a wind turbine foundation operational. This includes fabrication, storage, transport, handling and installation into the seabed.

[0020] Temporarily storing the large monopiles before shipping creates additional handling operations as quayside area is typically limited and expensive. Transferring the large monopiles on a barge or installation vessel poses problems as typical yard equipment such as cranes are rapidly reaching their maximum lifting capacity together with their maximum lifting height and reach.

[0021] Once offshore, the large monopiles need to be upended, because they are transported horizontally. The upending is becoming increasingly difficult, because of the large dimensions and weight of the monopiles. During installation of the large monopiles increasing sizes of hammers are required which currently do not exist. Larger hammers would also result in more noise during hammering.

[0022] An important disadvantage of the large monopiles is that they are difficult to remove when the monopile has reached its end of life. Cutting the monopile just below the mudline means that a large portion of the steel would remain under ground.

[0023] Jackets may overcome some of the drawbacks of the large monopiles, but jackets have disadvantages as well.

[0024] Jackets are typically installed on top of pre or post installed smaller piles. This has the benefit that the noise levels are reduced, because smaller piles may require less energy input. A drawback here are the additional steps required to install all the smaller piles together with creating the, usually permanent, connection between the smaller piles and the jacket.

[0025] A jacket type structure tends to be expensive to build and transport due to its footprint and complex construction. A benefit of the large footprint is a reduction in required lateral capacity opposed to a monopile, which allows for the smaller piles. Jackets are also better suited to counter the overturning moment.

OBJECT OF THE INVENTION

[0026] It is an object of the invention to provide a device for pushing at least five piles into the ground.

[0027] It is an object of the invention to provide a helical pile and a method for installing a helical pile which provides a higher tension capacity when installed, in particular while maintaining the compression capacity of the helical pile.

[0028] It is an object of the invention to overcome the drawbacks of the ever increasing dimensions of monopiles.

SUMMARY OF THE INVENTION

First Aspect

[0029] In order to achieve at least one objective, the present invention provides in a first aspect a device for pushing at least five piles into or pulling at least five piles out of the ground or a seabed, wherein in top view at least a number of the at least five piles define a polygonal configuration, wherein any of the remaining at least five piles are located within the polygon, the device comprising:

- **[0030]** a bridge assembly which when seen in top view defines at least five connecting locations,
- **[0031]** at least five pile connection assemblies via which in use each of the at least five piles is connected to the bridge assembly, wherein each pile connection assembly comprises:
  - **[0032]** an actuator which extends downward from the respective connecting location, wherein each actuator comprises an upper actuator part and a lower actuator part, wherein the upper actuator part is connected to the bridge assembly, wherein the actuator is configured to
    - **[0033]** extend in order to move the lower actuator part downward relative to the upper actuator part and/or
    - **[0034]** retract in order to move the lower actuator part upward relative to the upper actuator part,
  - **[0035]** a pile connector connected to the lower actuator part, wherein each pile connector is configured to be connected to an upper part of a pile which is to be pushed into or pulled out of the ground or seabed, wherein the pile connector is configured to move downward or upward relative to the upper actuator part together with the associated lower actuator part during the respective extension or retraction,
- **[0036]** a control device configured for alternately pushing or pulling at least one of the at least five piles over a distance into or out of the ground or seabed by applying a vertical force via the associated actuator to the at least one pile which is being pushed into or pulled out of the ground or seabed.

[0037] The present invention is based on the general idea that in order to push one pile into the ground, a push force (or compression force) is provided via an actuator connected to the bridge assembly. This push force results in a reaction force of the pile into the bridge assembly. This principle is reversed for pulling piles out of the ground.

[0038] An advantage of the invention is that the device can be “stand alone”. In other words, the device does not generate external loads as land based systems generally do, which external loads have to be carried by a separate crane or structure or foundation.

[0039] Another advantage of the device according to the invention is that, in contrast to piles that are installed by pile driving, measurement tools can remain on the equipment. This is normally not possible as the measurement system cannot survive the blows from the hammer. This allows direct read-out of the depths and orientations of the independent piles and/or the tool itself and of the loads which are exerted on the piles.

[0040] An advantage of at least five piles over fewer than five piles is redundancy in case one of the actuators fails, or if for example the pile connector fails. Then it is still possible to continue by retracting all but the failed actuator. Also there is a lower chance of unintentionally pulling one of the piles out, because more piles provide a higher pulling capacity. In addition, at least five piles allow for pushing in two piles simultaneously, resulting in a possible installation cycle of three steps. This provides a faster installation compared to a device configured to install four piles, because said four piles can only be installed one by one, resulting in a cycle of four steps.

[0041] In an embodiment of the device, the control device is configured for regulating at least the vertical force which is exerted by the actuator associated with the pile which is being pushed in or pulled out and/or at least the vertical forces which are exerted by at least two of the remaining actuators on associated remaining, stationary piles, in order to have the at least one pile which is pushed into or pulled out of the ground or seabed receive a greater vertical force than each of the remaining piles.

[0042] For the actuators stationary means not retracting and not extending. With vertical forces the absolute forces are meant. Hence, a negative pull force and positive push force are both considered a vertical force. For the piles stationary means that the piles are not being pushed in or pulled out.

[0043] Controlling the force of one or more actuators allows for measuring the pile capacity during installation. It also provides a direct control over the load applied to one or more piles thus providing more certainty and reliability to the installation process. Thirdly the force control provides direct feedback on issues when for example the actuator breaks down during use.

[0044] In an embodiment of the device, the control device is configured for alternately pushing at least one of the at least five piles over a distance into the ground or seabed by alternately:

- [0045] having at least one of the actuators associated with the at least one pile being pushed in extend, and/or by
- [0046] keeping at least one actuator associated with the at least one pile being pushed in substantially stationary while retracting at least three of the remaining actuators, and/or by
- [0047] keeping at least one actuator associated with the pile being pushed in substantially stationary while extending at least two opposite actuators, thereby pivoting the bridge assembly about a pivot axis extending between said at least one actuator and said at least two opposite actuators.

[0048] The first option of alternately extending at least one of the actuators is the simplest. The second and third option provide flexibility to the device.

[0049] In an embodiment of the device, the control device is configured for alternately pushing at least one of the at least five piles over a distance into the ground or seabed by alternately:

- [0050] having at least one of the actuators extend, wherein the control device is configured for regulating at least the vertical force which is exerted by the at least one actuator during the extension thereof in order to let the at least one pile which is pushed into the ground or seabed receive a greater vertical force than each of the remaining piles, and/or by
- [0051] keeping at least one actuator substantially stationary while retracting at least three of the remaining actuators, wherein the control device is configured for regulating at least the vertical force which is exerted by the at least three retracting actuators in order to let the at least one pile corresponding to the substantially stationary actuator receive a greater vertical force than each of the remaining, stationary piles, and/or by
- [0052] keeping at least one actuator which is associated with the pile being pushed in substantially stationary while extending at least two opposite actuators, thereby pivoting the bridge assembly about a pivot axis extending between said at least one actuator and said at least two opposite actuators, wherein the control device is configured for regulating at least the vertical force of the at least two opposite extending actuators in order to have the at least one pile being pushed in receive a greater vertical force than each of the remaining, stationary piles for pushing the at least one pile into the ground or seabed.

[0053] In an embodiment of the device, the at least one actuator which is associated with the at least one pile which is being pushed into the ground or seabed transfers the exerted vertical push force into the bridge assembly and wherein said push force is transferred at least partially from the bridge assembly as a tension force into at least two of the remaining, stationary piles via the respective pile connection assemblies.

[0054] In an embodiment of the device, the polygonal configuration defines a polygon with angles between 90-180 degrees.

[0055] In an embodiment of the device, when seen in top view the pile connection assemblies are arranged on a circle or an ellipse. This embodiment provides a clearer load distribution.

[0056] In an embodiment of the device, the pile connection assemblies are arranged equidistantly on a circumscribed circle or circumscribed ellipse of the polygon. This embodiment allows for a more clear load distribution. In particular for the circle, because the load distribution can be identical for each pile being pushed in.

[0057] In an embodiment of the device, the polygonal configuration is an irregular polygon.

[0058] In an embodiment of the device, all piles define the polygon configuration.

[0059] In an embodiment of the device, the pivot axis extends through two opposing actuators located between the at least one actuator associated with the pile being pushed in and the at least two opposite extending actuators, wherein the two opposing actuators are configured to be kept stationary during pushing of the at least one pile.

[0060] In an embodiment of the device, the control device is configured to keep a sum of the positive, vertical push forces and the negative, vertical pull forces of the actuators substantially zero during the push in of the at least one pile.

[0061] In an embodiment of the device, an equilibrium point is defined within the polygon, wherein the control device is configured to keep a sum of the moments applied by the actuators about said equilibrium point substantially zero.

[0062] In an embodiment the device comprises at least six connecting locations and six corresponding pile connection assemblies, the device being configured to alternately push at least two piles of the at least six piles into the ground or into the seabed simultaneously. This embodiment provides a fast installation as fewer steps are required, i.e. three steps.

[0063] In an embodiment of the device, the at least one or two actuators which is/are associated with the at least one or two piles which is/are being pushed into the ground or seabed transfers the exerted vertical push force into the bridge assembly and wherein said push force is transferred at least partially from the bridge assembly as a bending moment into at least two or three of the remaining, stationary piles via the respective pile connection assemblies.

[0064] In an embodiment of the device, each pile connection assembly comprises a sliding assembly which is rigidly connected to the bridge assembly, wherein the sliding assembly comprises a sleeve and one or more gripper actuators which can be switched between a gripping state and a released state, wherein:

[0065] in the released state the pile and/or pile connector can slide through the sleeve,

[0066] in the gripping state the sleeve is rigidly connected to the pile and/or pile connector, allowing a tension force and a bending moment to be transferred from the bridge assembly into the pile which is in the sleeve.

[0067] In an embodiment of the device, the pile connection assemblies are rigidly connected to one another via a base frame which is positioned below the bridge assembly and which is rigidly connected to the bridge assembly via at least one column, wherein the sliding assemblies are connected to the base frame.

[0068] In an embodiment of the device, in top view the bridge assembly has a circular or polygonal shape and comprises a central opening, wherein the bridge assembly extends around said central opening.

[0069] In an embodiment the device is configured for pushing piles into the ground or seabed which are not interlocked.

[0070] In an embodiment the device is configured for pushing piles which are positioned at a horizontal distance from one another and do not contact one another.

[0071] In an embodiment of the device, each pile connector comprises an insertable part which is configured to be inserted into an upper part of a tubular pile.

[0072] In an embodiment of the device, each pile connector comprises one or more gripper actuators to grip the upper part of the tubular piles.

[0073] In an embodiment the device comprises exactly six connecting assemblies and exactly six pile connectors, wherein the six pile connectors are arranged in a hexagonal configuration.

[0074] In an embodiment the device is configured to drive all piles vertically into the ground or seabed, wherein in particular all actuators and all pile connectors are oriented vertically.

[0075] In an embodiment of the device, a spacing distance between the pile connectors is approximately 0.5 times the diameter of the piles configured to be connected thereto.

[0076] In an embodiment of the device, a spacing distance between the pile connectors is 2 times or less of the diameter of the piles configured to be connected thereto.

[0077] In an embodiment of the device, a spacing distance between the pile connectors is between 2 and 4 times the diameter of the piles configured to be connected thereto.

[0078] In an embodiment of the device, each pile connection assembly is connected to the bridge assembly via a hinge.

[0079] In an embodiment of the device, the hinge has a hinge axis which extends perpendicular to the bisector of the associated corner of the polygon.

[0080] In an embodiment of the device, the hinge is of the ball joint type.

[0081] The present invention further relates to a method of pushing at least five, in particular at least six piles into the ground or into a seabed, the method comprising:

[0082] positioning the at least five piles on the ground or on a seabed, and connecting the device according to the first aspect of the invention to the upper parts of the piles, wherein each pile connection assembly is connected to an associated pile,

[0083] alternately pushing at least one of the at least five piles over a distance into the ground or seabed by applying a vertical force via the associated actuator to the at least one pile which is being pushed into the ground or seabed.

[0084] In an embodiment of the method, the at least one of the at least five piles or at least two of the at least six piles are alternately pushed into the ground or seabed by:

[0085] extending the at least one or at least two actuators which are associated with the at least one or at least two piles, and/or by

[0086] keeping at least one or at least two actuators associated with the at least one or at least two piles being pushed in substantially stationary while retracting at least three or at least four of the remaining actuators, and/or by

[0087] keeping at least one or at least two actuators associated with the at least one or at least two piles being pushed in substantially stationary while extending at least two opposite actuators, thereby pivoting the bridge assembly about a pivot axis extending between said at least one actuator and said at least two opposite actuators,

[0088] In an embodiment of the method, the at least one of the at least five piles or at least two of the at least six piles are alternately pushed into the ground or seabed by:

[0089] alternately pushing at least one of the at least five piles or at least two of the at least six piles over a distance into the ground or seabed by

[0090] extending the actuator or actuators which are associated with said at least one or at least two piles, wherein during the extension the control device regulates at least the vertical force exerted by the actuator or actuators which extend and the vertical force exerted by at least three of the remaining actuators in order to let the pile which is pushed into the ground or seabed receive a greater vertical force than each of the at least three remaining, stationary piles, and/or by

[0091] keeping at least one or at least two actuators substantially stationary while retracting at least three or at least four of the remaining actuators, wherein during the retraction the control device regulates at least the vertical force which is exerted by the at least one or at least two substantially stationary actuators and the vertical force exerted by the at least three or at least four retracting actuators in order to let the at least one or at least two piles corresponding to the at least one or at least two substantially stationary actuators receive a greater vertical force than each of the remaining, stationary piles for pushing the at least one or at least two piles associated with the at least one or at least two substantially stationary actuators into the ground or seabed, and/or by

[0092] keeping at least one or at least two actuators which are associated with the at least one or at least two piles being pushed in substantially stationary while extending at least two opposite actuators, thereby pivoting the bridge assembly about a pivot axis extending between said at least one actuator and said at least two opposite actuators, wherein the control device is configured for regulating at least the vertical force of the at least two opposite extending actuators in order to have the at least one pile being pushed in receive a greater vertical force than each of the remaining, stationary piles for pushing the at least one pile into the ground or seabed.

