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Description

TECHNICAL FIELD

[0001] The present disclosure relates to compensation of variations in movement and/or force of a load, in particular of a load suspended from a movable or moving hoisting system, such as in floating vessels.

BACKGROUND

[0002] Heave compensation systems for hoisting systems that are moving, e.g. being located on a moving object are well known and they may be divided in two general types: passive heave compensation relying on spring devices, which may provide energy dissipation, and active heave compensation relying on measurements, active feedback and operating units.

[0003] In some cases, passive and active heave compensation are combined. Such combinations may be divided in three general types.

[0004] A first type causes or affects movement of (part of) the hoisting device, e.g. see EP 228050 and WO 2012/039623. This, however complicates construction of the hoisting system and it can transform heave motion in vertical direction into motion in a lateral direction.

[0005] A second type combines passive and active actuation of hydraulic systems, e.g. see US 3912227, US 4121806, US 4215851, WO 2004/067435, DE 102005058952, WO 2007/145503, EP 2029423, WO 2012/161565, CN 202429940 U, CN 102556875. Such systems tend to be complex and require strong hydraulic pumps and/or bulky conduits and reservoirs for the hydraulic fluid. Further, the effective achievable stroke of such systems is determined by the length of the hydraulic cylinders.

[0006] A third type comprises systems wherein the effective length of the hoisting cable is adjusted by reeling in and/or paying out the hoisting cable, e.g. see WO 83/03815, US 6595494, US 2005/0179021, WO 2008/022125, US 7798471, WO 2009/120062, US 2009/0232625, WO 2009/036456, US 8297597, WO 2011/034422, CN 101948002, CN 102398856, WO 2012/112039, CN 202499677 U, CN 202643158 U, CN 202829415 U. This accelerates wear of the hoisting cable and it requires strong engines to manipulate the cable, in particular cables under full load, thus being bulky and consuming significant power.

[0007] Improvements in heave compensation are therefore desired.

[0008] For completeness, further reference is made to WO 2011/152711, disclosing a marine load raising and lowering system, to CN 101948002, disclosing a combined type heave compensating device, to WO 2011/034422, disclosing a multi-purpose hoisting device, and to WO 2013/070080, disclosing a vessel and crane with full dynamic compensation for vessel and wave motions and a control method thereof.

SUMMARY

[0009] Herewith, a method and an apparatus according to the appended claims are provided.

[0010] In an aspect a method for compensation movements and/or force variations of a load is provided, in particular of a load suspended from a movable or moving structure, more in particular a load suspended from a floating vessel, comprising the steps of:

connecting a first hoisting cable and a second hoisting cable with the load in parallel;
suspending the load from the first and second hoisting cables, wherein the first hoisting cable exerts a first lifting force on the load including a spring force, and wherein the second hoisting cable exerts a second lifting force on the load;
wherein the method comprises the step of controlling a position and/or movement of the load by compensating, in particular reducing, at least part of the spring force by adjusting the second lifting force and/or a length of the second hoisting cable.

[0011] Thus, the spring excursion amplitude, and therewith the position of the load with respect to the first hoisting cable, in particular with respect to the movable or moving structure, is adjustable by adjustment of the second cable providing adjustment of the second lifting force and/or length of the second hoisting cable, in particular by adjustment thereof with respect to the first lifting force. This increases control over the position and/or movement of the suspended load and reaction forces on the lifting cables and associated apparel caused by such movement. By connecting a first hoisting cable and a second hoisting cable with the load in parallel, active heave compensation and passive heave compensation systems are provided in parallel rather than in series as in common systems and a more accurate and/or faster control over the position and/or movement of the load can be effected.

[0012] By performing passive heave compensation and active heave compensation in parallel and with different cables, the active heave compensation needs to accommodate only part of the load weight, with the passive heave compensation accounting for another portion of the load weight; in order to compensate part of the spring force, or rather to compensate motion of the first lifting cable such as by movement of the structure from which the load is suspended, the second lifting force may be only a small fraction of the first lifting force. As an example, for lifting the suspended load from a stationary position in which the load is in an equilibrium position with respect to the first hoisting cable, wherein the spring force counteracts gravity on the load, the second lifting force need not (be sufficient to) carry the full weight of the load for raising the load from the stationary position; the bulk being supported by the first hoisting cable with the associated spring force. Thus the second lifting force

need only be a small fraction of the first lifting force to provide still a significant deviation from the equilibrium position and affect the position of the load with respect to the structure from which the load is suspended by the first and second lifting cables. Hence, the method facilitates accurate and detailed control over the position of a heavy load with comparatively small adjustment forces. Adjustment of the position of the load by adjustment of the first lifting force is possible, in which case both lifting forces may be adjusted together.

[0013] In the method, the tension force in the second hoisting cable is varied by varying the length of the second hoisting cable, which therefore automatically transfers load to/from the first hoisting cable from/to the second hoisting cable. Typically, the second lifting force may be less than about 25% of the first lifting force, in particular less than about 15% such as less than about 10%, e.g. about 5% of the first lifting force.

[0014] The present method obviates active heave compensation methods acting on a single hoisting cable (main hoisting cable) which generally is heavy, relatively stiff and moreover, bears all the weight of the load. Compared to such single cable systems, the present method allows active heave compensation with a comparatively much smaller and lighter-weight system, and the first cable can be adjusted under less than full load. It therefore suffers less wear than an actively adjusted hoisting cable. Further, the first cable may have a smaller cable diameter reducing wear when travelling over sheaves with a reasonable diameter.

[0015] Advantageously, the step of controlling a position and/or movement of the load by compensating at least part of the spring force by adjusting the second lifting force and/or a length of the second hoisting cable comprises adjusting a hoisting length of the second hoisting cable as a function of a variation in a hoisting length of the first cable, e.g. by taking in or paying out cable length together in different rates. In the present context, a hoisting length refers to the effective distance along the cable that an object can be displaced with the cable, e.g. a (free) hanging section of a crane cable. In case part of the cable would run forth and back plural times between the load and the object as in a sheaving system, the hoisting length is accordingly less than the actual length of cable involved.

