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**METHOD FOR VIBRATION DRIVING AND VIBRATION DRIVING ASSEMBLY**

The invention relates to a method for vibration driving of driveable elements into a footing, wherein high-frequency vibrations are introduced via the driveable element into the footing before a profile foot by means of a vibration device mounted on the driveable element, so that the footing before the profile foot is liquefied, whereby the driveable element is driven into the ground due its own weight and the weight of the vibration device.

Driveable elements in the form of piles, sheet piles, or other profiles can be driven into a footing by impact drivers or by vibration drivers. In contrast to vibration drivers, axially directed impulses are introduced over the driveable element in the footing with impact drivers. The insertion of driveable elements with the impact driver thus entails significant disadvantages, particularly in terms of environmental compatibility. The impact drivers introduce considerable tremors into the ground, so that the impact drivers are accompanied by an intense noise generation of up to 180 dB. Compared with the impact drivers, the vibration technology has advantages, for example, that are to be seen in that the excitation frequency of vibration drivers changes and so the specific geological and building dynamics requirements can be accommodated, which allows installation of foundations using vibration that is considerably more environmentally friendly in many cases.

Particularly in the production of offshore foundations, the impact driving of piles for what are termed monopiles, jackets, or other types of foundations is not uncontroversial, as the noise emissions during impact driving are substantially detrimental to marine mammals.

For an optimum establishment of a foundation, it is of particular importance to be able to measure the load capacity of the foundation accurately. This routinely presents difficulties with vibration-driven piles. Under certain conditions, vibration-driven piles can exhibit lower lateral load capacity compared to those driven by impact drivers. It is therefore known for piles or other foundation profiles to be vibration-driven for the first portion and then in addition driven by an impact driver for the last portion of their clamping length. For this purpose, it is necessary to provide both a vibration device and an impact driving rig on site. The accompanying set-up effort is disproportionate.

The expense associated with the transfer of the device makes the use of vibration driving uneconomical, particularly for large piles such as in the establishment of offshore wind turbines.

When inserting a driveable element into a footing by means of vibration driving, the vibration process can be interrupted by deactivating the vibration device. Continuation of the vibration process requires the reactivation of the vibration device. Due to the partial clamping of the pile by the footing, however, the vibration behaviour of the driveable element changes so that a further sinking of the driveable element by means of vibration drivers becomes difficult.

DE 1191755 B relates to a device for the driving of piles, tubes, sheet piles, or the like, with a vibration generator to which either a bundle of load plates or even a liquid tank is attached via an elastic connection.

The invention therefore has the object of providing a method for the vibration driving of piles into a footing, which enables an improved, discontinuous vibration driving of driveable elements into a footing. The present invention also has the object of providing a method for the vibration driving of driveable elements into a footing through the use of which an increased lateral load capacity in the driveable element can be achieved.

The present invention achieves this object through a method having the features of claim 1. Advantageous embodiments of the method are described in the dependent claims that refer to claim 1.

The present invention furthermore seeks to provide a vibration assembly by means of which an improved discontinuous vibration driving of driveable elements into a footing is enabled. This object is achieved through a vibration assembly with the features of claim 12. Advantageous embodiments of the method are described in the dependent claims that refer to claim 12.

More specifically, the object of the invention is achieved by a method for the vibration driving of a driveable element into a footing with the introduction of high-frequency vibrations, which are generated by a vibration device attached to the driveable element, via the driveable element in the footing before the profile foot of the driveable element under at least partial liquefaction of the footing before the profile foot, wherein the method is characterised in that a mass of the vibration device

and/or the driveable element is varied during the insertion of the driveable element into the footing.

By varying the mass of the vibrating device and/or the driveable element, the vibration behaviour of the driveable element is changed. Furthermore, by varying  
5 the mass and thus the weight force of the driveable element acting on the footing, the penetration rate of the driveable element into the footing can be adapted to the given requirements. Consequently, through reactivation of the vibration process after the vibration device was temporarily deactivated, it is possible to simplify the reinitiation of the penetration process of the driveable element into the footing by  
10 means of vibration driving. Changed vibration conditions for the driveable element must be taken into account when the mass of the vibrating device and/or the driveable element is varied. Further, the skin friction of the driveable element in the footing and the tip resistance of the driveable element can be overcome more easily. Since the penetration rate of the driveable element in the footing is also varied  
15 through variation of the mass of the driveable element and/or the vibration device, a lateral load capacity of the driveable element inserted into the footing can also be increased.