[0093] In an embodiment of the method, an exerted push force is transferred from the respective pushing actuator into the bridge assembly and transferred at least partially from the bridge assembly as a tension force into at least two or three of the remaining, stationary piles via the respective pile connection assemblies.

[0094] In an embodiment of the method, an exerted push force is transferred from the respective pushing actuator into the bridge assembly and transferred at least partially from the bridge assembly as a bending moment into at least two or three of the remaining, stationary piles via the respective pile connection assemblies.

[0095] In an embodiment of the method, the control device keeps a sum of the positive, vertical push forces and the negative, vertical pull forces of the actuators substantially zero.

[0096] In an embodiment of the method, an equilibrium point is defined within the polygon, wherein the control device keeps a sum of the moments applied by the actuators about said equilibrium point substantially zero.

[0097] In an embodiment of the method, the actuators are hydraulic cylinders, and wherein the control device regulates a pressure in said hydraulic cylinders.

[0098] In an embodiment of the method, the piles are tubular piles.

[0099] In an embodiment of the method, the piles are not interlocked and are in particular positioned at a horizontal distance from one another.

[0100] In an embodiment of the method, the bridge assembly moves downward together with the piles as they are pushed into the ground.

[0101] In an embodiment the method comprises:

- **[0102]** positioning at least five piles in a polygonal configuration in a temporary location,
- **[0103]** connecting the device according to the assembly to the at least five upper parts of the at least five piles,
- **[0104]** lifting the combination of the device and the at least five piles connected thereto to a target location on a seabed or on the ground.

[0105] In an embodiment of the method, a cycle is carried out, wherein each cycle comprises the following steps in the sequence as indicated:

- **[0106]** pushing the first pile over a distance into the ground or seabed,
- **[0107]** pushing the second pile over a distance into the ground or seabed,
- **[0108]** pushing the third pile over a distance into the ground or seabed,
- **[0109]** pushing the fourth pile over a distance into the ground or seabed,
- **[0110]** pushing the fifth pile over a distance into the ground or seabed.

[0111] In an embodiment of the method, each cycle further comprises pushing any subsequent pile over a distance into the ground or seabed.

[0112] In an embodiment of the method, a cycle is made, wherein each cycle comprises the following steps in the sequence as indicated:

- **[0113]** pushing the first pile and second pile simultaneously over a distance into the ground or seabed,
- **[0114]** pushing the third pile and fourth pile simultaneously over a distance into the ground or seabed,
- **[0115]** pushing the fifth pile and sixth pile simultaneously over a distance into the ground or seabed.

[0116] In an embodiment of the method, each cycle further comprises pushing subsequent pairs of piles over a distance into the ground or seabed.

[0117] In an embodiment of the method, groups of three piles or more are pushed into the ground or seabed simultaneously.

[0118] In an embodiment of the method, a cycle is made comprising a combination of pushing one pile into the ground and pushing at least two piles simultaneously into the ground or seabed.

[0119] In an embodiment of the method, the first step or the last step of the cycle comprises keeping at least one or two actuators substantially stationary while retracting the remaining actuators for pushing the at least one or two piles corresponding to the at least one or two substantially stationary actuators into the ground or seabed, and wherein the other steps comprise extending the at least one or two actuators for pushing the at least one or two piles corresponding to the at least one or two actuators into the ground or seabed.

[0120] In an embodiment of the method, the actuators comprise a hydraulic cylinder comprising a valve, wherein the actuators are kept substantially stationary by closing the valve in order to prevent a hydraulic medium from circulating.

[0121] In an embodiment of the method, the device is lifted by and suspended from a crane on an installation vessel at sea.

[0122] In an embodiment of the method, each of the at least five piles is pushed into the ground through a respective pile sleeve at a bottom end of a jacket.

[0123] A method for pulling at least five piles out of the ground or seabed comprises:

- **[0124]** connecting the device according to the first aspect of the invention to the upper ends of the piles, wherein each pile connection assembly is connected to an associated pile,
- **[0125]** alternately pulling at least one of the piles over a distance out of the ground or seabed by alternately
  - **[0126]** retracting the at least one or at least two actuators which are associated with the at least one or at least two piles, and/or by
  - **[0127]** keeping at least one or at least two actuators associated with the at least one or at least two piles being pulled out substantially stationary while extending at least three or at least four of the remaining actuators, and/or by
  - **[0128]** keeping at least one or at least two actuators associated with the at least one or at least two piles being pulled out substantially stationary while retracting at least two opposite actuators, thereby pivoting the bridge assembly about a pivot axis extending between said at least one actuator and said at least two opposite actuators.

[0129] The invention according to the first aspect further relates to a pile support frame provided on an installation vessel, wherein the pile support frame is configured to support at least five piles in a polygonal configuration and in a substantially vertical orientation and parallel to one another, wherein the pile support frame is open at an upper side, allowing the at least five piles to be gripped by the device.

[0130] In an embodiment the pile support frame comprises pile supports which are configured to support the piles at a distance from one another and with the upper part faces of the piles substantially flush.

[0131] The invention according to the first aspect yet further relates to a vessel comprising:

- **[0132]** the device according to the first aspect of the invention,
- **[0133]** a pile support frame, and
- **[0134]** a crane, wherein the crane is configured to lift the device and move the device to above the pile support frame to allow the device to being connected to piles provided in the pile support frame.

Second Aspect

[0135] In a second aspect of the present invention, a helical pile is provided for installation into the ground or seabed, the pile comprising:

- **[0136]** a first tubular section having a length and a first outer diameter, the first tubular section comprising a first end and an opposite, second end, the first end being configured to be inserted into the ground or seabed,
- **[0137]** a first helical section provided between the first end and second end or at the first end, the first helical section having a first pitch and a first pitch orientation,
- **[0138]** a second helical section provided between the first helical section and the second end at a distance from the first helical section, the second helical section having a second pitch and the first pitch orientation, wherein the second pitch is different from the first pitch.

[0139] The second aspect may be combined with the first aspect, but the second aspect may also be independent from the first aspect of the invention.

[0140] The helical pile is not a drill bit.

[0141] An advantage of the second aspect is that the difference between the first pitch and second pitch can provide an increase in both the tension capacity and the compression capacity of the pile when installed in the ground or seabed. This is further explained in the detailed description of the figures.

[0142] In an embodiment of the helical pile, the first helical section extends away from an outer surface of the first tubular section.

[0143] In an embodiment of the helical pile, the second helical section extends away from the outer surface of the first tubular section.

[0144] In an embodiment of the helical pile, the first helical section and the second helical section comprise a helical plate.

[0145] In an embodiment of the helical pile, the second pitch is smaller than the first pitch.

[0146] In an embodiment of the helical pile, the first end comprises a penetrating section configured to penetrate the soil.

[0147] In an embodiment of the helical pile, the penetrating section has a conical shape converging from the first end.

[0148] In an embodiment of the helical pile, an outer diameter of the first and/or second helical section is at least 1.5 times the first outer diameter.

[0149] In an embodiment of the helical pile, an outer diameter of the first helical section and/or second helical section increases in a direction from the first end towards the second end.

[0150] In an embodiment of the helical pile, the distance between the first helical pile and the second helical pile is at least 3 times the first outer diameter.

[0151] In an embodiment of the helical pile, the first diameter is constant between the first helical section and the second helical section.

[0152] In an embodiment of the helical pile, the helical pile has a substantially constant first outer diameter.

[0153] In an embodiment of the helical pile, the helical pile comprises a second tubular section connected to the second end of the first tubular section, wherein the second tubular section has a second outer diameter which is larger than the first outer diameter.

[0154] In an embodiment of the helical pile, the outer diameter of the first and second helical sections is equal to or smaller than the second outer diameter.

[0155] In an embodiment of the helical pile, the first tubular section and the second tubular section are connected via a tapered section.

[0156] In an embodiment of the helical pile, the first helical section and/or second helical section comprises a single rotation helix or a helix with a rotation higher than one.

[0157] In an embodiment of the helical pile, the first helical section and/or the second helical section comprises a circular helix.

[0158] In an embodiment of the helical pile, a top end of the helical pile comprises a female mating part configured to be engaged by a male mating part of the pile connector associated with a rotating actuator for rotating the pile about its longitudinal axis, or vice versa.

[0159] In an embodiment of the helical pile, the female part is configured to provide a bayonet coupling with the male part of the rotating actuator.

[0160] The second aspect of the invention further provides a method for installing a helical pile according to the second aspect of the present invention, the method comprising the steps:

- **[0161]** positioning the helical pile on the ground or the seabed in an upright orientation, wherein the first end is in contact with the ground or the seabed, and wherein the first helical section engages the ground or the seabed,
- **[0162]** moving the helical pile into the ground by rotating the helical pile about its longitudinal axis in a direction corresponding with the first pitch orientation of the helical sections, until the first helical section and the second helical section are both located at a predetermined distance below the ground or seabed,
- **[0163]** wherein the pile is moved downward into the ground or seabed over a distance equal to M times the first pitch of the first helical section by completely rotating the helical pile N times about its longitudinal axis, wherein N is greater than M.

[0164] In an embodiment of the method, the helical pile comprises the first helical section having the first pitch and a second helical section having a second pitch, wherein the second pitch is smaller than the first pitch.

[0165] In an embodiment of the helical pile, the second pitch is M/N times the first pitch.

[0166] Further a method is provided for installing at least two helical piles according to the present invention simultaneously, wherein a first helical pile comprises helical sections with a clockwise first pitch orientation when seen in top view, and wherein a second helical pile comprises helical sections with a counter clockwise first pitch orientation when seen in top view, the method comprising the steps:

[0167] positioning the helical piles on the ground or the seabed in an upright orientation, wherein the first ends are in contact with the ground or the seabed, and wherein the first helical sections engages the ground or the seabed,

[0168] providing an installation device comprising

[0169] a bridge assembly which when seen in top view defines at least two connecting locations,

[0170] at least two pile connection assemblies via which in use each of the at least two helical piles is connected to the bridge assembly, wherein each pile connection assembly comprises:

[0171] a rotating actuator configured to rotate in a clockwise and/or a counter clockwise direction relative to the bridge assembly when seen in top view,

[0172] a pile connector connected to the actuator, wherein each pile connector is configured to be connected to an upper part of a helical pile which is to be moved into the ground or seabed, wherein the pile connector is configured to be rotated by the associated actuator

[0173] connecting a first pile connector of the installation device to the first helical pile and a second pile connector of the installation device to the second helical pile,

[0174] rotating the first helical pile in the clockwise pitch orientation via the first pile connector and the associated actuator and simultaneously rotating the second helical pile in the counter clockwise direction via the second pile connector and the associated actuator.

[0175] In an embodiment of the method, the helical piles are moved downward into the ground or seabed over a distance equal to M times the first pitch of the first helical section by completely rotating the helical pile N times about its longitudinal axis, wherein N is greater than M.

[0176] The second aspect of the invention further provides a method for removing an installed helical pile according to the second aspect of the invention from the ground or seabed, the method comprising the step of rotating the pile in a direction opposite to the first pitch orientation of the helical sections.

[0177] In an embodiment of the method, at least two helical piles are removed simultaneously, wherein a first helical pile comprises helical sections in a clockwise pitch orientation when seen in top view, and wherein a second helical pile comprises helical sections in a counter clockwise pitch orientation when seen in top view, the method comprising the steps:

[0178] providing an installation device comprising

[0179] a bridge assembly which when seen in top view defines at least two connecting locations,

[0180] at least two pile connection assemblies via which in use each of the at least two helical piles is connected to the bridge assembly, wherein each pile connection assembly comprises:

[0181] a rotating actuator configured to rotate in a clockwise and/or a counter clockwise direction relative to the bridge assembly when seen in top view,

[0182] a pile connector connected to the actuator, wherein each pile connector is configured to be connected to an upper part of a helical pile which is to be moved into the ground or seabed, wherein the pile connector is configured to be rotated by the associated actuator

[0183] connecting a first pile connector of the installation device to the first helical pile and a second pile connector of the installation device to the second helical pile,

[0184] rotating the first helical pile in the counter clockwise pitch orientation via the first pile connector and the associated actuator and simultaneously rotating the second helical pile in the clockwise direction via the second pile connector and the associated actuator.

Third Aspect

[0185] In a third aspect the present invention provides a support structure for supporting a top structure above the ground or a seabed, the support structure comprising:

[0186] at least one support pile having a length and a first outer diameter, the at least one support pile comprising

[0187] an upper part configured and intended to extend above the ground or the seabed, wherein the upper part of the support pile is configured to be connected to the top structure,

[0188] a lower part configured to be in contact with the ground or seabed,

[0189] a plurality of foundation guides connected to the lower part of the at least one support pile, each foundation guide having an opening extending in a direction of the at least one support pile, the opening having an opening diameter, wherein each foundation guide is configured to accommodate a foundation pile, wherein the foundation pile is configured to extend through the foundation guide and at least partly into the ground or the seabed.

[0190] The third aspect may be combined with the first aspect and/or the second aspect. However, the third aspect may also be independent from the first and second aspect.

[0191] An advantage of the third aspect is that the support structure may be of a shorter length and diameter than a monopile having the same lateral and overturning capacity when the support structure is combined with foundation piles. This is beneficial, because the current development of ever increasing wind turbine dimensions makes the use of monopiles more and more difficult.