[0016] The sum of both the first and second lifting forces may be kept substantially constant so as not to accelerate the load and maintain a predetermined position of the load. Note that the first and second lifting forces may be controlled based on monitoring tension forces in the respective cables, e.g. via one or more force feedback systems in a winch, and/or based on monitoring (variations in) the actual position and/or movement of the load.

[0017] Within this text, the word "cable" refers to any form of a suitable flexible thin elongated component that can carry sufficient load for carrying out the required respective part of the method such as a rope, wire, cord, wire bundle, fibre rope, ribbon, chain, tether (e.g. steel

rod tether) and/or combinations thereof. The spring force may be provided by one or more of a pneumatic system, a pneumohydraulic system, a hydraulic system, a constant tension winch, a mechanical spring system e.g. having a reversibly deformable portion, and the like, which may at least partly be configured to provide a generally relatively low spring stiffness. The spring force may also be derived from elastic deformation of (at least part of) the first hoisting cable itself. A constant tension winch as referred to above can control the tension in a line run off the winch; it is used to achieve a constant line-pull set by an operator, e.g. a pneumatically and/or hydraulically controlled tension winch. The line-pull can be measured by a sensor, e.g. a load cell, and monitored by a control system. If the actual value of the line-pull differs from a pre-set value the winch will pay in or pay out the line to maintain the pre-set value. Adjustment of the cable tension may be possible by changing the tension set point value, e.g. by setting a constant reference pressure in the pneumatic and/or hydraulic system.

[0018] In an embodiment, the step of controlling a position and/or movement of the load comprises varying the second lifting force and/or a length of the second hoisting cable as a function of at least one of a position and a movement of the suspended load with respect to a reference, in particular as a function of a deviation from the reference.

[0019] Thus, the second lifting force allows active control of the position, force and/or movement of the load with respect to the reference, e.g. for active heave compensation against motion of a support and maintaining the load stationary with respect to the earth or a moving vessel. Note that (the spring force of) the first lifting force provides passive compensation of the force and/or movement of the load, e.g. for passive heave compensation. In the present method, active and passive heave compensation are arranged in parallel, rather than in series. The system is readily adjustable by direct control over the second cable within the maximum amplitude of the spring excursion without the need to adjust the first cable.

[0020] In an embodiment, the reference comprises at least one of a stationary point on the earth, a position of the load, a movement of the load, a tension force of the first hoisting cable, a spring force of the first hoisting cable, a spring excursion, the first lifting force of the first hoisting cable, the second lifting force and/or a tension force of the second hoisting cable. The reference position and/or movement of the load may (also) comprise one or more intended positions and/or movements of the load. The position and/or movement of the load may be predetermined with respect to at least part of a remote stationary or moving object, e.g. a target position on a quay or aboard a floating vessel or a part of the hoisting system itself in particular a point on a (vessel's) crane such as the crane tip.

[0021] Depending on the reference, this facilitates correcting the position and/or movement of the load for manoeuvring the load and/or placing a load in a desired

position, reducing force variations on the first and/or the second hoisting cable and/or associated equipment. An important purpose of the active heave compensation is to minimise relative motions between a hoisted object and a platform (foundation, moving vessel) the object is to land on, with as a final objective to reduce acceleration and impact on both the hoisted object and the platform. Note that plural references may be used either selectively, in succession and/or together, e.g. to define a bounded multidimensional parameter space in which the position and/or movement of the load is, should be and/or can be controlled.

[0022] The step of compensating at least part of the spring force by adjusting the second lifting force and/or a length of the second hoisting cable may be automated, e.g. comprising use of a sensor for sensing a position and/or movement of the load with respect to a reference, e.g. a suspending structure or a platform onto which the load is to be placed, and using a controller controlling at least one of a position and a movement of the suspended load based on one or more signals of the sensor. This allows executing the method generally faster and more reliably than with a human operator adjusting the second lifting force.

[0023] The method may comprise adjusting the first and second hoisting cables substantially simultaneously, e.g. paying out and/or taking in the respective cables. This facilitates controlled movement of the load. The adjustment of the first and second hoisting cables need not be at an equal rate or speed, so as to adjust the first and second lifting forces with respect to each other.

[0024] In an embodiment the spring force and/or the spring stiffness may be adjustable, e.g. in dependence of the lifting capacity of the second hoisting cable. Thus, the spring force and the second lifting force may be adjusted to the weight and/or other aspects of the load, e.g. size and shape of the load, deformability of (parts of) the load, drag on the load by air and/or water, etc.

[0025] In an embodiment, at least part of the load may be submerged in water, in particular sea water. Where applicable, the reference may comprise (part of) a sea bed and/or a structure on a sea bed. A (partly) submerged load experiences significant hydrodynamic forces such as drag and/or fluid inertia, commonly known as "added mass". Providing a spring force to the first hoisting cable provides passive heave compensation and can sometimes - depending on the shape etc. of the structure - effectively compensate for most wave motion, e.g. created, for instance, by roll, pitch, heave etc. of a vessel; the active heave compensation system as presently provided by the second hoisting cable allows to control (residual) movements and/or forces of the load with respect to moving water and/or a moving support structure, in particular a vessel on the water and conversely with respect to the (stationary) environment such as (structures on) the sea bed. The present method is particularly effective in air, where the effect of drag on the load and/or added mass inertia, and hence activation of the passive

heave compensator in the first hoisting wire, is minimal.

[0026] In an embodiment, the method comprises using two cables from one hoisting device, e.g. a crane or winch assembly, as first and second hoisting cables, respectively. Thus, one crane may carry most of the weight of the load with a first cable, e.g. the main hoisting cable, and compensate at least part of the spring force provided by (the heave compensation of) the main hoisting cable by employing an auxiliary cable of the same crane and adjusting the second lifting force provided by that auxiliary cable. This increases ease and/or reliability of manipulation of the first and second hoisting cables with respect to each other. Similarly, an assembly of two or more winches or a combination of one or more cranes and winches may be suitably employed, wherein the cranes and/or winches may be positioned on a single or on different hoisting structures. Note that commonly in cranes free portions of all hoisting cables generally hang from substantially equal positions, but this is not required. Further, both first and second hoisting cables may readily extend generally parallel to each other and engage the load close to each other, so that forces applied with one of the hoisting cables can relatively directly affect forces in the other one of the hoisting cables.