The method for vibration driving of driveable elements in a footing thus comprises the following vibration steps: Attaching a vibration device to the driveable element,  
20 positioning the driveable element on the footing, and activating the vibration device so that high-frequency vibrations are introduced via the driveable element in the footing from a profile foot of the driveable element under at least partial liquefaction of the footing before the profile foot, wherein a mass of the vibration device and/or the driveable element is varied during the insertion of the driveable element into the  
25 footing.

The vibration device can also be referred to as vibrator or vibration hammer. The driveable element can be in the form of sheet piling, sheet profiles, in the form of piles, in particular foundation piles for example monopiles or, for example, in the form of any desired profile designs.

30 High-frequency vibrations in the sense of the present invention are to be understood as vibrations that are suitable for propagation in the footing so as to overcome both the skin friction and the tip resistance to the soil of the driveable element inserted

into the footing, with the soil before the profile foot becoming quasi-liquefied, whereby the driveable element can penetrate into the footing by virtue of its weight force.

Although the term "vibration drivers" is used in the following, the insertion process  
5 is realised without the impact-based driving of the profile that is usual for impact drivers.

An high-frequency oscillation in the context of the present invention is to be understood as, for example, a vibration within a frequency band of approx. 5 Hz to 150 Hz, preferably 10 Hz to 50 Hz.

10 A profile foot in the context of the invention is to be understood as the leading end of the driveable element to be inserted into the footing.

A footing in the sense of the present invention is envisioned to be essentially sedimentary subsoil, either onshore or offshore.

The method fundamentally doesn't differentiate between an onshore footing and an  
15 offshore footing.

According to a preferred embodiment of the method, the mass of the vibration device and/or the driveable element is increased during the penetration into the footing.

The extra weight can be, for example, a steel weight, a concrete weight, or a ballast  
20 tank, the additional weight being attached either to the vibration device and/or the driveable element.

The penetration process of the driveable element into the footing is to be understood as the process in which the driveable element is inserted into the footing to the intended final depth. This penetration process can of course be interrupted. During  
25 these interruptions, in which the vibration device is deactivated, the mass of the vibration device and/or the driveable element can be increased by mounting at least one additional weight to either the vibration device and/or the driveable element.

According to a further preferred embodiment, the mass of the vibrating device and/or the driveable element is reduced during the insertion of the driveable element.

30 For example, the mass of the vibration device and/or the driveable element is first increased, whereupon the mass of the vibration device and/or the driveable element is reduced. This can be realised, for example, by mounting a ballast tank that is filled

with liquid or pourable ballast, for example, in the form of sand or water, on the vibration device and/or the driveable element. During vibration device activation, the ballast can be discharged from the ballast tank, whereby while a vibration device is activated, the mass of the driveable element and/or the vibration device is also reduced.

By reducing the mass of the vibration device and/or the driveable element, in particular, the penetration rate of the driveable element into the footing is changed, in particular decreased. Due to a decreased penetration rate of the driveable element into the footing, the lateral load capacity of the driveable element is increased.

Preferably, the mass of the vibration device and/or the driveable element is reduced such that a reduction in the penetration rate of the driveable element is achieved. As already mentioned above, a reduced penetration rate of the driveable element into the footing leads to an increased lateral load capacity of the driveable element in the footing.

The variation of the mass of the vibration device and/or the driveable element is preferably realised after a deactivation of the vibration device and before a reactivation of the vibration device. As already mentioned above, particularly an increase in the mass of the vibration device and/or the driveable element is realised during a vibration pause, for example, by mounting an additional weight to the driveable element and/or the vibration device. In the event that a ballast tank is attached to the vibration device and/or to the driveable element, the mass can be realised by filling the ballast tank with ballast.

As already mentioned above, a reduction in the mass of the vibration device and/or the driveable element is preferably realised with an activated vibration device.

In particular, the resonance frequency can be influenced by a reduction in the mass of the vibration device and/or the driveable element, so that by reducing the corresponding mass, the penetration rate of the driveable element into the footing can be specifically varied, in particular can be reduced.