[0192] In an embodiment the support structure comprises:

[0193] one support pile having a length and a first outer diameter, the support pile comprising

[0194] an upper part configured and intended to extend above the ground or the seabed, wherein the upper part of the support pile is configured to be connected to the top structure,

[0195] a lower part, wherein at least a bottom part of the lower part is configured and intended to extend into the ground or the seabed,

[0196] a plurality of foundation guides connected to the lower part of the support pile, each foundation guide having an opening extending in a direction of the support pile, the opening having an opening diameter, wherein each foundation guide is configured to accommodate a foundation pile, wherein the foundation pile is configured to extend through the foundation guide and at least partly into the ground or the seabed.

[0197] In an embodiment of the support structure, the foundation guides are provided at a distance above a bottom end of the at least one support pile.

[0198] In an embodiment of the support structure, a longitudinal axis of the opening of the foundation guides extends parallel to a central axis of the at least one support pile.

[0199] In an embodiment of the support structure, in top view the foundation guides are arranged around the at least one support pile.

[0200] In an embodiment of the support structure, in top view the foundation guides are arranged equidistantly around the at least one support pile.

[0201] In an embodiment of the support structure, the support pile comprises a widening part extending over a distance upwards from the lower end, the widening part having a second outer diameter which is greater than the first outer diameter, wherein in top view the foundation guides extend outside the first outer diameter and inside the widening part having the second outer diameter.

[0202] In an embodiment of the support structure, a length of the foundation guide is at least twice the opening diameter of the opening of the foundation guide.

[0203] In an embodiment of the support structure, the foundation guide is a sleeve.

[0204] In an embodiment of the support structure, the foundation guide comprises a centering member around the opening at the top end thereof, the centering member being configured to center and guide a bottom end of a foundation pile into the opening of the foundation guide.

[0205] In an embodiment of the support structure, at least one annular recess is provided in an inner side of the sleeve, the annular recess being configured and intended to form a female part of a swaging connection between the foundation pile and the sleeve.

[0206] In an embodiment the support structure comprises at least three foundation guides.

[0207] In an embodiment of the support structure, the foundation guides are connected to each other via a foundation frame, the foundation frame being connected to and extending around the at least one support pile for providing stiffness to the connection between the foundation guides and the at least one support pile.

[0208] In an embodiment of the support structure, a bottom end of the foundation guide is configured and intended to rest on the ground or the seabed.

[0209] In an embodiment of the support structure, the opening diameter of the foundation guides is smaller than the first outer diameter, in particular at least 3 times smaller.

[0210] In an embodiment the support structure has a single support pile.

[0211] In an embodiment of the support structure, the opening of the foundation guide is located at less than 2 times the opening diameter away from an outer surface of the at least one support pile, in particular less than once the opening diameter.

[0212] In an embodiment of the support structure, the lower part of the support pile is configured to extend into the ground or seabed by a distance of at least one time the first outer diameter of the support pile.

[0213] In an embodiment of the support structure, a suction bucket is provided inside the lower part of the support pile for moving the lower part of the support pile into the ground or the seabed via suction.

[0214] In the third aspect further a support assembly is provided for supporting a top structure above the ground or a seabed, the support assembly comprising:

[0215] a support structure according to the third aspect of the invention,

[0216] a plurality of foundation piles, wherein each foundation pile extends through a respective foundation guide and is configured and intended to extend at least partly into the ground or the seabed over a foundation depth for providing resistance against overturning of the support pile.

[0217] In an embodiment of the support assembly, wherein the foundation piles are arranged around the first outer diameter of the at least one support pile.

[0218] In an embodiment of the support assembly, the first outer diameter of the support pile is greater than an outer diameter of the foundation piles.

[0219] In an embodiment of the support assembly, the foundation piles have the same outer diameter.

[0220] In an embodiment of the support assembly, the foundation piles are arranged equidistantly around the support pile.

[0221] In an embodiment of the support assembly, in top view the foundation piles define a cyclic polygon.

[0222] In an embodiment the support assembly comprises at least three foundation piles.

[0223] In an embodiment of the support assembly, the top structure is a wind turbine.

[0224] In an embodiment of the support assembly, the foundation pile comprises at least one helix at a lower end thereof extending around the outer surface, wherein the foundation pile is configured to be rotated about its longitudinal axis during installation into the ground or the seabed.

[0225] In an embodiment of the support assembly, a plurality of foundation piles are helical piles according to the second aspect of the invention.

[0226] In an embodiment of the support assembly, prior to installation at least 50 percent of the length of the foundation piles are located adjacent the support pile, in particular at least 60 percent, more in particular at least 80 percent.

[0227] In an embodiment of the support assembly, after installation of the support assembly at least 60 percent of the length of the foundation piles extends below the support pile.

[0228] The third aspect of the present invention further provides a floating vessel for transporting at least one support assembly, wherein during transport the at least one support assembly is provided on a deck of the floating vessel in a vertical orientation.

[0229] The present invention according to the third aspect provides a method for installing the support assembly according to the invention, the method comprising the steps of:

- **[0230]** positioning the support pile with its bottom end on the ground or the seabed and moving a part of the lower part of the support pile into the ground or the seabed,
- **[0231]** positioning the foundation piles in the foundation guides and on the ground or the seabed and moving the foundation piles at least partly into the ground or the seabed over the foundation depth.

[0232] In an embodiment of the method, the at least one support pile is positioned on the ground or the seabed first, and the foundation piles are subsequently positioned on the ground or the seabed by inserting the foundation piles through the foundation guides.

[0233] In an embodiment of the method, the at least one support pile and the foundation piles are lowered and positioned on the ground or the seabed simultaneously by a crane, in particular by lowering the support assembly to the ground or the seabed with said crane, wherein the foundation piles already extend through the foundation guides.

[0234] In an embodiment of the method, the foundation piles are moved into the ground or the seabed by an installation device, wherein the installation device comprises:

- **[0235]** a bridge assembly which when seen in top view defines a plurality of connecting locations corresponding to the plurality of foundation piles,
- **[0236]** a plurality of pile connection assemblies via which in use each foundation pile is connected to the bridge assembly, wherein each pile connection assembly comprises:
  - **[0237]** a pile connector wherein each pile connector is configured to be connected to an upper part of each foundation pile which is to be moved into the ground or seabed,
  - **[0238]** wherein at least a plurality of the pile connection assemblies comprise an actuator which extends downward from the respective connecting location, wherein each actuator comprises an upper actuator part and a lower actuator part, wherein the upper actuator part is connected to the bridge assembly, wherein the lower actuator part is connected to a corresponding pile connector.

[0239] In an embodiment of the method, the bridge assembly comprises a central opening through which the at least one support pile extends, and wherein the installation device moves downward relative to the support pile during installation of the foundation piles.

[0240] In an embodiment of the method, at least two foundation piles comprise a helix at a lower part thereof, wherein at least two actuators of the installation device are rotatable for moving corresponding said foundation piles comprising the helix into the ground or the seabed by rotating the foundation piles about their respective longitudinal axis.

[0241] In an embodiment of the method, the at least two foundation piles connected to the rotatable actuators are helical piles according to the second aspect of the invention.

[0242] In an embodiment of the method, the support assembly is connected to a lowering assembly for lowering and positioning the support assembly on the ground or the seabed.

[0243] In an embodiment of the method, the lowering assembly comprises the installation device for moving the foundation piles into the ground or the seabed.

[0244] In an embodiment of the method, the pile connectors of the installation device are connected to the foundation piles during lowering and positioning of the foundation piles.

[0245] In an embodiment of the method, the foundation piles extend through the foundation guides during the lowering and positioning of the support assembly.

[0246] In an embodiment of the method, the foundation piles are pushed into the ground by a device according to the first aspect of the invention comprising a central opening, wherein said device extends around the at least one support pile, wherein the at least one support pile extends through the central opening.

[0247] In an embodiment of the method, the foundation piles are moved into the ground or the seabed by hammering, screwing, pushing, or a combination thereof.

[0248] In an embodiment the method further comprises fixating the foundation piles to their respective foundation guide.

[0249] In an embodiment of the method, the foundation piles are fixated to their respective foundation guide by grouting, swaging, or a combination thereof.

[0250] In an embodiment of the method, after the support assembly is installed, the installation device is moved away from the support assembly, in particular by moving the installation device upward relative to the support pile.

[0251] In an embodiment of the method, the support assembly is installed in a vertical orientation.

[0252] In an embodiment of the method, the foundation piles are moved into the ground or the seabed vertically.

[0253] In an embodiment of the method, a suction bucket is provided inside the lower part of the support pile, and wherein the lower part is moved into the ground or the seabed at least in part via suction.

[0254] In an embodiment of the method, the foundation piles are helical piles, and wherein the lower part of the at least one support pile is moved into the ground or seabed at least in part by a downward force exerted by the helical piles on the foundation guides or by pushing the installation device connected to the foundation piles upwards relative to the support pile.

[0255] In an embodiment of the method, after the foundation piles are installed the orientation of the support pile is adjusted by moving the foundation piles relative to the support pile or by moving the support pile relative to the foundation piles.

[0256] The present invention according to the third aspect further provides an installation device for moving foundation piles of a support assembly into the ground or the seabed, the installation device comprising:

[0257] a bridge assembly which when seen in top view defines a plurality of connecting locations corresponding to the plurality of foundation piles,

[0258] a plurality of pile connection assemblies via which in use each foundation pile is connected to the bridge assembly, wherein each pile connection assembly comprises:

[0259] a pile connector wherein each pile connector is configured to be connected to an upper part of each foundation pile which is to be moved into the ground or seabed,

[0260] wherein at least a plurality of the pile connection assemblies comprise an actuator which extends downward from the respective connecting location, wherein each actuator comprises an upper actuator part and a lower actuator part, wherein the upper actuator part is connected to the bridge assembly, wherein the lower actuator part is connected to a corresponding pile connector.

[0261] In an embodiment of the installation device, the bridge assembly comprises a central opening through which the at least one support pile is configured to extend, wherein the bridge assembly comprises a plurality of guides for guiding the movement of the installation device relative to the support pile, wherein the guides extend into the central opening.

[0262] In an embodiment of the installation device, the guides are configured to engage the support pile and to transfer a bending moment of the foundation piles as a force into the support pile via the bridge assembly.

[0263] In an embodiment of the installation device, the pile connector comprising a male or female mating part configured to mate with a corresponding mating part of a foundation pile.

[0264] In an embodiment of the installation device, the installation device comprises an engaging member configured to engage the support pile and to exert a force on the support pile in a vertical direction.

[0265] In an embodiment of the installation device, the at least two rotating actuators are counter rotating relative to each other.

[0266] These and other aspects of the invention will be more readily appreciated as the same becomes better understood by reference to the following detailed description and considered in connection with the accompanying drawings in which like reference symbols designate like parts.

BRIEF DESCRIPTION OF THE FIGURES

[0267] FIG. **1**A shows a perspective view of an embodiment of a device according to a first aspect of the invention.

[0268] FIG. **1**B shows a perspective view of another embodiment of a device according to a first aspect of the invention.

[0269] FIGS. **2**A-**2**C show a perspective view of the device of FIG. **1**B pushing in one pile by extending one actuator.

[0270] FIG. **3**A-**3**C show a perspective view of the device of FIG. **1**B pushing in two piles by extending two associated actuators.

[0271] FIGS. **4**A-**4**C show a perspective view of the device of FIG. **1**B pushing in one pile by retracting the remaining actuators.

[0272] FIGS. **5**A-**5**C show a perspective view of the device of FIG. **1**B pushing in two piles by retracting the remaining actuators.

[0273] FIGS. **6** and **7** show in perspective view another embodiment of the device according to the first aspect of the invention pushing in two piles by pivoting the bridge assembly.

[0274] FIG. **8**-**11** show different views of another embodiment of the device according to the invention.

[0275] FIGS. **12**-**15** show different steps of installing at least five pile using a device according to the invention.

[0276] FIG. **16**-**26** schematically show top views of force distributions for different polygonal configurations of devices according to the invention.

[0277] FIG. **27** shows a side view of an embodiment of a helical pile according to a second aspect of the present invention.

[0278] FIG. **28** shows a side view of an embodiment of a helical section with increasing diameter.

[0279] FIG. **29** shows a perspective view of another embodiment of a helical pile according to the second aspect of the invention, comprising a second tubular section.

[0280] FIGS. **30**-**32** schematically show the working principles of helical sections.

[0281] FIGS. **33**-**35** show in perspective view an embodiment of installing a helical pile according to the invention.

[0282] FIG. **36** shows in perspective view an embodiment of installing two helical piles simultaneously.

[0283] FIG. **37** shows in perspective view a close up of the first ends of the two helical piles of FIG. **36**.

[0284] FIG. **38** shows a perspective view of an embodiment of a support structure and a support assembly according to a third aspect of the present invention.

[0285] FIG. **39**A shows a cross-sectional view of another embodiment of a support structure and support assembly comprising a widening part.

[0286] FIG. **39**B shows a top view of the embodiment of FIG. **39**A.

[0287] FIG. **40** shows a cross-sectional view of another embodiment of the support structure according to the invention, comprising a suction bucket.

[0288] FIGS. **41**A-**41**E show different steps of an embodiment of a method for installing a support assembly according to the present invention.

[0289] FIG. **42** shows different steps of an installation method for a support assembly comprising six push-in piles using a device according to the first aspect of the invention.

[0290] FIG. **43**A shows different steps of an installation method for a support assembly comprising three piles which are hammered in by a hammering device.

[0291] FIG. **43**B schematically shows a step of the method of FIG. **43**A.

[0292] FIG. **44** shows in cross-section a swaged connection between a foundation pile and a foundation guide of the support assembly.