[0027] An embodiment comprises lifting the load with two or more hoisting systems, each hoisting system comprising at least a first and a second hoisting cable, respectively, and the method comprising connecting each of the respective first and a second hoisting cables to the load, and performing the method according to any one of the preceding claims with each of the hoisting systems connected to the load, wherein in particular at least one of the respective hoisting systems is operated in a slave mode to the another one of the respective hoisting systems. Thus, a large load may be hoisted with two or more cranes, each of which employing the method described herein. This facilitates manipulation of the load.

[0028] The method provided herewith may also facilitate supporting relatively heavy loads with relatively small or light-weight hoisting devices.

[0029] In accordance with the preceding, herewith an apparatus for performing the described method is provided. The apparatus, comprises a first hoisting cable and a second hoisting cable. The first hoisting cable is connectable to a load and the second hoisting cable is connectable to the load. The first hoisting cable is configured to provide, at least when connected with the load, a lifting force including a spring force, e.g. the first hoisting cable being elastic and/or operably connected with a spring device. The second hoisting cable, in particular the hoisting length and/or lifting force thereof, is adjustable relative to the first hoisting cable, at least when connected with the load for compensating at least part of the spring force by adjusting the second lifting force. The apparatus comprises a sensor configured to detect at least one of the position and/or movement of the load with respect to a reference and wherein the second cable is operably connected with a controller which in turn is

connected with the sensor and is configured to adjust the second hoisting cable in response to one or more signals from the sensor.

[0030] In particular, the first hoisting cable is connectable to the load in a first connection, and the second hoisting cable is connectable to the load in the first connection and/or a second connection near the first connection. Thus, the first and second cables engage the load close to each other and forces applied with one of the hoisting cables can relatively directly affect forces in the other one of the hoisting cables.

[0031] In particular, the reference may comprise at least one of the group comprising a predetermined position of the load, a movement of the load, a tension force of the first hoisting cable, a spring force of the first hoisting cable, the first lifting force of the first hoisting cable, the second lifting force and/or a tension force of the second hoisting cable and wherein in particular the position and/or movement of the load are predetermined with respect to at least part of a remote stationary or moving object, e.g. a target position on a floating vessel for placement of the load.

[0032] The apparatus may comprise one hoisting device, e.g. a crane, providing both the first and second hoisting cables. In particular the first cable may be a main hoisting cable and the second cable may be an auxiliary cable.

[0033] In an embodiment, the apparatus is configured for being itself at least partly suspended from a hoisting system, e.g. a crane, and in turn suspending the load with respect to a base, e.g. at least one of the first and second hoisting cables extending between the base and the load. In particular the apparatus and the load may be movably attached together to form an integrated assembly, wherein the apparatus may comprise a power source and/or a connection to an external power source such as a remote operated vehicle. Such apparatus can be used suspended from a hoisting cable and thus employed, which allows reaching great depths with the load while benefiting from the present concepts. A benefit from suspending the apparatus from a hoisting system instead of the other way around is that a more direct control over the position and/or movement of the load may be achieved if no cable is positioned between the compensation apparatus and the load.

[0034] The system may, e.g., be realised with (i) a main hoisting wire from above sea level to a first depth, say, 1,600 m deep. (ii) a beam complete with hoisting system at the first depth. (iii) the load being suspended beneath the beam with (iv) a main lift wire complete with passive heave compensation (forming the first hoisting cable) and (v) an additional lifting wire of which the length can be controlled (forming the second hoisting cable). Hence the beam is at the first depth and the load at a second depth, below the first depth, say, 1,620 m. Note that the first cable running between the beam and the load can be a, possibly passively heave compensated, fixed penant or hoisting wire with high stiffness.

[0035] In a further aspect, a vessel is provided comprising at least one apparatus as described herein. Such vessel exhibits improved heave compensation with respect to simplicity, costs and/or weight.

[0036] In a particular embodiment, the vessel comprises one or more, e.g. two, hoisting systems with first and second hoisting cables, e.g. cranes and wherein the vessel is configured to lift the load with two or more of the hoisting systems each performing the method as described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

[0037] The above-described aspects will hereafter be more explained with further details and benefits with reference to the drawings showing an embodiment by way of example.

Fig. 1 indicates an embodiment of an apparatus as provided herewith;
Figs. 2-5 indicate further embodiments.

DETAILED DESCRIPTION OF EMBODIMENTS

[0038] It is noted that the drawings are schematic, not necessarily to scale and that details that are not required for understanding the present invention may have been omitted. The terms "upward", "downward", "below", "above", and the like relate to the embodiments as oriented in the drawings, unless otherwise specified. Further, elements that are at least substantially identical or that perform an at least substantially identical function are denoted by the same number.

[0039] Fig. 1 indicates as an exemplary embodiment an offshore vessel 1 floating on a body of water W and being provided with a crane 3 having a mast 5 and a boom 7. A load 9 is suspended from (the boom 7 of) the crane 3 via a first hoisting cable 11 and a second hoisting cable 13. The load 9 may be placed on a target position on a fixed object 15 such as a platform fixed to the seabed. Note that in other cases the target position may be on a movable object, e.g. a floating vessel, and/or may be submerged.

[0040] In the shown configuration, the first hoisting cable 11, or main wire, has a connector 12 determining a first hoisting length L11 from the crane down. The first hoisting cable 11 is connected with the load 9 through a spring element 17 suspended from the main wire 11, and, here, a sling 19, together spanning a length LS. Thus, the load 9 is suspended from the crane boom 7 by a suspension length L9 ($L9 = L11 + LS$). The first hoisting length L11 is adjustable, e.g. by reeling in and/or paying out the cable 11 from a first winch 21.