As already mentioned at the outset, an increase in the mass of the vibration device and/or the driveable element is preferably realised by mounting an additional weight on the vibration device and/or the driveable element. The additional weight can be

embodied as steel weight, concrete weight, or as a ballast tank, wherein pourable or liquid material, in particular sand or water, can be filled into the ballast tank.

In the event that a ballast tank is attached to the vibration device and/or the driveable element, a reduction in the mass of the vibration device and/or the driveable element is preferably realised by discharging ballast from the ballast tank with an activated vibration device. Thus, the penetration rate of the driveable element into the footing can be changed dynamically.

According to a preferred embodiment of the method according to the invention, an additional weight is elastically connected to the vibration device.

10 A vibrational excitation of the additional weight(s) is realised with an activated vibration device due to the elastic attachment, so that in addition to its excitation function the vibration device itself acts as a type of high-frequency hammer. In the elastic coupling of the vibration device and the additional weight, the additional weight can be provided in a variable manner over time, i.e., the mass of the  
15 additional weight varies over time, whereby a dynamic amplification and a dynamic adjustment of the frequency, more specifically the excitation frequency, is achieved. Due to the elastic coupling of the additional weight with the vibration device, the additional weight relating to the vibration device can oscillate at a beat frequency that results from the excitation frequency of the vibration device, the mass of the  
20 additional weight, and a spring constant, wherein the spring constant results from the elastic connection of the additional weight to the vibration device.

Preferably, the method according to the invention comprises a process step of depositing water in the region of the profile foot of the driveable element. An injection line, which is driven into the footing together with the profile foot of the driveable  
25 element, can be provided for this purpose. By means of a corresponding method, the penetration rate of the driveable element into the footing can be increased.

Preferably, a vibration frequency of the vibration device during the vibration process is varied within a given liquefaction frequency band of the footing. Thus, the variation of the vibration frequency is preferably done such that a targeted change in the  
30 penetration rate of the profile is caused by the frequency change.

Here, it is envisioned according to the invention that either specifically the penetration rate of the driveable element into the footing and/or the frequency is

varied such that a soil stabilisation or soil compaction is achieved during insertion of the driveable element or upon reaching the predetermined final depth of the driveable element to increase the lateral load capacity of the inserted driveable element.

- 5 As already mentioned at the outset, the method differs fundamentally from that of what are termed impact drivers in that the vibration device is positively connected to a driveable element head and no impact pulses are introduced via the driveable element into the footing.

The targeted change in the vibration frequency is realised according to the invention  
10 in addition to the necessary frequency change, which is indispensable in each vibrating operation to start up and again shut down the vibration device. Such a frequency change that is necessary for starting and stopping the vibration operation is not to be understood as a variation of the vibration frequency in the sense of the present invention.

- 15 As mentioned at the outset, the invention is sometimes based on the recognition that for the subsequent load capacity of vibration-driven driveable element, the choice of the penetration progress during insertion as well as of the vibration frequency for a given penetration progress is crucial. The choice of an high penetration rate for the driveable element is, under certain circumstances,  
20 accompanied by a decreased final load capacity of the driveable element. Finally, the invention also based on the recognition that a vibration without significant penetration progress likewise contributes significantly to an increase in the load capacity of the driveable element.

Basically, the penetration rate can be adjusted via the frequency of the vibrator as  
25 well as on the effective weight force of the driveable element and the vibration device. The effective weight force of the driveable element and the vibration device can additionally be influenced by the load on a crane or other lifting equipment.

The influence of the weight force of the driveable element effect and the vibration device can thus also be realised via a load variation from a crane or other lifting  
30 equipment.

The effective weight force of the driveable element according to the invention is to be understood as the proportion of the weight force which is brought to bear on the footing via the profile foot and the skin friction of the driveable element.

The object on which the present invention is based is further achieved through a vibration assembly comprising a vibration device that is attachable or attached to a driveable element, wherein the vibration assembly further comprises at least one additional weight that can be attached to the vibration device and/or to the driveable element.

The connection of the additional weight to the vibration device and/or the driveable element is preferably embodied to be elastic. A corresponding elastic connection can in particular be realised via springs embodied to be correspondingly stable.