[0293] FIG. **45** shows another embodiment of an installation method for a support assembly according to the invention.

[0294] FIG. **46** shows yet another embodiment of an installation method for a support assembly according to the invention.

DETAILED DESCRIPTION OF THE FIGURES

[0295] Turning to FIGS. **1** to **7**, in a first aspect of the invention a first embodiment of a device **1** is shown for pushing at least five piles into the ground or into a seabed **3**. The device **1** is also capable of pulling at least five piles **2** out of the ground or seabed **3**. In fact, all of the shown embodiments of the device **1** are configured to pull out at least five piles. The device **1** in FIG. **1**A is configured to push five piles into the ground or seabed **3**. The device **1** in FIG. **1**B is for pushing six piles **2**.**1**, **2**.**2**, **2**.**3**, **2**.**4**, **2**.**5**, **2**.**6** into the ground or seabed **3**. It is to be understood that the invention is suited for at least five piles and that in the following description the embodiment for six piles is merely exemplary.

[0296] In top view at least a number of the at least five piles define a polygonal configuration **5**, wherein any of the remaining at least five piles are located within the polygon. In the shown embodiment of FIGS. **2** to **6** all six piles define the polygon, in particular a cyclic polygon **238**. Hence, there are no remaining piles located within the polygon **24** for said embodiment. A cyclic polygon provides for a load distribution which is easier to regulate.

[0297] The device **1** comprises a bridge assembly **7** which when seen in top view defines at least five connecting locations **8**.**1**, **8**.**2**, **8**.**3**, **8**.**4**, **8**.**5**, **8**.**6**, see FIG. **3**A.

[0298] The device **1** comprises six pile connection assemblies **9**.**1**, **9**.**2**, **9**.**3**, **9**.**4**. **9**.**5**, **9**.**6** via which in use each of the six piles is connected to the bridge assembly **7**. Each pile connection assembly **9** comprises an actuator **10**.**1**, **10**.**2**, **10**.**3**, **10**.**4**, **10**.**5**, **10**.**6** which extends downward from the respective connecting location **8**.

[0299] Each actuator **10** comprises an upper actuator part **11** and a lower actuator part **12**. The upper actuator part **11** is connected to the bridge assembly **7**. The actuator **10** is configured to extend in order to move the lower actuator part **12** downward relative to the upper actuator part **11** and/or to retract in order to move the lower actuator part **12** upward relative to the upper actuator part **11**.

[0300] The pile connection assembly comprises a pile connector **15** connected to the lower actuator part **12**. Each pile connector **15** is configured to be connected to an upper part **16** of a pile which is to be pushed into the ground or seabed **3**. The pile connector **15** is configured to move downward or upward relative to the upper actuator part **11** together with the associated lower actuator part **12** during the respective extension or retraction. It may also be possible to connect two pile connectors **15** to one actuator **10**, so one actuator **10** can push in or pull out two piles.

[0301] In top view the bridge assembly **7** has a circular or polygonal shape and comprises a central opening **58**, wherein the bridge assembly **7** extends around this central opening **58**.

[0302] The device **1** is configured to drive all piles vertically into the ground or seabed **3**. All actuators **10** and all pile connectors **15** are therefore oriented vertically.

[0303] Each pile connector **15** comprises an insertable part **60** which is configured to be inserted into an upper part **16** of a tubular pile.

[0304] Each pile connector **15** comprises one or more gripper actuators **38** to grip the upper part **16** of the tubular piles.

[0305] The piles **2** are not interlocked. Hence, the device **1** is configured for pushing piles into the ground or seabed **3** which are not interlocked.

[0306] The piles **2** are positioned at a horizontal distance from one another and do not contact one another.

[0307] The piles may be spaced as closely together as possible. A pile spacing distance **62** (FIG. **2**A) is however limited by the minimum required spacing **67** between the actuators **10** and the fabrication of the device **1** according to the invention.

[0308] It was found that the tension and compression capacity of the piles increase exponentially at a pile spacing of 2 pile diameters D**1** and less, wherein the tension capacity has a steeper exponential increase with decreasing pile spacing compared to the compression capacity.

[0309] It was further found that a spacing between 2 to 4 pile diameters D**1** already has a more or less linearly increasing effect on the difference between tension and compression capacity, with the same advantage of allowing the deadweight of the device **1** to be reduced.

[0310] Each pile connection assembly **9** is connected to the bridge assembly **7** via a hinge **63**. The hinge **63** can reduce the bending moments on the cylinders **43** of the actuators **10** while pushing. Without a hinge **63** the actuator **10** which is pushed would receive a moment around the connection location of the hinge **63** or hinge axis **23**.

[0311] The hinge **63** has a hinge axis **64** which extends perpendicular to the bisector **65** of the associated corner **66** of the polygon, see for example FIG. **16**.

[0312] The embodiment as shown in FIGS. **6** and **7** comprises hinges **63** between the pile connection assemblies **9** and the bridge assembly **7** of the ball joint type which have a plurality of hinge axes. This provides more freedom of motion between the respective pile connection assembly and the bridge assembly **7** in order to allow the pivoting motion of the bridge assembly **7**, as shown in FIG. **7**. In this embodiment substantially no bending moments are transferred from the pile actuators **10** to the bridge assembly **7** and vice versa.

[0313] The device **1** comprises a control device **17** which is configured for alternately pushing at least one of the at least five piles **2** over a distance **18** into the ground or seabed **3** by applying a vertical force via the associated actuator **10** to the at least one pile which is being pushed into the ground or seabed **3**.

[0314] The distance **18** over which the piles are pushed into the ground are shown as the distance the actuators extend or retract in the FIGS. **2** to **7**.

[0315] The control device **17** is configured for regulating at least the vertical force which is exerted by the actuator **10** associated with the pile which is being pushed in and/or at least the vertical forces which are exerted by at least two of the remaining actuators **10** on associated remaining, stationary piles. The control device **17** regulates said vertical force in order to have the at least one pile which is pushed into the ground or seabed **3** receive a greater vertical force than each of the remaining piles. There are multiple ways to push the piles into the ground, as will be further elucidated later.

[0316] The control device **17** may be configured for alternately pushing at least one of the at least five piles over a distance **18** into the ground or seabed **3** by alternately:

[0317] having at least one of the actuators **10** associated with the at least one pile **2** being pushed in extend, and/or by

[0318] keeping at least one actuator **10** associated with the at least one pile **2** being pushed in substantially stationary while retracting at least three of the remaining actuators **10**, and/or by

[0319] keeping at least one actuator **10** associated with the pile **2** being pushed in substantially stationary while extending at least two opposite actuators **22**, thereby pivoting the bridge assembly **7** about a pivot axis **23** (FIG. **7**) extending between said at least one actuator **10** and said at least two opposite actuators **22**.

[0320] An order of the three options may be combined during installation of the piles with the device **1** according to the invention. Also the options itself may be combined. For example the first and second option can be combined by extending at least one actuator **10** and retracting the remaining actuators **10**.

[0321] FIGS. **2**A-**2**C and FIG. **3**A-**3**C schematically show the first option, wherein at least one actuator **10** extends. FIGS. **2**A-**2**C show an embodiment wherein one pile **2.3** is pushed in over a distance **18** (FIG. **2**C). FIGS. **3**A-**3**C show an embodiment where two piles **2.3**, **2.4** are pushed in simultaneously over a distance **18** (FIG. **3**C). Here the control device **17** is configured for regulating at least the vertical force which is exerted by the at least one associated actuator **10** during the extension thereof in order to let the at least one pile which is pushed into the ground or seabed **3** receive a greater vertical force than each of the remaining piles **2.1**, **2.2**, **2.5**, **2.6**.

[0322] FIGS. **4**A-**4**C and FIGS. **5**A-**5**C schematically show the second option, wherein at least one actuator **10** associated with the pile **2** to be pushed in is kept substantially stationary. The remaining actuators **10** retract. FIGS. **4**A-**4**C show an embodiment wherein one pile **2.3** is pushed in over a distance **18** (FIG. **4**A). FIGS. **5**A-**5**C show an embodiment wherein two piles **2.3**, **2.4** are pushed in simultaneously over a distance **18** (FIG. **5**A). Here the control device **17** is configured for regulating at least the vertical force which is exerted by the at least three retracting actuators **10** in order to let the at least one pile **2.3**, **2.4** corresponding to the substantially stationary actuator **10** receive a greater vertical force than each of the remaining, stationary piles **2.1**, **2.2**, **2.5**, **2.6**.

[0323] FIGS. **6** and **7** schematically show the third option, wherein the bridge assembly **7** is pivoted about the pivot axis **23**. The pivot axis **23** is different for each pile or pair of piles which is pushed in and does not remain in a horizontal plane. In the embodiment shown the piles **2.3**, **2.4** adjacent the piles **2.5**, **2.6** being pushed in are chosen as the pivot axis **23**, wherein the pivot axis **23** extends through the hinges of the opposing actuators **29** associated with piles **2.3**, **2.4**. The opposing actuators **29** may be kept stationary during pushing. Here the control device **17** is configured for regulating at least the vertical force of the at least two opposite extending actuators **10** associated with piles **2.1**, **2.2** in order to have the piles **2.5**, **2.6** being pushed in receive a greater vertical force than each of the remaining, stationary piles **2.1**, **2.2**, **2.3**, **2.4** for pushing the two piles **2.5**, **2.6** into the ground or seabed **3** over a distance **18** (FIG. **7**).

[0324] The at least one actuator **10** which is associated with the at least one pile which is being pushed into the ground or seabed **3** transfers the exerted vertical push force into the bridge assembly **7**. Said push force is transferred at least partially from the bridge assembly **7** as a tension force into at least two of the remaining, stationary piles via the respective pile connection assemblies. It may also be possible to transfer the push force at least partially from the bridge assembly **7** as a bending moment into at least two of the remaining, stationary piles.

[0325] Different types of polygonal configurations **5** are possible. In the shown embodiment of FIGS. **1**-**7** the six pile connection assemblies are arranged as a cyclic polygon in top view, wherein all six piles are arranged equidistantly on a circumscribed circle **27** of the polygon, see also FIG. **17**.

[0326] The polygonal configuration **5** can be a polygon **24** with angles **25** (FIG. **16**) between 90-180 degrees. In top view the pile connection assemblies may be arranged on a circle or an ellipse. The pile connection assemblies **9** may be arranged equidistantly on a circumscribed circle or circumscribed ellipse of the polygon. It is also possible that the polygonal configuration **5** is an irregular polygon **28**.

[0327] The control device **17** may be configured to keep a sum of the positive, vertical push forces and the negative, vertical pull forces of the actuators **10** substantially zero during the push in of the at least one pile.

[0328] An equilibrium point **33** is defined within the polygon. The control device **17** may be configured to keep a sum of the moments applied by the actuators **10** about said equilibrium point **33** substantially zero.

[0329] FIGS. **8**-**11** schematically show different views of a second embodiment of a device **1** according to the invention for pushing at least five piles **2.1**, **2.2**, **2.3**, **2.4**, **2.5** into the ground or seabed **3**. This embodiment has no central opening **58**. The shown second embodiment is configured to push in six piles. The sixth pile **2.6** is not visible. In FIG. **9** one pile **2.5** is disconnected from its associated pile connector **15** to show said pile connector **15**.

[0330] A difference with the first embodiment of FIGS. **1**-**6** is that each pile connection assembly comprises a sliding assembly **36** which is rigidly connected to the bridge assembly **7**. The sliding assembly **36** comprises a sleeve **37** and one or more gripper actuators **38** which can be switched between a gripping state and a released state.

[0331] In the released state the pile and/or pile connector **15** can slide through the sleeve **37**. In the gripping state the sleeve **37** is rigidly connected to the pile and/or pile connector **15**, allowing a tension force and a bending moment to be transferred from the bridge assembly **7** into the pile which is in the sleeve **37**.

[0332] The pile connection assemblies **9** are rigidly connected to one another via a base frame **41** which is positioned below the bridge assembly **7** and which is rigidly connected to the bridge assembly **7** via at least one column **42**. The sliding assemblies are connected to the base frame **41**.

Operation

[0333] Turning to FIGS. **12** to **15**, when the device **1** is to be used in an offshore environment, the device **1** may be operated from a vessel **69**. The vessel **69** may be a semi-submersible, regular vessel, barge or any other type of vessel. In FIGS. **12** to **15** the second embodiment as shown in FIGS. **8**-**11** of the device **1** is used. The first embodiment of the device **1** may also be used.

[0334] A pile support frame **73** may be provided on the vessel **69**. The pile support frame **73** is configured to support at least five piles **2** in a pickup configuration. In the pickup configuration, the at least five piles are positioned parallel to one another at mutual interspacing which corresponds to the interspacing between the connecting locations **8**. Preferably the piles are oriented vertically or substantially vertically. In the embodiment of FIG. **12**, the pile support frame **73** is located inside a column **81** of the semi-sub vessel **69** and an upper end of the pile support frame **73** is located at the deck level. In case of a regular hull, the pile support frame **73** may be located inside the hull.

[0335] Different embodiments of the pile support frame **73** are also possible. For instance the pile support frame **73** may be positioned on deck **78** and rise upward from the deck **78** or may be positioned in a moonpool. Or the pile support frame **73** may be provided on a cantilevered platform extending beyond a contour of the vessel **69**.

[0336] In operation, the vessel **69** is positioned at a target location, for instance at a base or bottom end **71** of a leg of a jacket **72**. The target location may obviously be any location at which piles need to be driven into the seabed **3**. The device **1** can for instance be used for installing piles into an already installed (part) of a structure (e.g. jacket **72** or template or any other structure) or for so-called "pre-piling", in case the structure or part thereof is not yet in place and eventually is placed over the pre-installed piles.