[0041] The second hoisting cable 13, or auxiliary wire, is connected to the load 9 without intervening spring element and determines a second hoisting length L13 from the crane down. The second hoisting length L13 is adjustable, e.g. reeling in and/or paying out the cable 13

from a controllable second winch 23.

[0042] The second hoisting cable 13 may be connected with the load 9 at the same point(s) as the first hoisting cable 11 and any intervening structure (spring device, sling, etc.) or at one or more different connection points. The first and second hoisting cables 11, 13 may hang from the crane boom 7 at equal or different heights, e.g. using sheaves running on a common or on different axes. Thus, the suspension length L9 and the second hoisting length L13 may be equal or different.

[0043] The stiffness of the spring element, e.g. a spring constant, should be selected such that the load 9 is suspended within the dynamic range of the spring and the length LS is variable. Thus, the first hoisting cable 11 exerts a first lifting force on the load including a spring force due to the spring element 17 and the total suspension length L9 is variable while the first hoisting length L11 is constant. As a consequence, in absence of the second hoisting cable 13 or at least in absence of influence of the second hoisting cable 13, the load 9 may move up and down with respect to (the boom 7 of) the crane 3 without adjustment of the first hoisting cable 11. This provides passive heave compensation to the load 9 for movements of the vessel 1, in particular when the load 9 is submerged in the water W and subject to significant drag and "added mass". The spring stiffness determines the spring force on the load 9 and excursions of the load 9 from an initial position, i.e. the length LS and variations thereof. The possible length variation of LS (and hence L9) is determined by a maximum excursion amplitude allowed by the spring element 17.

[0044] As indicated, the spring element 17 typically may take the form of one or more hydraulic cylinder-piston assemblies coupled with an at least partly gas-filled volume 25. By adjusting the gas pressure in the volume 25, the pressure in the hydraulic assembly may be adjusted and an equilibrium piston position may be determined, and thus an equilibrium position of the load 9 with respect to the connector 12, such that equal up- and downward spring excursions SE and corresponding variations in LS are possible.

[0045] In case the first hoisting cable 11 would be directly connected to the load, the suspension length L9 and the first hoisting length L11 would be equal, e.g. in case the spring force would be derived from elasticity of the cable itself, from a constant tension winch and/or from a movable crane element.

[0046] According to the presently provided concepts, the second hoisting cable 13 is provided and connected with the load 9 in parallel to the first hoisting cable 11. By adjustment of (the hoisting length L13 of) the second hoisting cable 13, in particular pulling in the second hoisting cable 13, the second hoisting cable 13 may exert a lifting force on the load 9, taking over part of the weight of the load 9 from the first lifting cable 11 and the spring element 17, (partly) relaxing the spring element 17 and reducing the spring force and reducing the length LS. Thus, the spring force of the spring element 17, or rather

the spring force component of the first lifting force is at least partly compensated. By increasing or reducing the length L13, i.e. extending or retracting the second hoisting cable 13, the lengths L9 and LS may be varied separate from variations of the length L11. Since gravity and other forces acting on the load 9, e.g. accelerations due to wave motion, are supported primarily by the first hoisting cable 11 and the spring element 17, such variations of the length LS can be realised with a relatively small second hoisting force by the second hoisting cable 13, depending on the stiffness of the spring element 17.

[0047] Note that the second cable 13 may hang loose and inoperative if not required, therewith not affecting the passive heave compensation. Note further that the active heave compensation system provided by the second hoisting cable 13 in principle does not add mass to the total load suspended from the first hoisting cable 11.

[0048] A number of optional motion and/or position sensors 27, 29, 31, 33 are provided and (here: wirelessly) connected with a controller 35. Thus, the position and/or movement of (the hull of) the vessel 1, the (tip of the) crane boom 7, the load 9 and the platform 15 may be determined with respect to each other, and/or with respect to one or more particular sensors and thus may define one or more reference positions for positioning and/or moving the load 9. In particular, a separation S of the load 9 from (a target position on the object 15) may be determined and used for controlling a position and/or movement of the load 9, e.g. through comparison of the (relative) positions of the sensors 29 and 31, e.g. for smoothly placing or lifting the load 9 onto/from the platform 15. More, less and/or differently arranged and/or differently arranged and/or connected sensors may be provided, e.g. a sensor monitoring piston movements in a cylinder of a hydraulic spring element.

[0049] In this example, the controller 35 is connected to the second winch 23 and optionally to the first winch 21 so that, in response to one or more signals from one or more sensors 27-33 the position and/or movement of the load 9 may be automatically controlled by adjustment of the first and/or second winches 21, 23. E.g., placing the load 9 onto the (stationary) platform 15 with a moving floating vessel 1 may comprise lowering the load 9 by concurrent extension of the first and second hoisting cables 11, 13 but at different velocities, such that the second hoisting cable 13 exerts an increasing lifting force and compensates reducing variation in length LS. Thus, the effect of the extension of the first hoisting cable 11 is reduced by adjustment of the second hoisting cable 13 and the load 9 nears the platform 15 at lower velocity than by lowering the load 9 with the first hoisting cable 11 alone. The separation of the load 9 and the platform 15 may then be controlled to accurate degree by relative adjustment of the first and second hoisting cables 11, 13 by the controller 35 in dependence of signals from the sensors 29 and 31, e.g. providing separation data, and possibly from the sensor 27 providing data on movement of the hoisting structure 3. Upon contact of the load 9 with

the platform 15 the second hoisting cable 13 may quickly be extended relative to the first hoisting cable 11 and further wave motion of the vessel 1 and/or any deformation of the crane 5 may be compensated by the spring element 17 until the first hoisting cable 11 is also extended and the load 9 is securely placed.

[0050] Figs. 2-5 show further embodiments.