The vibration driver will be explained below with reference to the accompanying figure, as shown below:

Figure 1            A schematic view of a driveable element fitted with a vibration device that is suspended from a crane, said element being driven into a footing.

In figure 1 can be seen the design of a vibration driver assembly according to the invention. The vibration driver assembly has an hydraulic assembly 14 and a vibration device 10 which is connected to an hydraulic pump 16 of the hydraulic assembly 14 by means of hydraulic hoses 17. The hydraulic assembly 14 further comprises an internal combustion engine 15 that is embodied for driving the hydraulic pump 16. At least one hydraulic motor 11 is arranged in the vibration device 10 and is embodied for driving the unbalanced masses 12. Axial vibrations in a driveable element 1 embodied as profile 1 are introduced by counter-rotating unbalanced masses 12, wherein the driveable element 1 is connected with the vibration device 10 by means of a clamping device 13. From figure 1 can also be seen that the vibration device 10 including the attached driveable element 1 is attached to a crane 6, so that a weight force acting on a profile foot 3 of the driveable element 1 can be influenced by a corresponding support jib on the crane 6.

In the illustrated exemplary embodiment, the vibration device is 10 hydraulically driven. However, the present invention is not limited to an hydraulic driving of the vibration device 10 because the unbalanced masses 12 of the vibration assembly

10 can also be driven electrically. There is no limitation with regard to the driving of the unbalanced masses 12.

As already mentioned at the outset, vibration device 10 is clamped on a piling head 4 of the driveable element 1 by means of the clamping device 13, thus positively  
5 attached thereto and comprising a drive in the form of the hydraulic motor 11 and a spring-mass system in the form of the unbalanced masses 12 via which the profile 1 or the profile head 4 is set into a vertically oscillating movement, so that a standing wave propagates in the profile 1. Some of this vibrational energy introduced into the profile 1 is consumed by the skin friction of the profile 1 penetrating the footing 2. A  
10 part of the vibrational energy that becomes the vibrational energy arriving at the profile foot 3 that is needed to overcome the tip resistance of the profile 1 during the penetration into the footing 2, which ultimately causes the penetration of the profile 1 into the footing 2.

The vibrations introduced via the vibration device 10 propagate through the profile  
15 1 from the profile head 4 over the length of the profile 1 to the profile foot 3 and into the footing 2, so that the footing 2 below or before the profile foot 3 is liquefied and the skin friction of the clamping length of the profile 1 inserted into the footing is overcome, so that the profile 1 penetrates into the footing 2 by virtue of its weight force when the load on the crane 6 is adjusted accordingly.

20 It is envisioned according to the invention that a mass of the vibration device 10 and/or the driveable element 1 is varied during the insertion or penetration of the driveable element into the footing. For this purpose, the vibration arrangement in the illustrated embodiment has two additional weights 20, which are elastically attached to the vibration device 10. The connection between the additional weights 20 and  
25 the vibration device is thus realised via a spring connection 21.

However, although not shown in the figure, it is also possible that the additional weight(s) 20 is/are rigidly connected with the vibration device 10.

Due to the elastic attachment of additional weights 20 with the vibration device 10, a vibrational excitation of the additional weight(s) 20 is realised with an activated  
30 vibration device 10, so that in addition to its excitation function the vibration device 10 itself acts as a type of high-frequency hammer. Because the additional weights 20 vibrate at a beat frequency relating to the vibration device 10, wherein the beat

frequency results from the excitation frequency determined by the rotational speed of the unbalanced masses 12, the mass of the additional weights 20, and the spring force depending on the spring connection 21 between the additional weights 20 and the vibration device 10.

- 5 It is further envisioned according to the invention that the vibration frequency of the vibration device 10 as excitation frequency varies over the insertion length up to the final depth of the profile 2 and possibly beyond in a redensification phase.

The vibration frequency of the vibration device 10 can be varied over a frequency range of between 5 Hz to 150 Hz, preferably between 10 Hz to 50 Hz, during the  
10 vibration operation within a given liquefaction frequency band of the footing 2 so that, for example, a targeted change in the penetration rate of the profile 1 can be achieved by changing the frequency within this frequency band in the range between 5 Hz and 150 Hz.