[0337] It is noted that pre-piling can be done with an intermediate template on the sea-floor, the use of a spacer frame could however act as a guidance frame that comes with the piles rather than pre-installing a temporary guidance frame. This would result in a reduction of execution time.

[0338] This could, when used for pre-piling, eliminate having a complex pre-pilling template with adjustable inclination systems.

[0339] At least five piles **2** are positioned in the pile support frame **73**. The piles may be tubular.

[0340] The device **1** may be lifted from the deck **78** of a vessel **69** with a crane **68**. The crane **68** lifts the device **1** and subsequently places the device **1** on the at least five piles. Next, the grippers are moved outward and grip the upper ends of the tubular piles, thereby connecting each pile connection assembly to an associated pile. The device **1** is now connected to the at least five piles.

[0341] Turning to FIG. **13**, the crane **68** subsequently lifts the combination of the device **1** and the at least five piles from the pile support frame **73** and moves the combination to the target location. In order to improve the stability of the combination, temporary wires, braces, brackets, stops or similar device **1** may be provided to prevent the at least five piles **2** from colliding during the lift, to maintain a required spacing of the lower ends of the piles and to prevent the moving parts of the device **1** from moving.

[0342] Optionally, the device **1** can be equipped with a spacer frame to limit relative movement between the piles and between the piles and the device **1**. This spacer frame can be hung off underneath the device **1** or be suspended on the piles itself, allowing to install and remove it in one lift or in two separate lifts.

[0343] The connection between the spacer frame and the device **1** can for instance be formed by either slings, chains or rigid materials.

[0344] Turning to FIG. **14**, the combination of the device **1** and the piles **2** is subsequently lowered into the base of a leg of a jacket **72**. The base **84** comprises a base plate and pile sleeves **70** which extend upwardly from the base plate. The at least five piles are lowered into the at least five pile sleeves **70**. This requires a certain degree of control and accuracy. The bottom ends of the piles are maintained at the required distance from one another by any of the temporary devices discussed above. The pile sleeves **70** may comprise tapered pile guides **83** at their upper ends to facilitate the positioning of the piles into the pile sleeves **70**.

[0345] In an embodiment, the initial start-up loads can be transferred to the pile sleeves **70** by providing a rigid connection between the pile connection assemblies of the piles **2** which are under tension and the associated pile sleeves **70**. This allows to be able to (partly) omit the use of ballast weight for the start-up weight during the time that limited soil capacity is activated.

[0346] It is noted that in an alternative embodiment, the piles may be positioned and lowered into the pile sleeves **70** individually and sequentially, for instance by the crane **68**, and prior to the device **1** being positioned on top of the piles. Next, the device **1** is positioned on top of the at least five piles **2**. In this embodiment, no pile support frame **73** is required.

[0347] When the bottom ends of the piles contact the seabed **3**, initially the piles will sink into the seabed **3** under their own weight and the weight of the device **1** over a certain distance, e.g. 50 cm. Additional ballast weight may be provide on top of the device **1** to increase this distance and to improve the overall functioning of the device **1**.

[0348] When all piles are inside the pile sleeves **70** and the device **1** is on top of the piles and has gripped the piles (which in top view are in polygonal configuration **5**), the device **1** can start operating. The piles are alternately pushed in over a distance **18** into the ground or seabed **3** by applying a vertical force via the associated actuator **10** to the at least one pile. The device **1** may alternately push in one pile or more piles simultaneously, or any combination thereof. FIG. **15** shows the piles being pushed in the ground over a certain depth.

[0349] The bridge assembly **7** moves downward together with the piles as they are pushed into the ground.

[0350] During operation of the device **1** there are multiple options to push in the at least five piles. A few examples are described next with reference to FIGS. **16** to **27**. The examples should be construed as merely exemplary and not limiting the invention. Each corner of the shown polygons **5** resembles a pile connection assembly **9** comprising an actuator **10** and a pile connector **15** which is connected to a pile **2**. The exerted forces are indicated by the letter F and a corresponding number. The shown forces F**1**-F**7** are given as example and do not take into account the weight of any installation equipment or the weight of the pile itself.

[0351] Said actuators **10** can be hydraulic cylinders, and the control device **17** may regulate a pressure in said hydraulic cylinders for exerting the vertical forces F. The hydraulic cylinder **43** may comprise a valve which can be closed in order to prevent a hydraulic medium from circulating. This way an actuator **10** can be kept substantially stationary.

[0352] FIG. **16** shows an example of a device **1** configures to push in five piles, one at each corner of the polygon, i.e. pentagon. The corners are located on the circumscribed circle **27**. The pile associated with the force F**1** is pushed into the ground. The force exerted on said pile is raised to 3000 mT (for example). 3000 mT is an example which is a realistic top end capacity for very dense North Sea sands, although this is of course dependent on the outer diameter and wall thickness of the pile. The vertical force on two opposite piles F**3** and F**4** is 927 mT which is a push force. A push force is indicated with a plus sign. The forces F**2** and

F**5** on the associated piles are pull forces, indicated by the minus sign. There is a force equilibrium on all piles, wherein the pile associated with F**1** receives a greater vertical force than each of the remaining piles. Hence, said pile F**1** will be pushed downward.

[0353] The force F**1** can be achieved by having the associated actuator **10** extend, by retracting the remaining actuators **10** associated with forces F**2**-F**5**, by pivoting the bridge assembly **7** about a pivot axis **23**, e.g. a pivot axis **23** extending through piles F**2** and F**5**, or by any combination thereof.

[0354] The equilibrium point **33** is located on the pivot axis. If a different force distribution is chosen, said equilibrium point may be located at a different location. This applies to all shown embodiments of FIGS. **16**-**26**.

[0355] FIGS. **17** and **18** show different push in configurations for a six pile device **1** arranged as a hexagon.

[0356] FIG. **17** shows how one of the six piles is pushed in, namely the pile receiving force F**1** of 3000 mT. The force F**3** is associated with the pile opposite to the pile which is pushed in. F**3** is a push force of 1000 mT. Pull forces F**2** and F**4** are each 2000 mT. The two piles adjacent the pile receiving the force F**3** are substantially idle, or passive during this push in configuration. The force F**1** can be achieved by having the associated actuator **10** extend, by retracting the remaining piles, by pivoting the bridge assembly **7** about a pivot axis **23** extending through piles F**2** and F**4**, or by any combination thereof. The pile connection assemblies associated with each corner are arranged on circumscribed circle **27**.

[0357] FIG. **18** shows the simultaneous push in of two piles associated with forces F**1** and F**4**. All remaining piles receive a pull force F**2**, F**3**, F**5**, F**6** of 1500 mT. This embodiment is also shown in FIGS. **3**A-**3**C or in FIGS. **5**A-**5**C. In FIGS. **3**A-**3**C two piles are pushed in by extending the corresponding actuators **10**. In FIGS. **5**A-**5**C two piles are pushed in by retracting the remaining actuators **10**. The force distribution can be similar in both embodiments.

[0358] Opposite loads, for example F**2** and F**6**, do not necessarily need to be identical. When one pile experiences less soil resistance, this pile can be pushed with more ease than the opposite pile being pushed.

[0359] FIG. **19** shows an embodiment of a device **1** configures to push in seven piles. In the shown embodiment one pile associated with force F**1** is pushed in. The device **1** is also suited to push in two piles simultaneously.

[0360] FIGS. **20**-**22** show an embodiment of a device **1** configured to push in eight piles, arranged in an octagon.

[0361] The push in configuration of FIG. **20** pushes in two piles simultaneously, namely the piles associated with forces F**1** and F**4**. Four of the six remaining actuators **10** are configured to exert a vertical pull force F**2**, F**3**, F**5**, F**6** on their associated piles.

[0362] The push in configuration of FIG. **21** pushes in one pile, i.e. the pile connected to the pile connection assembly associated with force F**1**. Two opposite actuators **22** exert a relatively small push force F**3**, F**4** of 311 mT to their associated piles. The opposing actuators **29** associated with vertical pull forces F**2** and F**5** exert a pull force of 1811 mT on their associated piles. Three piles are substantially idle in this configuration.

[0363] In the push in configuration of FIG. **22** four piles are substantially idle. The pile receiving push force F**1** is pushed in with a vertical force of 3000 mT. The opposite actuator **10** exerts a push force F**3** of 514 mT. The opposing actuators **29** adjacent the pile being pushed in exert a pull force of 1757 mT on their associated piles. The force F**1** can be achieved by having the associated actuator **10** extend, by retracting the remaining piles, by pivoting the bridge assembly **7** about a pivot axis **23**, e.g. extending through piles F**2** and F**4**, or by any combination thereof.

[0364] FIG. **23** shows a device **1** for pushing in seven piles, wherein the pile connection assemblies define an irregular polygon **28**. The two piles associated with forces F**1** and F**5** are pushed in simultaneously. All remaining piles experience a pull force of either 829 mT or 1757 mT.

[0365] FIG. **24** shows the embodiment of FIG. **23**, wherein one pile is pushed in, namely the pile receiving push force F**1** of 3000 mT. The actuator **10** opposite of the pile which is being pushed in receives a push force F**3** of 514 mT. Pull forces F**2** and F**4** are exerted by the opposing actuators **29** on the piles adjacent the pile which is being pushed in.

[0366] FIGS. **25** and **26** show an embodiment of the device **1** configured to push in five piles. Four of the five piles define the polygonal configuration **5**, i.e. F**1** to F**4**. One remaining pile, F**5**, is located within the polygon. In this embodiment, a difference in forces between the piles which are pushed in is transferred as a bending moment in other piles via the bridge assembly **7**.

[0367] In FIG. **25** two piles are pushed in simultaneously, namely the piles associated with vertical push forces F**1** and F**3**. The remaining actuators **10** exert a pull force F**2**, F**4**, F**5** on their associated piles.

[0368] In the configuration of FIG. **26** the middle pile is pushed in by a push force F**1** of 3000 mT. The four remaining piles experience a pull force F**2**-F**5** of 750 mT via their associated actuators **10**.

[0369] During operation the device **1** may carry out a cycle. A cycle may comprise in sequence:

- **[0370]** pushing the first pile **2.1** over a distance **18** into the ground or seabed **3**,
- **[0371]** pushing the second pile **2.2** over a distance **18** into the ground or seabed **3**,
- **[0372]** pushing the third pile **2.3** over a distance **18** into the ground or seabed **3**,
- **[0373]** pushing the fourth pile **2.4** over a distance **18** into the ground or seabed **3**,
- **[0374]** pushing the fifth pile **2.5** over a distance **18** into the ground or seabed **3**.

[0375] If there are more than five piles to be pushed in, each cycle further comprises pushing any subsequent pile over a distance **18** into the ground or seabed **3**.

[0376] A cycle may also comprise in sequence:

- **[0377]** pushing the first pile **2.1** and second pile **2.2** simultaneously over a distance **18** into the ground or seabed **3**,
- **[0378]** pushing the third pile **2.3** and fourth pile **2.4** simultaneously over a distance **18** into the ground or seabed **3**,
- **[0379]** pushing the fifth pile **2.5** and sixth pile **2.6** simultaneously over a distance **18** into the ground or seabed **3**.

[0380] If more than six piles, each cycle comprises pushing any subsequent pairs of piles over a distance **18** into the ground or seabed **3**.

[0381] The cycles of pushing in one pile and two piles may also be combined, both sequentially as internally. It may also be possible to push in groups of three piles or more into the ground simultaneously.

[0382] In an advantageous embodiment, the first step or the last step of the cycle comprises keeping at least one or two actuators **10** substantially stationary while retracting the remaining actuators **10** for pushing the at least one or two piles corresponding to the at least one or two substantially stationary actuators **10** into the ground or seabed **3**. The other steps comprise extending the at least one or two actuators **10** for pushing the at least one or two piles corresponding to the at least one or two actuators **10** into the ground or seabed **3**.

[0383] As the device **1** is also configured to pull out at least five piles, the cycle to do so is in essence the same as pushing in at least five piles, but reversed.

[0384] A method for pulling out the at least five piles **2** comprises the steps:

- **[0385]** connecting the device **1** according to the first aspect of the invention to the upper ends of the piles, wherein each pile connection assembly **9** is connected to an associated pile **2**,
- **[0386]** alternately pulling at least one of the piles over a distance out of the ground or seabed by alternately
  - **[0387]** retracting the at least one or at least two actuators **10** which are associated with the at least one or at least two piles **2**, and/or by
  - **[0388]** keeping at least one or at least two actuators **10** associated with the at least one or at least two piles being pulled out substantially stationary while extending at least three or at least four of the remaining actuators, and/or by
  - **[0389]** keeping at least one or at least two actuators associated with the at least one or at least two piles being pulled out substantially stationary while retracting at least two opposite actuators, thereby pivoting the bridge assembly about a pivot axis **23** extending between said at least one actuator and said at least two opposite actuators.

Second Aspect

[0390] Turning to FIG. **27**, a side view of an embodiment of a helical pile **100** according to a second aspect of the invention is shown, namely a helical pile **100** for installation into the ground or seabed **3**.

[0391] The helical pile **100** comprises a first tubular section **101** having a length **102** and a first outer diameter **103**. The first tubular section **101** comprises a first end **104** and an opposite, second end **105**. The first end **104** is configured to be inserted into the ground or seabed **3**.

[0392] The helical pile **100** comprises a first helical section **106** which is provided between the first end **104** and second end **105**. In the shown embodiments the first helical section **106** is provided at the first end **104**. The first helical section **106** has a first pitch **107** and a first pitch orientation **108**. The first pitch orientation **108** is the direction of the helical section as it extends around the first tubular section **101** from the second end **105** toward the first end **104**, when seen in top view. In FIG. **27** the first pitch orientation **108** is clockwise **134**.