[0051] Fig. 2 shows an embodiment which may be understood as an inverse of the embodiment shown in Fig. 1: here, a crane 5 is arranged on a stationary object 15 such as a platform and provides the first and second hoisting cables 11, 13, for together hoisting a load 9 in accordance with the foregoing. The first hoisting cable 11 is provided with a spring element 17 and the second hoisting cable 13 is adjustable for compensating the spring force of the spring element 17. As indicated, the crane 5 can transfer the 9 load onto (or from) a vessel 1 floating on a body of water W, wherein adjustment of the first and second cables 11, 13 may be used to control the position and/or movement of the load 9 so as to compensate wave-induced motion of the vessel 1 according to the explanations supra. For a particularly smooth and shock-free transfer of the load 9, the vessel 1 and load 9 are provided with sensors 33, 29, respectively, connected with a controller 35 for controlling operation of the crane and adjustment of the first and second hoisting cables 11, 13, so that position and/or movement of the load 9 may be controlled with respect to the position and/or movement of (the sensor 33 of) the vessel 1, taking the latter as a reference rather than the stationary crane 5.

[0052] Fig. 3 indicates a vessel 1 with a first crane 5A and a second crane 5B. The first hoisting cable 11 connects the first crane 5A with the load 9 (which here is submerged in the body of water W) and the second hoisting cable 11 connects the second crane 5B with the load 9. Thus, the first and second hoisting cables 11, 13 may be adjusted independently. Such system may be preferred in case the first hoisting cable 11 is provided with a passive heave compensation system realised by deformation of at least part of the first crane 5A and / or cable 11. Further, such system facilitates modifying and/or retrofitting of an existing hoisting system with passive heave compensation. Instead of the first and/or second cranes 5A, 5B, one or more winches and/or capstans may be used.

[0053] Fig. 4 indicates a vessel 100 comprising two cranes 5M and 5S respectively, for dual crane operation wherein both cranes together hoist a load. Here, the load is suspended from each crane by respective first and second hoisting cables 11, 13. Thus, on each side of the load 9 engaged by the respective cranes 5M, 5S, passive and active heave compensation can be performed in parallel as explained hereinbefore by appropriately adjusting the respective first and/or second hoisting cables 11, 13 with respect to each other. For manipulating the load 9, one of the cranes, e.g. 5S, may be operated in slave-mode to the other crane 5M. This may entail master-slave

operation of the respective first hoisting cables 11 and controlled adjustment of the respective second cables 13 relative to the respective first cables 11 for heave compensation of the respective suspension lengths.

[0054] Fig. 5 indicates an embodiment of an apparatus 110 which is itself suspended from a crane 5 by a hoisting cable 111. The apparatus 110 comprises a base 50 and the load 9 is suspended from the base 50 by first and second hoisting cables 11, 13 extending from (a respective winch 21, 23 on) the base 50 to the load 9. Here, the first cable 11 is connected to a constant tension winch 21 with adjustable offset tension by an adjustable spring element 117. The second hoisting cable 13 is connected to a winch 23 which may be controlled to reel in or pay out the second hoisting cable 13 by a controller 135 on the basis of one or more signals from one or more sensors (not shown) on the load 9, the vessel 1, the base 50, the spring element 117 and/or a portion of the sea bed.

[0055] The invention is not restricted to the above described embodiments which can be varied in a number of ways within the scope of the claims. For instance it is also possible to have the load hanging from two cranes, each of which providing a respective "first hoisting cable" and to have one second hoisting cable to the load, in particular engaging the load at or near a position above the centre of gravity of the load, e.g. between the cranes. The second hoisting cable may run from one of the cranes or from another hoisting support e.g. a winch. This enables active heave compensation of the load in a dual crane operation with a simplified setup compared to Fig. 4.

[0056] The second lifting force may include a second spring force, e.g. with the method comprising providing the second hoisting cable with a second spring force, in particular being higher than (e.g. due to a stiffer spring) or at least distinct from the first spring force. Thus, the second hoisting cable may also be subject to passive compensation of forces and/or movements such as passive heave compensation. Such second spring force and/or its spring stiffness may be adjustable, e.g. in dependence of the lifting capacity of the second hoisting cable.

[0057] Existing hoisting systems may comprise plural hoisting cables; the present method can increase their operational flexibility for which (controllers of) such hoisting systems may be modified to provide an apparatus as provided herewith.

[0058] Various aspects of the presently provided method may be implemented as a program product for use with a computer system, in particular a computer system for controlling adjustment of the first and/or second cable(s) of an apparatus as described herein, where the program(s) of the program product define functions of the embodiments (including the methods described herein). In one embodiment, the program(s) can be contained on a variety of non-transitory computer-readable storage media, where, as used herein, the expression "non-transitory computer readable storage media" comprises all

computer-readable media, with the sole exception being a transitory, propagating signal. In another embodiment, the program(s) can be contained on a variety of transitory computer-readable storage media. Illustrative computer-readable storage media include, but are not limited to: (i) non-writable storage media (e.g., read-only memory devices within a computer such as CD-ROM disks readable by a CD-ROM drive, ROM chips or any type of solid-state nonvolatile semiconductor memory) on which information is permanently stored; and (ii) writable storage media (e.g., flash memory, floppy disks within a diskette drive or hard-disk drive or any type of solid-state random-access semiconductor memory) on which alterable information is stored.

[0059] Elements and aspects discussed for or in relation with a particular embodiment may be suitably combined with elements and aspects of other embodiments, unless explicitly stated otherwise.

Claims

1. A method for compensation of variations of movements and/or forces of a suspended load (9), in particular a load (9) suspended from a movable or moving structure (1), more in particular a load (9) suspended from a floating vessel (1), comprising the steps of:

connecting a first hoisting cable (11) and a second hoisting cable (13) with the load (9) in parallel;

suspending the load (9) from the first and second hoisting cables (11, 13), wherein the first hoisting cable (11) exerts a first lifting force on the load (9) including a spring force for passive heave compensation on the load (9) and wherein the second hoisting cable (13) exerts a second lifting force on the load (9) for active heave compensation on the load (9);

characterized in that the method comprises the step of active heave compensation on the load (9) by controlling a position and/or movement of the load (9) by compensating, in particular reducing, at least part of the passive heave compensation spring force by adjusting the second lifting force and/or a length of the second hoisting cable (13).