A change in the penetration rate of the profile 1 can alternatively be achieved  
15 whereby the frequency is selected within the frequency band between 5 and 150 Hz, preferably between 10 Hz and 50 Hz, so that a lowest possible penetration rate of the profile 1 is achieved, so that the profile 1 just barely penetrates into the footing 2 by virtue its weight force and the weight force of the mounted vibration device 10.

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Reference symbol list

|    |    |                                                                   |
|----|----|-------------------------------------------------------------------|
|    | 1  | Driveable element / Profile                                       |
|    | 2  | Footing                                                           |
| 5  | 3  | Profile foot                                                      |
|    | 4  | Profile head                                                      |
|    | 5  | Vibration driver                                                  |
|    | 6  | Crane                                                             |
|    | 10 | Vibration device / Vibration driver / Vibration hammer / Vibrator |
| 10 | 11 | Hydraulic motor (of the vibration device)                         |
|    | 12 | Unbalanced mass (of the vibration device)                         |
|    | 13 | Clamping device                                                   |
|    | 14 | Hydraulic assembly                                                |
|    | 15 | Internal combustion engine                                        |
| 15 | 16 | Hydraulic pump                                                    |
|    | 17 | Hydraulic hoses                                                   |
|    | 20 | Supplementary weight                                              |
|    | 21 | Spring connection / elastic connection                            |

## FREMGANGSMÅDE TIL VIBRATIONS RAMNING OG VIBRATIONS RAMNINGS- ANORDNING

### PATENTKRAV

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1. Fremgangsmåde til vibrationsramning af et drivbart element (1) ned i en underbund (2) under indførelse af højfrekvente vibrationer, som genereres ved hjælp af en vibrationsanordning (10), der er fastgjort til det drivbare element (1), ved hjælp af hvilken fremgangsmåde det drivbare element (1) i underbunden (2) foran en profilfod (3) på det drivbare element (1) med mindst delvis likvefaktion af underbunden (2) foran 10 profilfoden (3), hvor en masse af vibrationsanordningen (10) og/eller af det drivbare element (1) varieres under indbringelsen af det drivbare element (1) i underbunden (2), **kendetegnet ved, at** en vibrationsfrekvens af vibrationsanordningen (10) under vibrationsprocessen varieres inden for et givet likvefaktionsfrekvensbånd af 15 underbunden (2).
2. Fremgangsmåde ifølge krav 1, **kendetegnet ved, at** vibrationsanordningens (10) masse og/eller det drivbare elements (1) masse forøges under indbringningen.
3. Fremgangsmåde ifølge et af de foregående krav, **kendetegnet ved, at** vibrationsanordningens (10) masse og/eller det drivbare elements (1) masse 20 formindskes under indbringelsen af det drivbare element (1).
4. Fremgangsmåde ifølge krav 3, **kendetegnet ved, at** vibrationsanordningens (10) masse og/eller det drivbare elements (1) masse formindskes på en sådan måde, der opnås en formindskelse af det drivbare elements (1) indbringningshastighed.
5. Fremgangsmåde ifølge et af de foregående krav, **kendetegnet ved, at** 25 variationen af vibrationsanordningens (10) masse og/eller det drivbare elements (1) masse sker efter en deaktivering af vibrationsanordningen (10) og før en genaktivering af vibrationsanordningen (10).
6. Fremgangsmåde ifølge et af kravene 4 eller 5, **kendetegnet ved, at** der sker en formindskelse af vibrationsanordningens (10) masse og/eller det drivbare elements (1) 30 masse ved aktiveret vibrationsanordning (10).

7. Fremgangsmåde ifølge et af de foregående krav, **kendetegnet ved, at** der sker en forøgelse af massen via en anbringelse af en ekstravægt (20) på vibrationsanordningen (10) og/eller på det drivbare element (1).
8. Fremgangsmåde ifølge et af de foregående krav, hvis nævnte krav afhænger af  
5 krav 3, **kendetegnet ved, at** der fastgøres en ballasttank på vibrationsanordningen (10) og/eller på det drivbare element (1), hvorved der sker en formindskelse af vibrationsanordningens (10) masse via aftapning af ballast fra ballasttanken ved aktiveret vibrationsanordning (10).
9. Fremgangsmåde ifølge et af de foregående krav, **kendetegnet ved, at** en  
10 ekstravægt er fastgjort elastisk på vibrationsanordningen (10).
10. Fremgangsmåde ifølge et af de foregående krav, **kendetegnet ved, at** der deponeres en fluid, navnlig vand, i området med profilfoden (3).