[0393] The helical pile **100** comprises a second helical section **109** which is provided between the first helical section **106** and the second end **105** at a distance **110** from the first helical section **106**. The second helical section **109** has a second pitch **111** and the same first pitch orientation **108** as the first helical section **106**.

[0394] The second pitch **111** is different from the first pitch **107**.

[0395] The second pitch **111** is smaller than the first pitch **107**.

[0396] The first outer diameter **103** is constant between the first helical section **106** and the second helical section **109**. The first outer diameter **103** may however also vary.

[0397] The distance between the first helical section **106** and the second helical section **109** is preferably at least 3 times the first outer diameter **103**.

[0398] The first helical section **106** extends away from an outer surface **112** of the first tubular section **101**. The first helical section **106** is provided on said outer surface **232** **112**.

[0399] The second helical section **109** extends away from the outer surface **112** of the first tubular section **101**. The second helical section **109** is provided on said outer surface **112**.

[0400] The first helical section **106** and the second helical section **109** comprise a helical plate **113**, i.e. a plate which extends as a helix around the first tubular section **101**.

[0401] The first end **104** comprises a penetrating section **114** configured to penetrate the soil. Said penetrating section **114** can have different shapes. A shape which is shown is a conical shape **115** converging from the first end **104**.

[0402] An outer diameter **116** of the first and/or second helical section **109** may be at least 1.5 times the first outer diameter **103**. In FIG. **27** the outer diameters **116** of the first and second helical sections **106**, **109** are constant and identical to each other.

[0403] FIG. **28** schematically shows a side view of another embodiment of the first helical section **106**. A lower part is shown of the first tubular section **101** comprising the first helical section **106**. An outer diameter **116** of the first helical section **106** increases in a direction **117** from the first end **104** towards the second end **105**. Also an outer diameter **116** of the second helical section **109** may increase in this way. This provides a smoother penetrating of the helical sections into the ground or seabed **3** during the rotation of the pile about its longitudinal axis **122**.

[0404] The helical section of FIG. **28** extends more than one rotation about the pile. The first and second helical sections **106**, **109** of the embodiment of FIG. **27** extend one rotation about the pile.

[0405] The first helical section and second helical section of the embodiment as shown in FIG. **27** comprise a single helix, i.e. a helix with one rotation. Rotations may also be called turns, or circumvolutions. The embodiment of FIG. **28** shows an embodiment in which the helical sections comprise a helix **106** with two rotations. In general the helical sections have a helix with less than three full rotations, or turns. A rotation of three or more would result in a too high frictional resistance. A higher frictional resistance requires more force and therefore higher loads on the installation equipment and on the pile.

[0406] The helical pile **100** of FIG. **27** has a substantially constant first outer diameter **103**.

[0407] In a different embodiment, as shown in the perspective view of FIG. **29**, the helical pile **100** comprises a second tubular section **118** connected to the second end **105**. The second tubular section **118** has a second outer diameter **119** which is larger than the first outer diameter **103**.

[0408] The outer diameter **116** of the first and second helical sections **106**, **109** is equal to or smaller than the second outer diameter **119**. This embodiment allows the helical pile **100** to be inserted through sleeves having an opening diameter close to, but at least minimally larger than the second outer diameter **119**, while providing an effective screw in effect.

[0409] The first tubular section **101** and the second tubular section **118** are connected via a tapered section **120** at their respective ends. The connection between the first tubular section and second tubular section may also be other than a tapered section, for example a stepped increase.

[0410] The longitudinal axis of the second tubular section coincides with the longitudinal axis of the first tubular section.

[0411] The first helical section **106** and/or the second helical section **109** of the embodiments in FIGS. **27** and **29** are a circular helix, i.e. one with constant radius.

[0412] The first helical section **106** of the embodiment of FIG. **28** is a conic helix at the tip, and then gradually goes over into a circular helix.

[0413] The top end **126** of the helical pile **100** may comprises a female mating part **127** configured to be engaged by a male mating part **128** of a pile connector **15** associated with a rotating actuator **129** for rotating the pile about its longitudinal axis **122**, or vice versa. This is shown in FIG. **41**D, wherein the top end **126** of the helical pile **100** comprises a slot like a slotted screw.

[0414] FIG. **27** shows another embodiment of the female mating part **127**, namely a bayonet female part configured to provide bayonet coupling with the male part **128** of the rotating actuator **129**.

Operation

[0415] Turning to FIGS. **30** and **31**, two installation concepts are shown for a helical pile **100** comprising a single helical section **106** having a pitch and pitch orientation.

[0416] FIG. **30** schematically shows the concept of 'self-weight' installation. During self-weight installation the vertical pressure on the pile is kept substantially constant. The pile screws itself down. It however takes more than one rotation of the pile about its longitudinal axis **122** to move the pile down one pitch associated with the helical section. The ratio between the rotations of the pile and the amount of pitches the pile moves down because of those rotations is higher than one. This results in an increase of soil stress above the helical section, because soil is moved upwards by the helical section. A larger tension capacity is achieved with this type of installation, which is beneficial when a higher uplift capacity is desired.

[0417] FIG. **31** schematically shows the concept of 'pitch-matched' installation. During 'pitch-matched' installation the pile **100** is moved exactly one pitch of the helical section downwards per rotation of the pile. In order to achieve this an axial force has to be applied to the pile. The axial force leads to an increase of the compressive capacity, because the soil below the helical section is pre-loaded during installation. A higher compressive capacity may be beneficial, because it leads to a higher bearing capacity of the pile.

[0418] The helical pile **100** according to the invention is configured to advantageously combine both installation concepts. That is when the second pitch **111** of the second helical section **109** is different from the first pitch **107** of the first helical section **106**, in particular when the second pitch **111** is smaller than the first pitch **107**. This is schematically shown in FIG. **32**, wherein the 'self-weight' installation concept and the 'pitch-matched' concept are combined.

[0419] The pile of FIG. **32** is the same helical pile **100** as FIG. **27**, except for the bayonet coupling **130**. The first helical section **106** has a first pitch **107** which is greater than the second pitch **111** of the second helical section **109**.

[0420] The helical pile **100** is installed in such a way that the first helical section **106** makes use of the self-weight concept and the second helical section **109** makes use of the pitch-matched concept. This way the soil between the two helical sections is activated in order to provide both a higher tension capacity and a higher compressive capacity.

[0421] Turning to FIGS. **33** to **35**, a method is shown for installing the helical pile **100** according to the second aspect of the invention. The helical pile as shown in FIG. **29** is used. In the shown embodiment the helical pile **100** is installed through a sleeve **70** at a bottom of a jacket **72** structure. The helical pile **100** can however be used in combination with other structures as well.

[0422] The method comprises

- **[0423]** positioning the helical pile **100** on the ground or the seabed **3** in an upright orientation, wherein the first end **104** is in contact with the ground or the seabed **3**, and wherein the first helical section **106** engages the ground or the seabed **3**, as shown in FIG. **33**,
- **[0424]** moving the helical pile **100** into the ground by rotating the helical pile **100** about its longitudinal axis **122** in a direction **131** corresponding with the first pitch orientation **108** of the helical sections, until the first helical section **106** and the second helical section **109** are both located at a predetermined distance **132** below the ground or seabed **3**, as shown in FIGS. **34** and **35**.
- **[0425]** connecting a structure to the installed helical pile **100**, wherein the installed helical pile **100** forms a foundation or part of a foundation of said structure **72** and transfers horizontal and/or vertical loads which are exerted by the structure **72** onto the installed helical pile to the surrounding soil.

[0426] The structure **72** may for example be a jacket structure **72**, as shown in FIG. **36**, or a support structure **200** as shown in FIG. **39**A.

[0427] The pile is moved downward into the ground or seabed **3** over a distance equal to M times the first pitch **107** of the first helical section **106** by completely rotating the helical pile **100** N times about its longitudinal axis **122**, wherein N is greater than M. This way the first helical section **106** is installed using the self-weight concept, while the second helical section **109** is installed using the pitch-matched concept. The first helical section **106** in a way pulls the second helical section **109** down, thereby providing the required axial force for the pitch-matched concept of the second helical section **109**.

[0428] The method is rather effective when the second pitch **111** is M/N times the first pitch **107**, because that results in a relatively high activation of the soil between the first helical section **106** and the second helical section **109**.

[0429] FIGS. **36** and **37** schematically show a step of a method for installing at least two helical piles **100** according to the second aspect of the invention simultaneously. For this method a first helical pile **100**, here the left one, comprises helical sections **106**, **109** with a clockwise first pitch orientation **108** when seen in top view. A second helical pile **100**, here the right one, comprises helical sections with a counter clockwise first pitch orientation **108** when seen in top view.

[0430] The method comprises positioning the helical piles **100** on the ground or the seabed **3** in an upright orientation, wherein the first ends **104** are in contact with the ground or the seabed **3**, and wherein the first helical sections **106** engages the ground or the seabed **3**

[0431] An installation device **136** as shown in for example FIG. **41**D is provided. The installation device **136** comprises a bridge assembly **7** which when seen in top view defines at least two connecting locations **8**. The installation device **136** has at least two pile connection assemblies via which in use each of the at least two helical piles **100** is connected to the bridge assembly **7**.

[0432] Each pile connection assembly comprises a rotating actuator **129** configured to rotate in a clockwise **134** and/or a counter clockwise **135** direction relative to the bridge assembly **7** when seen in top view.

[0433] The pile connection assembly comprises a pile connector **15** which is connected to the rotating actuator **129**. Each pile connector **15** is configured to be connected to an upper part **16** of a helical pile **100** which is to be moved into the ground or seabed **3**. The pile connector **15** is configured to be rotated by the associated rotating actuator **129**.

[0434] The method further comprises connecting a first pile connector **15** of the installation device **136** to the first helical pile **100** and a second pile connector **15** of the installation device **136** to the second helical pile **100**. Connecting the pile connectors **15** to the helical piles **100** may be done prior to positioning the helical piles **100** on the ground or seabed **3**.

[0435] Next the first, left helical pile **100** is rotated in the clockwise **134** pitch orientation via the second pile connector **145** and the associated actuators **129** simultaneously rotates the second, right helical pile **100** in the counter clockwise **135** direction via the second pile connector **146** and the associated actuator **129**. By having counter rotating actuator **129** the torque loads exerted on the piles and the installation device **136** are balanced.

[0436] The helical piles **100** may be moved downward into the ground or seabed **3** over a distance equal to M times the first pitch **107** of the first helical section **106** by completely rotating the helical pile **100** N times about its longitudinal axis **122**, wherein N is greater than M.

[0437] The present invention further provides a method for removing an installed helical pile **100** according to the invention from the ground or seabed **3**, the method comprising the step of rotating the pile in a direction opposite to the first pitch orientation **108** of the helical sections.

[0438] It is also possible to remove at least two installed helical piles **100** simultaneously, wherein a first helical pile **100** comprises helical sections in a clockwise **134** pitch orientation when seen in top view, and wherein a second helical pile **100** comprises helical sections in a counter clockwise **135** pitch orientation when seen in top view.

[0439] The method comprising the steps of connecting the installation device **136** to the at least two piles by connecting the second pile connector **145** to the first helical pile **100** and the second pile connector **146** to the second helical pile **100**.

[0440] Next the first helical pile **100** is rotated in the counter clockwise **135** pitch orientation via the second pile connector **145** and the associated actuator **10** and the second helical pile **100** is rotated simultaneously in the clockwise **134** direction via the second pile connector **146** and the associated actuator **10**.

[0441] An advantage of counter rotating two helical piles **100** is that less residual moment is transferred to the surrounding, be it the vessel **69** operating the tool, the foundation itself or the piles **100** themselves or any combination thereof.

[0442] To prevent that one helical pile **100** moves into the ground substantially faster than the other, speed can be controlled while keeping the torque as close as possible to the one that needs to catch up. This is easiest when using electric motors, typically equipped with an additional gearbox, where a setting can be chosen as max torque, (close to) zero speed. Hydraulic motors can also be used. These however require more complex steering of the moments along with the speed to account for the differences.

Third Aspect

[0443] Turning to FIG. **38** a third aspect of the invention is shown, a support structure **200** for supporting a top structure above the ground or a seabed **3**. The top structure can be for example a wind turbine.

[0444] The support structure **200** comprises at least one support pile **202** having a length **203** and a first outer diameter **204**. In the shown embodiments a single support pile **202** is shown.

[0445] The support pile **202** comprises an upper part **205** which is configured and intended to extend above the ground or the seabed **3**. The upper part **205** of the support pile **202** is configured to be connected to the top structure.

[0446] The support pile **202** is configured to exert an upward vertical force on the top structure in order to carry the top structure.

[0447] A lower part **206** of the at least one support pile **202** is in contact with the ground or seabed **3**. The lower part **206** may rest on the ground or seabed **3**. When the lower part **206** rests on the seabed, there is less lateral resistance.

[0448] In the shown embodiment a bottom part **212** of the lower part **206** extends over a distance **213** into the seabed **3**. An advantage of this embodiment is that the bottom part **212** of the support pile **202** which extends into the ground provides lateral capacity to the support structure **200**. As the support pile **202** takes over at least a part of the lateral capacity from the foundation piles **211**, the foundation piles **211** may have a smaller diameter. A smaller diameter of the foundation piles **211** in turn requires a lower installation force for the foundation piles **211**.

[0449] The lower part **206** of the support pile **202** may be configured to extend into the ground or seabed **3** by a distance of at least one time the first outer diameter **204** of the support pile **202**.

[0450] The support pile **202** comprises a plurality of foundation guides **207** which are connected to the lower part **206** of the at least one support pile **202**. The embodiment of FIG. **38** has six foundation guides **207**. Each foundation guide **207** has an opening **208** (FIG. **39**B) extending in a direction of the at least one support pile **202**. The direction of the opening may also be angled with respect to the support pile **202**. The opening has an opening diameter **210**. Each foundation guide **207** accommodates a foundation pile **211**, wherein the foundation pile **211** extends through the foundation guide **207** and at least partly into the ground or the seabed **3**.