2. The method of claim 1, wherein the step of controlling a position and/or movement of the load (9) comprises varying the second lifting force and/or a length of the second hoisting cable (13) as a function of at least one of a position and a movement of the suspended load (9) with respect to a reference, in particular as a function of a deviation from the reference.
3. The method of claim 2, wherein the reference com-

prises at least one of the group comprising a stationary point on the earth, a position of the load (9), a movement of the load (9), a tension force of the first hoisting cable (11), a spring force of the first hoisting cable (11), a spring excursion, the first lifting force of the first hoisting cable (11), the second lifting force and/or a tension force of the second hoisting cable (13), and wherein in particular the position and/or movement of the load (9) are determined with respect to at least part of a remote stationary or moving object, e.g. a target position on a floating vessel (1) for placement of the load (9).

4. The method of any preceding claim, comprising adjusting the first and second hoisting cables (11, 13) substantially simultaneously, e.g. paying out and/or taking in the first and second cables (11, 13) together.

5. The method of any preceding claim, wherein the sum of the first and second lifting forces is substantially constant.

6. The method of any preceding claim, wherein the spring force and/or spring stiffness is adjustable, in particular in dependence of a lifting capacity of the second hoisting cable (13).

7. The method of any preceding claim, wherein at least part of the load (9) is submerged in water (W), in particular sea water (W), and wherein in case of a method of at least claim 2 or 3 the reference may comprise part of a sea bed and/or a structure on a sea bed.

8. The method of any preceding claim, wherein the method comprises using two cables (11, 13) from one hoisting device, e.g. a crane (3, 5, 5A, 5B) or a winch assembly (21, 23), as first and second hoisting cables (11, 13), respectively.

9. The method of any preceding claim, comprising lifting the load (9) with two or more hoisting systems, each hoisting system comprising at least a first and a second hoisting cable (11, 13), respectively, and the method comprising connecting each of the respective first and a second hoisting cables (11, 13) to the load (9), and performing the method according to any one of the preceding claims with each of the hoisting systems connected to the load (9), wherein at least one of the respective hoisting systems may be operated in a slave mode to another one of the respective hoisting systems.

10. An apparatus for performing the method of any preceding claim, comprising a first hoisting cable (11) and a second hoisting cable (13), the first hoisting cable (11) being connectable to a load (9) and the

second hoisting cable (13) being connectable to the load (9) in parallel,

wherein the first hoisting cable (11) is configured to provide, at least when connected with the load (9), a lifting force including a spring force for passive heave compensation on the load (9), e.g. the first hoisting cable (11) being elastic and/or operably connected with a spring device, and wherein the second hoisting cable (13), at least when connected with the load (9) in parallel with the first cable (11), is adjustable relative to the first hoisting cable (11) for active heave compensation on the load (9), and

characterized in that the apparatus comprises a sensor (27, 29, 31, 33) configured to detect at least one of the position and/or movement of the load (9) with respect to a reference and wherein the second cable (13) is operably connected with a controller (35) which in turn is connected with the sensor (27, 29, 31, 33) and is configured to adjust the second hoisting cable (13) in response to one or more signals from the sensor (27, 29, 31, 33) for compensating, in particular reducing, at least part of the passive heave compensation spring force of the first cable (11) for active heave compensation on the load (9).

11. The apparatus of claim 10, wherein the reference comprises at least one of the group comprising a predetermined position of the load (9), a movement of the load (9), a tension force of the first hoisting cable (11), a spring force of the first hoisting cable (11), the first lifting force of the first hoisting cable (11), and a tension force of the second hoisting cable (13).
12. The apparatus according to any one of claims 10-11, comprising one hoisting device (3, 5, 5A, 5B, 21, 23), e.g. a crane or a winch assembly, providing both the first and second hoisting cables (11, 13), wherein in particular the first cable (11) is a main hoisting cable and the second cable (13) is an auxiliary cable.
13. The apparatus according to any one of claims 10-13, the apparatus being configured for being at least partly suspended from a hoisting system and in turn suspending the load (9) with respect to a base, wherein in particular at least one of the first and second hoisting cables (11, 13) extends between the base and the load (9), and wherein the apparatus and the load (9) may be movably attached together to form an integrated assembly, and wherein optionally the apparatus comprises a power source and/or a connection to an external power source such as a remote operated vehicle.
14. A vessel (1) comprising at least one apparatus according to any one of claims 10-13.
15. The vessel (1) according to claim 14, comprising plu-

ral apparatus according to claim 12, in particular two such apparatus, and being configured to perform the method according to claim 9.

Patentansprüche

1. Ein Verfahren zur Kompensation von Veränderungen von Bewegungen und/oder Kräften einer aufgehängten Last (9), bevorzugt einer Last (9), welche an einer bewegbaren oder sich bewegenden Struktur (1) aufgehängt ist, noch bevorzugter einer Last (9), welche an einem schwimmenden Wasserfahrzeug (1) aufgehängt ist, aufweisend die Schritte des:

parallel- bzw. nebengeschalteten Verbindens eines ersten Hubseils (11) und eines zweiten Hubseils (13) mit der Last (9),
Aufhängens der Last (9) an dem ersten und dem zweiten Hubseil (11, 13), wobei das erste Hubseil (11) eine erste Anhebekraft auf die Last (9), welche eine Federkraft zur passiven Seegangskompensation an der Last (9) aufweist, ausübt, und wobei das zweite Hubseil (13) auf die Last (9) eine zweite Anhebekraft zur aktiven Seegangskompensation an der Last (9) ausübt,
gekennzeichnet dadurch, dass das Verfahren aufweist den Schritt der aktiven Seegangskompensation an der Last (9) durch Steuern einer Position und/oder Bewegung der Last (9) durch Kompensieren, insbesondere Verringern, wenigstens eines Teils der Passiven-Seegangskompensation-Federkraft durch Einstellen der zweiten Anhebekraft und/oder einer Länge des zweiten Hubseils (13).