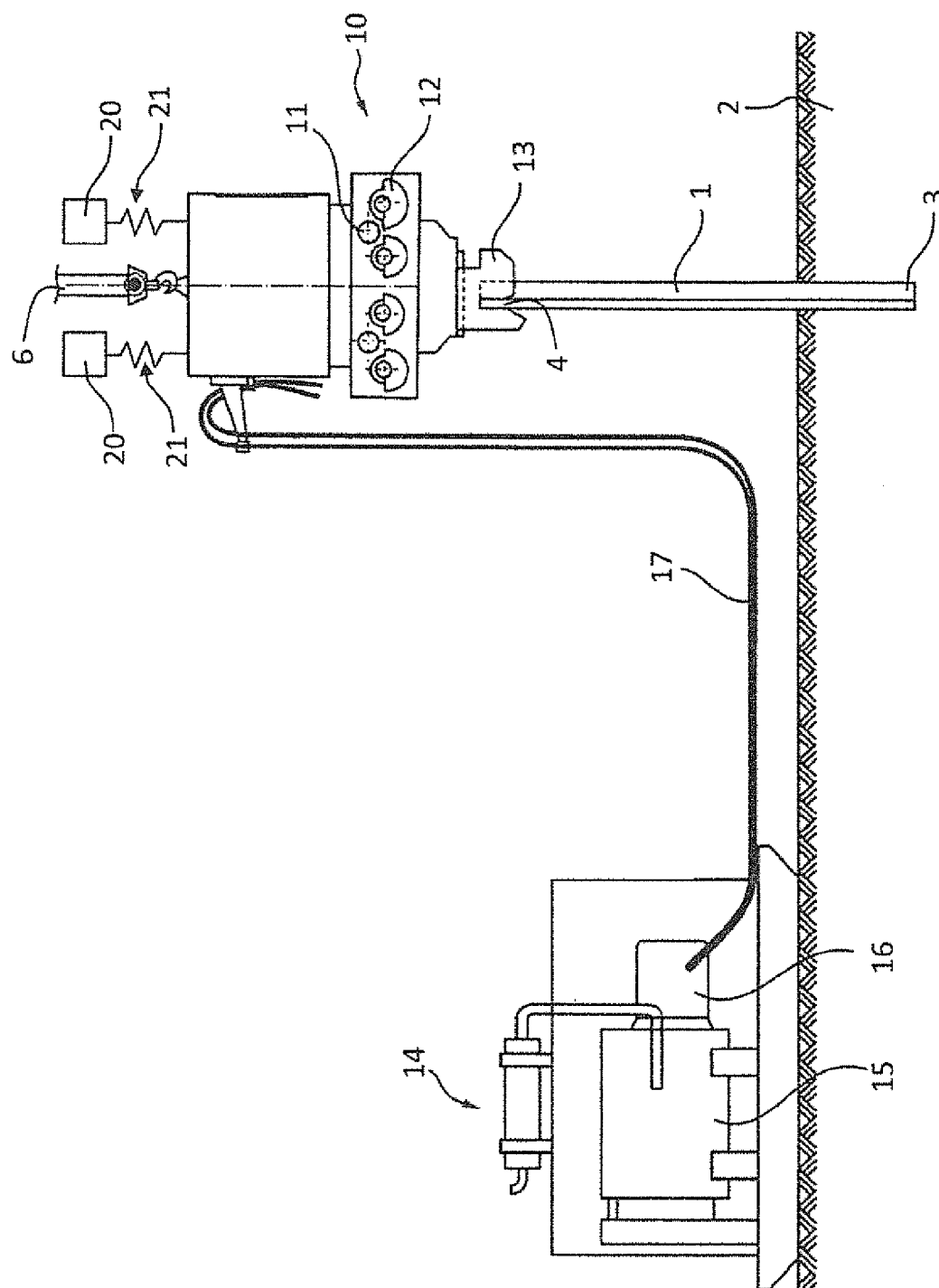


Fig. 1