[0451] The foundation guides **207** are configured to receive a vertical force from the foundation piles **211**.

[0452] The support structure **200** comprises at least three foundation guides **207**.

[0453] When the support pile **202** is configured to extend into the ground or seabed **3**, the foundation guides **207** are typically provided at a distance **213** above a bottom end **224** of the at least one support pile **202**.

[0454] A longitudinal axis **215** of the opening of the foundation guides **207** may extend parallel to a central axis **216** of the at least one support pile **202**.

[0455] In top view the foundation guides **207** are arranged around the at least one support pile **202**.

[0456] In said top view the foundation guides **207** may be arranged equidistantly around the at least one support pile **202**, see for example the embodiment of FIG. **39**B.

[0457] A length **220** of the foundation guide **207** may be at least twice the opening diameter **210** of the opening of the foundation guide.

[0458] The opening diameter **210** of the foundation guides **207** is smaller than the first outer diameter **204**, in particular at least 3 times smaller.

[0459] In the shown embodiment, the foundation guides **207** are sleeves **221**.

[0460] The opening of the foundation guide **207** is located at less than 2 times the opening diameter **210** away from an outer surface **232** of the at least one support pile **202**, in particular less than once the opening diameter **210**. This allows for a compact support structure **200**, and subsequently for a compact support assembly **235**.

[0461] The foundation guides **207** are connected to each other via a foundation frame **229**. The foundation frame **229** is connected to and extends around the support pile **202**. The foundation frame **229** provides stiffness to the connection between the foundation guides **207** and the at least one support pile **202**. The support pile **202** usually is a slender structure having a relatively high diameter of wall thickness ratio. This lead to a behaviour like a soda can, i.e. the wall of the support pile **202** has a low resistance to radial forces. Hence, the foundation frame **229** is provided for additional stiffness.

[0462] The foundation guides **207** may comprise a centering member **222** around the opening at the top end **223** thereof, as shown in for example FIG. **40**. The centering member **222** is configured to center and guide a bottom end **230** of a foundation pile **211** into the opening of the foundation guide.

[0463] FIGS. **39**A and **39**B schematically show an embodiment wherein the support pile **202** comprises a widening part **217** which extends over a distance **218** upwards from the bottom end **224**. The widening part **217** is configured to extend into the ground or seabed **3**. The widening part **217** has a second outer diameter **219** which is greater than the first outer diameter **237 204 116 103**. In the top view of FIG. **39**B it is shown that the foundation guides **207** extend outside the first outer diameter **204** and inside the widening part **217** having the second outer diameter **219**. The widening part **217** provides additional lateral capacity to the support structure **200**.

[0464] FIG. **40** shows an embodiment of the support structure **200**, wherein a suction bucket **234** is provided inside the lower part **206** of the support pile **202**. The suction bucket **234** comprises a reinforced plate **235**. The suction bucket is configured to be connected to a pump for providing under pressure inside the suction bucket **234** for moving the lower part **206** of the support pile **202** into the ground or the seabed **3** via suction or at least partly via suction.

[0465] At least one annular recess **225** is provided in an inner side **226** of the sleeve **221**, the annular recess **225** being configured and intended to form a female part **227** of a swaging connection **228** between the foundation pile **211** and the sleeve **221**, see FIG. **44**.

[0466] The support structure **200** is part of a support assembly **235** according to another aspect of the invention for supporting a top structure above the ground or a seabed **3**. The top structure may for example be a wind turbine. An embodiment of the support assembly **235** is shown in FIG. **38**.

[0467] The support assembly **235** comprises a plurality of foundation piles **211**, in particular at least three. Each foundation pile **211** extends through a respective foundation guide **207** and is configured and intended to extend at least partly into the ground or the seabed **3** over a foundation depth **236** (FIG. **42**). When installed the foundation piles **211** provide resistance against overturning of the support pile **202**, as well as lateral resistance.

[0468] The foundation piles **211** are arranged around the first outer diameter **204**, i.e. around the outer surface **232** of the at least one support pile **202**.

[0469] The first outer diameter **204** of the support pile **202** is greater than an outer diameter **237** of the foundation piles **211** (FIG. **39**B), for example at least three times greater.

[0470] The foundation piles **211** may have the same outer diameter **237**.

[0471] The foundation piles **211** are arranged equidistantly around the support pile **202**. In a preferred embodiment the foundation piles **211** define a cyclic polygon **24** when seen in top view, see for example FIG. **39**B. Also the foundation piles **211** of FIG. **40** define a cyclic polygon **24** of four in top view.

[0472] One or more of the foundation piles **211** may comprises at least one helical section at a lower end thereof extending around the outer surface **232**, as shown in the embodiment of FIG. **39**A. The foundation pile **211** with here two helical sections **106**, **109** is configured to be rotated about its longitudinal axis in order to move the foundation pile **211** into the ground or the seabed **3**. The helices of all piles in the embodiment of FIG. **39**A have a counter clockwise pitch orientation when seen in top view. Also the first pitch **107** and the second pitch **111** of the helical foundation piles **211** are substantially the same.

[0473] Helical piles **100** according to the second aspect of the invention may also be advantageously used as foundation piles **211**. Also a combination of helical piles **100** and piles without helices may be used.

[0474] Prior to installation of the support assembly **235**, the foundation piles **211** may located adjacent the support pile **202**. At least 80 percent of the length **242** of the foundation piles **211** are located adjacent the support pile **202**. In the shown embodiment of FIG. **41**, the foundation piles **211** overlap the support pile **202** with more than 90 percent of their length **242**. An advantage of the support assembly **235** is that the support pile **202** can be of shorter length **203** compared to a monopile offering the same lateral and overturning capacity. The foundation piles **211** provide a telescopic effect, so that the total length **203** of the support assembly **235** prior to installation is much shorter than a monopile. The shorter length **203** is beneficial for storage and transport, because the support assembly **235** is easier to store and transport vertically compared to a monopile, which is typically transported horizontally.

[0475] After installation of the support assembly **235** at least 60 percent of the length **242** of the foundation piles **211** extends below the support pile **202**.

[0476] The invention further provides a floating vessel **69** comprising at least one support assembly **235**. During transport the at least one support assembly **235** is provided on the vessel **69**, in particular on a deck **78** of the floating vessel **69**, in a vertical orientation.

[0477] A benefit of the support assembly **235** is that when provided with the foundation frame **229** the bottom of the support structure **200** has strong points to allow for vertical transport. Where a typical monopile has a relatively weak bottom section consisting only of a thin walled tubular, the present invention has sufficient strength and stiffness at the bottom to be able to support the assembly in a vertical position while subjected to the motions and the resulting accelerations during marine transport.

Operation

[0478] Methods for installing different embodiments of the support assembly **235** into the seabed **3** below a waterline **4** are shown in FIGS. **41** to **44**.

[0479] FIG. **41**A shows an embodiment of a method for installing a support assembly **235** wherein helical piles **100** are used as foundation piles **211**. The method is shown from left to right.

[0480] The method comprises positioning the support pile **202** with its bottom end **224** on the ground or the seabed **3**. In this embodiment the foundation piles **211** extend through the foundation guides **207** in the form of sleeves and are located adjacent the support pile **202** during lowering of the support assembly **235**. The outer diameter of the helical sections is greater than the opening diameter of the foundation guides. This way, the support pile rests on the helical sections **106**, **109** of the foundation piles via the foundation guides during lowering.

[0481] The foundation piles **211** are connected at their top ends **126** to pile connectors **15** of an installation device **136** for moving the foundation piles **211** into the seabed **3**. The installation device **136** is part of a lowering assembly **241** and is connected to a lowering frame **244** above the top end **251** of the support pile **202** via cables **252**. See FIG. **41**E for an example of the lowering frame **244**. The distance between the lowering frame and the installation device **136** can be altered by altering the length of the cables. The lowering assembly **241** is typically connected to a crane **68** on board an installation vessel **69**. The crane **68** moves the lowering assembly **241** and thereby the support assembly **235** down to the seabed **3**.

[0482] Next a part of the lower part **206** of the support pile **202** is moved into the seabed **3**.

[0483] The foundation piles **211** are in this embodiment already located in the foundation guides **207** and on the seabed **3**. The foundation piles **211** may also be positioned in the foundation guides **207** and on the seabed **3** after the support pile **202** is positioned on the seabed **3**.

[0484] Next the foundation piles **211** are moved into the ground or the seabed **3** over the foundation depth **236** by the installation device **136**. Here the foundation piles **211** are helical piles **100**. Hence the installation device **136** rotates the helical piles **100** in order to move them down. During this step the cables by which the installation device **136** is connected to the lowering frame are slacked, as shown in FIG. **41**B. This way, the weight of the installation device **136** provides an additional downwards force on the foundation piles **211** which may assist the installation thereof.

[0485] When the foundation piles **211** have reached their foundation depth **236**, or predetermined penetrating depth, the installation device **136** is disconnected from the foundation piles **211** and subsequently moved upward relative to the support pile **202** and away therefrom. This is depicted in the two steps on the right of FIG. **41**A and in FIG. **41**D.

[0486] Turning to FIG. **41**D, the installation device **136**, which is suited for installing helical piles **100**, comprises a bridge assembly **7** which when seen in top view defines a plurality of connecting locations **8** corresponding to the plurality of foundation piles **211**. The installation device **136** comprises a plurality of pile connection assemblies **9** via which in use each foundation pile **211** is connected to the bridge assembly **7**.

[0487] Each pile connection assembly **9** comprises a pile connector **15**. Each pile connector **15** is configured to be connected to an upper part **205** of each foundation pile **211** which is to be moved into the ground or seabed **3**.

[0488] At least a plurality of, but preferably all the pile connection assemblies **9** comprise an actuator **10** which extends downward from the respective connecting location. Each actuator **10** comprises an upper actuator part **11** and a lower actuator part **12**. The upper actuator part **11** is connected to the bridge assembly **7**. The lower actuator part **12** is connected to a corresponding pile connector **15**.

[0489] The actuators **10** may be hydraulic actuators configured to extend and/or retract. The actuators **10** may also be rotating actuators **129**. Also a combination of extending/retracting actuators **10** and rotating actuators **129** is possible. Rotating actuators **129** are required for installing helical piles **100**, for example helical piles **100** according to the second aspect of the invention.

[0490] The bridge assembly **7** comprises a central opening **58** through which the at least one support pile **202** extends. The installation device **136** moves downward relative to the support pile **202** during installation of the foundation piles **211**.

[0491] The bridge assembly **7** may comprise a plurality of guides **245** for guiding the movement of the installation device **136** relative to the support pile **202**, wherein the guides extend into the central opening **58**.

[0492] The guides may also be configured to engage the support pile **202** and to transfer a bending moment of the foundation piles **211** as a force into the support pile **202** via the bridge assembly **7**.

[0493] The actuators **10** are rotating actuators **129**, wherein the pile connector **15** comprising a male or female mating part **128 127** configured to mate with a corresponding mating part of a foundation pile **211**. Here the male part is provided on the pile connector **15** as a sideways extending pin. The female part **227** is proved on the foundation pile **211** in the form of a slot.

[0494] The rotating actuators **129** can rotate both ways about a central axis thereof. In order to move in multiple piles at the same time, one half of the rotating actuators **129** may rotate in a clockwise **134** direction and the other half of the rotating actuators **129** may rotate in the counter clockwise **135** direction. This way the torque on the installation device **136** is balanced. The helical piles **100** then have corresponding clockwise **134** and counter clockwise **135** oriented helical sections, as shown in FIG. **41**C.

[0495] The installation device **136** may also comprise an engaging member **247** configured to engage the support pile **202** and to exert a force on the support pile **202** in a vertical direction. Here the guide **245** is also the engaging member **247**.

[0496] The lower part **206** of the support pile **202** can be moved into the ground or seabed **3** at least in part by a downward force exerted by the helical piles **100** on the foundation guides **207** or by pushing the installation device **136** connected to the foundation piles **211** upwards relative to the support pile **202**.

[0497] During this process of pushing the support pile **202** further into the ground, levelling can be performed on the support pile **202** by pushing harder on one side than the other, via the foundation piles **211**. This can be beneficial if installation tolerances are tight or to minimise/remove the use of a gripper frame or temporary installation template. The same levelling process can be done with push in piles and a device **1** according to the first aspect of the invention.

[0498] FIG. **42** shows an embodiment of the method wherein six foundation piles **211** are pushed into the ground by a device **1** according to the first aspect of the invention having the central opening **58**. Said device **1** extends around the at least one support pile **202**, wherein the at least one support pile **202** extends through the central opening **58**. Here the support pile **202** does not extend into seabed **3**, but rests on the seabed **3**.

[0499] From left to right FIG. **42** shows the positioning of the support assembly **235** on the seabed **3**. The installation device **1** is already connected to the foundation piles **211**, but this may also occur after the positioning of the foundation piles **211**. Next the foundation piles **211** are moved into the ground by pushing. The middle step shows the foundation piles **211** having reached their predetermined penetration depth. The fourth step is disconnecting the installation device **1**. The right step shows the moving away of the installation device **1** from the support assembly **235**, in particular by moving the installation device **136** upward relative to the support pile **202**.

[0500] The foundation piles **211** may in general be moved into the ground or the seabed **3** by hammering, screwing, pushing, or a combination thereof.

[0501] The support assembly **235** may be installed in a vertical orientation. Also the foundation piles **211** may be moved into the ground or the seabed **3** vertically.