2. Das Verfahren gemäß Anspruch 1, wobei der Schritt des Steuerns einer Position und/oder Bewegung der Last (9) aufweist Verändern der zweiten Anhebekraft und/oder einer Länge des zweiten Hubseils in Abhängigkeit von wenigstens einer von einer Position und einer Bewegung der aufgehängten Last (9) bezüglich einer Referenz, insbesondere in Abhängigkeit von einer Abweichung von der Referenz.
3. Das Verfahren gemäß Anspruch 2, wobei die Referenz wenigstens eine/einen aus der Gruppe aufweist, welche einen stationären Punkt an der Erde, eine Position der Last (9), eine Bewegung der Last (9), eine Zugkraft des ersten Hubseils (11), eine Federkraft des ersten Hubseils (11), eine Federauslenkung, die erste Anhebekraft des ersten Hubseils (11), die zweite Anhebekraft und/oder eine Zugkraft des zweiten Hubseils (13) aufweist, und wobei insbesondere die Position und/oder Bewegung der Last (9) ermittelt werden bezüglich wenigstens eines Teils eines entfernten stationären oder sich bewegenden Objekts, z.B. einer Zielposition an einem

schwimmenden Wasserfahrzeug (1) zur Platzierung der Last (9).

4. Das Verfahren gemäß irgendeinem vorhergehenden Anspruch, aufweisend im Wesentlichen gleichzeitiges Einstellen des ersten und des zweiten Hubseils (11, 13), z.B. gemeinsames Ausgeben und/oder Einholen des ersten und des zweiten Seils (11, 13). 5
5. Das Verfahren gemäß irgendeinem vorhergehenden Anspruch, wobei die Summe der ersten und der zweiten Anhebekraft im Wesentlichen konstant ist. 10
6. Das Verfahren gemäß irgendeinem vorhergehenden Anspruch, wobei die Federkraft und/oder Federsteifigkeit einstellbar ist, insbesondere in Abhängigkeit von einer Anhebekapazität des zweiten Hubseils (13). 15
7. Das Verfahren gemäß irgendeinem vorhergehenden Anspruch, wobei wenigstens ein Teil der Last (9) im Wasser (W), insbesondere Meerwasser (W), untergetaucht ist, und wobei im Fall eines Verfahrens von wenigstens Anspruch 2 oder 3 die Referenz einen Teil eines Meeresgrunds und/oder einer Struktur an einem Meeresgrund aufweisen kann. 20
8. Das Verfahren gemäß irgendeinem vorhergehenden Anspruch, wobei das Verfahren aufweist Verwenden von zwei Seilen (11, 13) von einer Hebevorrichtung, z.B. eines Krans (3, 5, 5A, 5B) oder einer Windeneinrichtung (21, 23), jeweilig als ein erstes und ein zweites Hubseil (11, 13). 25
9. Das Verfahren gemäß irgendeinem vorhergehenden Anspruch, aufweisend Anheben der Last (9) mit zwei oder mehr Hebesystemen, wobei jedes Hebesystem jeweilig wenigstens ein erstes und ein zweites Hubseil (11, 13) aufweist, und wobei das Verfahren aufweist Verbinden von jedem von dem jeweiligen ersten und einem zweiten Hubseil (11, 13) mit der Last (9) und Durchführen des Verfahrens gemäß irgendeinem der vorhergehenden Ansprüche, wobei jedes der Hebesysteme mit der Last (9) verbunden ist, 30
wobei wenigstens eines der jeweiligen Hebesysteme in einem Slave-Modus bezüglich eines anderen der jeweiligen Hebesysteme betrieben werden kann. 35
10. Eine Vorrichtung zum Durchführen des Verfahrens von irgendeinem der vorhergehenden Ansprüche, aufweisend ein erstes Hubseil (11) und ein zweites Hubseil (13), wobei das erste Hubseil (11) mit einer Last (9) verbindbar ist und parallelgeschaltet das zweite Hubseil (13) mit der Last (9) verbindbar ist, wobei das erste Hubseil (11) dazu eingerichtet ist, wenigstens wenn mit der Last (9) verbunden, eine 40
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Anhebekraft bereitzustellen, welche eine Federkraft zur passiven Seegangskompensation an der Last (9) aufweist, wobei z.B. das erste Hubseil (11) elastisch ist und/oder mit einer Federvorrichtung betriebsfähig verbunden ist, und wobei das zweite Hubseil (13), wenigstens wenn parallelgeschaltet mit dem ersten Hubseil (11) mit der Last (9) verbunden ist, relativ zu dem ersten Hubseil (11) zur aktiven Seegangskompensation an der Last (9) einstellbar ist, und

gekennzeichnet dadurch, dass die Vorrichtung einen Sensor (27, 28, 31, 33) aufweist, welcher dazu eingerichtet ist, wenigstens eine von einer Position und/oder Bewegung der Last (9) bezüglich einer Referenz zu detektieren, und wobei das zweite Seil (13) mit einer Steuereinrichtung (35) betriebsfähig verbunden ist, welche wiederum mit dem Sensor (27, 29, 31, 33) verbunden ist und dazu eingerichtet ist, das zweite Hubseil (13) einzustellen in Reaktion auf ein oder mehrere Signale von dem Sensor (27, 29, 31, 33) zum Kompensieren, insbesondere Verrin-
gern, wenigstens eines Teils der Passive-Seegangskompensation-Federkraft auf das erste Seil (11) zur aktiven Seegangskompensation an der Last (9).