[0502] When a support assembly **235** comprising a support pile **202** with a suction bucket **234** is installed, as for example shown in the embodiment of FIG. **40**, the lower part **206** can be moved into the ground or the seabed **3** at least in part via suction.

[0503] FIG. **43**A shows an embodiment of the method for installing a support assembly **235** having three foundation piles **211** and one support pile **202**. Here the foundation piles **211** are installed using installation device **136** comprising hammers, or vibro-hammers **254** as actuators **10**, see FIG. **43**B.

[0504] From left to right, the support pile **202** is first positioned on the seabed **3** and moved partly into the seabed **3**. Next the foundation piles **211** are hammered into the seabed **3**. In the middle the foundation piles **211** have reached their predetermined penetration depth. The fourth and fifth step show the disconnecting and moving away of the installation device **136**, see also FIG. **43**B.

[0505] After the foundation piles **211** are installed the orientation of the support pile **202** may be adjusted by moving the foundation piles **211** relative to the support pile **202** or by moving the support pile **202** relative to the foundation piles **211**.

[0506] In a later step the foundation piles **211** are fixated to their respective foundation guide. This can be done in different ways, for example by grouting, swaging, or a combination thereof.

[0507] FIG. **44** shows an example of a swaging connection **228**. The foundation pile **211** extends through the foundation guide **207**, see the left cross-section of FIG. **44**. On an inner side **226** of the foundation guide **207** at least one annular recess **225** is provided. Here this is achieved by providing annular rings **255** on the inner side **226** at a distance from each other. A swaging tool is inserted in the foundation pile **211** which increases the pressure in the part of the pile which is located in the foundation guide. Because of the pressure increase the wall **256** of the foundation pile **211** will be pushed in the at least one annular recess **225**, as shown in the right cross-section of FIG. **44**. This provides an effective fixation.

[0508] FIG. **45** shows another embodiment of a method of installing a support assembly **237** according to the invention into the ground or a seabed. The method as shown in FIG. **45** is in particular beneficial for more rocky soil **3**.**2**. The method comprises the steps of positioning the support pile **202** with its bottom end on the ground or the seabed and moving a part of the lower part **206** of the support pile **202** into the ground or the seabed **3**, and the steps of positioning the foundation piles **211** in the foundation guides **207** and moving the foundation piles **211** at least partly into the ground or the seabed **3** over the foundation depth **238**.

[0509] The method is shown in steps A to J of FIG. **45**. Step A shows the lowering of an embodiment of the support structure **200** according to the invention towards the seabed **3**. A lower end of the foundation frame **229** is located a distance above the lower end of the support pile **202**.

[0510] Step B shows a step of moving the lower part **206** of the support pile **202** into the seabed **3**. This can for example be done by self-weight penetration, vibro-hammering the support pile, or via a suction bucket inside the lower part of the support pile.

[0511] Step C shows a step wherein the support pile **202** has reached its desired penetration depth. The foundation frame **229** and/or the foundation guides **207** have come to rest on the seabed.

[0512] Step D shows the lowering of a casing **257** to the foundation guides, wherein step E shows multiple casings **257**, i.e. one for each foundation guide **207**, extending through the foundation guides and into the soil, in particular up to the point where the casings **257** hit the more rocky ground layer **3**.**2**. The casings may be installed via hammering, vibro-hammering or any other suitable installation method. The soil above the more rocky ground layer **3**.**2** is typically a sand or clay layer **3**.**1**. The casings **257** are hollow tubes or pipes that allow for the insertion of a drill **258**.

[0513] Step F shows said drill **258** which is lowered towards the casing **257**. The drill **258** is shown schematically. Hence the drive for driving the drill is not shown. The drill **258** is subsequently inserted through the casing **257** and drills a hole **261** through the more rocky ground layer **3**.**2**.

Step G shows the step in which the drill has reached its final drilling depth. The final drilling depth is substantially equal to the final foundation depth for the foundation piles.

[0514] Once the drill **258** has been removed from the drilled hole **261** a foundation pile is inserted in the drilled hole. This is shown in steps H and I. The foundation pile **211** may have grout ridges **262** that project outwards from the outer surface of the pile. The grout ridges **262** are shown as horizontal lines in FIG. **45**.

[0515] Step J shows the step of grouting the foundation piles. Grout **259** is provided between one or more of the foundation piles **211** and the surrounding soil **3.2**. Grout **259** may also be provided between one or more of the foundation piles **211** and their respective foundation guides **207** or casings **257**.

[0516] FIG. **46** shows yet another embodiment of a method of installing a support assembly **237** according to the invention into the ground or a seabed **3**. The method comprises the steps of positioning the support pile **202** with its bottom end on the ground or the seabed and moving a part of the lower part **206** of the support pile **202** into the ground or the seabed **3**. Further steps are positioning the foundation piles **211** in the foundation guides **207** and moving the foundation piles **211** at least partly into the ground or the seabed over the foundation depth.

[0517] The method is shown in steps A to J of FIG. **46**. A difference with the other embodiments of the method according to the invention is that the support pile **202** and the foundation guides **207** of the support structure **200** are connected to each other in a later stage, in particular in a final stage of the installation instead of prior to installation.

[0518] Step A shows the lowering of the foundation guides **207** to the seabed **3**. The foundation guides **207** are connected to a lowering template **260** for lowering the foundation guides and foundation frame **229** to the seabed. The lowering template may be connected to the crane on board of an installation vessel. The lowering template **260** allows for a controlled set down of the foundation frame and guides and is removed after the foundation frame is installed.

[0519] When the foundation guides **207** are positioned on the seabed, as shown in step B, casings **257** may be inserted through the foundation guides. This may be the case when the foundation piles are to be provided through a more rocky ground layer **3.2**. In case the foundation piles only have to extend through a softer ground layer, e.g. a sand or clay layer **3.1**, the casings may be omitted, because the foundation piles may be driven directly into the soil without pre-drilling holes. For installation of the support assembly in a softer ground layer steps B to F may therefore be omitted. Also the grouting between the foundation piles and the soil in steps H to J may be omitted.

[0520] Step C shows multiple casings **257**, i.e. one for each foundation guide **207**, extending through the foundation guides and into the soil **3.1**, in particular up to the point where the casings hit the more rocky ground layer **3.2**.

[0521] Step D shows a drill **258** which is lowered towards the casing **257**. The drill is subsequently inserted through the casing **257** and drills a hole **261** through the more rocky ground layer **3.2**. Step E shows the step in which the drill has reached its final drilling depth. The final drilling depth is substantially equal to the final foundation depth for the foundation piles.

[0522] Once the drill has been removed from the drilled hole **261** a foundation pile **211** is inserted in the drilled hole. This is shown in steps F and G. The foundation pile may have grout ridges **262** that project outwards from the outer surface of the pile. The grout ridges **262** are shown as horizontal lines.

[0523] Step H shows the grouting step, wherein grout **259** is provided between one or more of the foundation piles **211** and the surrounding soil **3.2**. Also one or more of the foundation piles **211** may be grouted to their respective foundation guides **207** or casings **257**. The casings **257** may be grouted to the foundation guides **207**. Step H shows the removal of the lowering template **260**. The removal is typically done after grouting and by lifting the template with the onboard crane.

[0524] Step I shows the lowering of the support pile **202** towards the foundation guides **207**. The support pile **202** is inserted between the foundation guides **207** and subsequently moved into the seabed **3**. The support pile may be moved into the seabed by hammering, vibro-hammering, a suction bucket **235** or any other suitable installation method. An advantage of this embodiment is that the support pile is not yet connected to the foundation guides so that hammering does not have a negative effect on the structure of the foundation guides.

[0525] Step J shows the support pile **202** after it has reached its final penetration depth. The support pile **202** may be provided with stopper members (not shown) that extend from the outer surface of the support pile **202**. The stopper members, for example brackets in the form of inverted consoles, are configured to rest on the foundation frame **229**. This way the penetration depth of the support pile may be controlled while the stopper members provide extra support between the support pile and the foundation guides and piles when installed. After reaching its final penetration depth the support pile **202** may be grouted to the foundation guides, here the foundation frame.

[0526] The terms “a” or “an”, as used herein, are defined as one or more than one. The term plurality, as used herein, is defined as two or more than two. The term another, as used herein, is defined as at least a second or more. The terms including and/or having, as used herein, are defined as comprising i.e., open language, not excluding other elements or steps.

[0527] Any reference signs in the claims should not be construed as limiting the scope of the claims or the invention. It will be recognized that a specific embodiment as claimed may not achieve all of the stated objects.

[0528] The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage.

[0529] White lines between text paragraphs in the text above indicate that the technical features presented in the paragraph may be considered independent from technical features discussed in a preceding paragraph or in a subsequent paragraph.

1-142. (canceled)

143. A support structure for supporting a top structure, in particular a wind turbine, above the ground or a seabed, the support structure comprising:

one single support pile having a length and a first outer diameter, the one single support pile comprising:

an upper part configured and intended to extend above the ground or the seabed, wherein the upper part of the support pile is configured to be connected to the top structure, and

a lower part configured to be in contact with the ground or seabed,

wherein the support pile is configured to exert an upward vertical force on the top structure in order to carry the top structure, and

a plurality of foundation guides connected to the lower part of the single support pile, each foundation guide having an opening extending in a direction of the support pile, the opening having an opening diameter, wherein each foundation guide is configured to accommodate a foundation pile, wherein the foundation pile is configured to extend through the foundation guide and at least partly into the ground or the seabed, wherein the foundation guides are configured to receive a vertical force from the foundation piles.

144. A support structure for supporting a top structure above the ground or a seabed, the support structure comprising:

one single support pile having a length and a first outer diameter, the support pile comprising:

an upper part configured and intended to extend above the ground or the seabed, wherein the upper part of the support pile is configured to be connected to the top structure, and

a lower part, wherein at least a bottom part of the lower part is configured and intended to extend into the ground or the seabed, and

a plurality of foundation guides connected to the lower part of the support pile, each foundation guide having an opening extending in a direction of the support pile, the opening having an opening diameter, wherein each foundation guide is configured to accommodate a foundation pile, wherein the foundation pile is configured to extend through the foundation guide and at least partly into the ground or the seabed.

145. The support structure according to claim **144**, wherein the foundation guides are provided at a distance above a bottom end of the support pile.

146. The support structure according to claim **144**, wherein a longitudinal axis of the opening of the foundation guides extends parallel to a central axis of the support pile.

147. The support structure according to claim **144**, wherein in top view the foundation guides are arranged around the support pile.

148. The support structure according to claim **144**, wherein the support pile comprises a widening part extending over a distance upwards from the lower end, the widening part having a second outer diameter which is greater than the first outer diameter, wherein in top view the foundation guides extend outside the first outer diameter and inside the widening part having the second outer diameter.

149. The support structure according to claim **144**, wherein a length of the foundation guide is at least twice the opening diameter of the opening of the foundation guide.

150. The support structure according to claim **144**, comprising at least three foundation guides.

151. The support structure according to claim **144**, wherein the foundation guides are connected to each other via a foundation frame, the foundation frame being connected to and extending around the support pile for providing stiffness to the connection between the foundation guides and the support pile.

152. The support structure according to claim **144**, wherein a bottom end of the foundation guide is configured and intended to rest on the ground or the seabed.

153. The support structure according to claim **144**, wherein the opening diameter of the foundation guides is smaller than the first outer diameter, in particular at least 3 times smaller.

154. The support structure according to claim **144**, wherein the lower part of the support pile is configured to extend into the ground or seabed by a distance of at least one time the first outer diameter of the support pile.

155. The support structure according to claim **144**, wherein a suction bucket is provided inside the lower part of the support pile for moving the lower part of the support pile into the ground or the seabed via suction.

156. A support assembly for supporting a top structure above the ground or a seabed, the support assembly comprising:

a support structure according to claim **144**, and

a plurality of foundation piles, wherein each foundation pile extends through a respective foundation guide and is configured and intended to extend at least partly into the ground or the seabed over a foundation depth for providing resistance against overturning of the support pile.

157. The support assembly according to claim **156**, wherein the top structure is a wind turbine.

158. The support assembly according to claim **156**, wherein the foundation pile comprises at least one helix at a lower end thereof extending around the outer surface, wherein the foundation pile is configured to be rotated about its longitudinal axis during installation into the ground or the seabed.

159. A method for installing the support assembly according to claim **156** into the ground or a seabed, the method comprising the steps of:

positioning the single support pile with its bottom end on the ground or the seabed and moving a part of the lower part of the support pile into the ground or the seabed, and

positioning the foundation piles in the foundation guides and moving the foundation piles at least partly into the ground or the seabed over the foundation depth.

160. The method according to claim **159**, wherein the foundation guides and foundation piles are installed first, wherein after the foundation guides and foundation piles are installed the support pile is lowered to the seabed and installed.

161. The method according to claim **159**, wherein the foundation piles are moved into the ground or the seabed by an installation device, wherein the installation device comprises:

a bridge assembly which when seen in top view defines a plurality of connecting locations corresponding to the plurality of foundation piles, and a plurality of pile connection assemblies via which in use each foundation pile is connected to the bridge assembly, wherein each pile connection assembly comprises:

a pile connector wherein each pile connector is configured to be connected to an upper part of each foundation pile which is to be moved into the ground or seabed,

wherein at least a plurality of the pile connection assemblies comprise an actuator which extends downward from the respective connecting location, wherein each actuator comprises an upper actuator part and a lower actuator part, wherein the upper actuator part is connected to the bridge assembly, wherein the lower actuator part is connected to a corresponding pile connector.

162. The method according to claim **161**, wherein the bridge assembly comprises a central opening through which the support pile extends, and wherein the installation device moves downward relative to the support pile during installation of the foundation piles.

163. The method according to claim **159**, wherein the foundation piles extend through the foundation guides during the lowering and positioning of the support assembly.

* * * * *