11. Die Vorrichtung gemäß Anspruch 10, wobei die Referenz wenigstens eine/einen aus der Gruppe aufweist, welche eine vorbestimmte Position der Last (9), eine Bewegung der Last (9), eine Zugkraft des ersten Hubseils (11), eine Federkraft des ersten Hubseils (11), die erste Anhebekraft des ersten Hubseils (11) und eine Zugkraft des zweiten Hubseils (13) aufweist. 30

12. Die Vorrichtung gemäß irgendeinem der Ansprüche 10-11, aufweisend eine Hebevorrichtung (3, 5, 5A, 5B, 21, 23), z.B. einen Kran oder eine Windeneinrichtung, welche sowohl das erste als auch das zweite Hubseil (11, 13) bereitstellt, wobei insbesondere das erste Hubseil (11) ein Haupthubseil und das zweite Hubseil (13) ein Nebenseil ist. 35

13. Die Vorrichtung gemäß irgendeinem der Ansprüche 10-13, wobei die Vorrichtung dazu eingerichtet ist, wenigstens teilweise an einem Hebesystem aufgehängt zu sein und wiederum die Last (9) bezüglich einer Basis aufzuhängen, wobei insbesondere wenigstens eines von dem ersten und dem zweiten Hubseil (11, 13) sich zwischen der Basis und der Last (9) erstreckt, und 40
wobei die Vorrichtung und die Last (9) bewegbar miteinander befestigt sind, um eine integrierte Einrichtung zu bilden, und wobei optional die Vorrichtung eine Energiequelle und/oder eine Verbindung mit einer externen Energiequelle, wie zum Beispiel ein fernbedientes Fahrzeug, aufweist. 45
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14. Ein Wasserfahrzeug (1), welches wenigstens eine Vorrichtung gemäß irgendeinem der Ansprüche 10-13 aufweist.
15. Das Wasserfahrzeug gemäß Anspruch 14, welches mehrere Vorrichtungen gemäß Anspruch 12 aufweist, insbesondere zwei solcher Vorrichtungen, und welches dazu eingerichtet ist, das Verfahren gemäß Anspruch 9 durchzuführen.

Revendications

1. Procédé pour la compensation des variations de mouvements et/ou de forces d'une charge suspendue (9), en particulier une charge (9) suspendue à une structure mobile ou en mouvement (1), plus particulièrement une charge (9) suspendue à un bâtiment flottant (1), comprenant les étapes consistant à :

raccorder un premier câble de levage (11) et un second câble de levage (13) à la charge (9), en parallèle ;

suspendre la charge (9) aux premier et second câbles de levage (11, 13), dans lequel le premier câble de levage (11) exerce une première force de levage sur la charge (9) comprenant une force de rappel pour la compensation de pilonnement passif sur la charge (9) et dans lequel le second câble de levage (13) exerce une seconde force de levage sur la charge (9) pour la compensation de pilonnement actif sur la charge (9) ;

caractérisé en ce que le procédé comprend l'étape consistant à compenser le pilonnement actif sur la charge (9) en contrôlant une position et/ou un mouvement de la charge (9) en compensant, en particulier en réduisant au moins une partie de la force de rappel de compensation de pilonnement passif en ajustant la seconde force de levage et/ou une longueur du second câble de levage (13).

2. Procédé selon la revendication 1, dans lequel l'étape consistant à contrôler une position et/ou le mouvement de la charge (9) comprend l'étape consistant à modifier la seconde force de levage et/ou une longueur du second câble de levage (13) en fonction d'au moins l'un parmi une position et un mouvement de la charge suspendue (9) par rapport à une référence, en particulier en fonction d'une déviation de la référence.
3. Procédé selon la revendication 2, dans lequel la référence comprend au moins un élément du groupe comprenant un point fixe sur la terre, une position de la charge (9), un mouvement de la charge (9),

une force de tension du premier câble de levage (11), une force de rappel du premier câble de levage (11), une course élastique, la première force de levage du premier câble de levage (11), la seconde force de levage et/ou une force de tension du second câble de levage (13) et dans lequel, en particulier, la position et/ou le mouvement de la charge (9) sont déterminés par rapport à au moins une partie d'un objet fixe ou mobile à distance, par exemple, une position cible sur un bâtiment flottant (1) pour la mise en place de la charge (9).

4. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape consistant à ajuster les premier et second câbles de levage (11, 13) sensiblement simultanément, par exemple, en déroulant et/ou en enroulant les premier et second câbles (11, 13) ensemble.

5. Procédé selon l'une quelconque des revendications précédentes, dans lequel la somme des première et seconde forces de levage est sensiblement constante.

6. Procédé selon l'une quelconque des revendications précédentes, dans lequel la force de rappel et/ou la rigidité de rappel est ajustable, en particulier en fonction d'une capacité de levage du second câble de levage (13).

7. Procédé selon l'une quelconque des revendications précédentes, dans lequel au moins une partie de la charge (9) est immergée dans l'eau (W), en particulier dans l'eau de mer (W), et dans lequel, dans le cas d'un procédé selon au moins la revendication 2 ou 3, la référence peut comprendre une partie du fond marin et/ou d'une structure sur un fond marin.

8. Procédé selon l'une quelconque des revendications précédentes, dans lequel le procédé comprend l'étape consistant à utiliser deux câbles (11, 13) d'un dispositif de levage, par exemple, une grue (3, 5, 5A, 5B) ou un ensemble de treuil (21, 23), en tant que premier et second câbles de levage (11, 13), respectivement.

9. Procédé selon l'une quelconque des revendications précédentes, comprenant l'étape consistant à lever la charge (9) avec deux ou plusieurs systèmes de levage, chaque système de levage comprenant au moins un premier et un second câble de levage (11, 13), respectivement et le procédé comprenant l'étape consistant à raccorder chacun des premier et second câbles de levage (11, 13) respectifs à la charge (9) et réaliser le procédé selon l'une quelconque des revendications précédentes, avec chacun des systèmes de levage raccordés à la charge (9), dans lequel au moins l'un des systèmes de levage

respectifs peut être actionné dans un mode esclave par rapport à l'autre des systèmes de levage respectifs.

10. Appareil pour réaliser le procédé selon l'une quelconque des revendications précédentes, comprenant un premier câble de levage (11) et un second câble de levage (13), le premier câble de levage (11) pouvant être raccordé à une charge (9) et le second câble de levage (13) pouvant être raccordé à la charge (9) en parallèle, dans lequel le premier câble de levage (11) est configuré pour fournir, au moins lorsqu'il est raccordé avec la charge (9), une force de levage comprenant une force de rappel pour la compensation de pilonnement passif sur la charge (9), par exemple, le premier câble de levage (11) étant élastique et/ou raccordé de manière opérationnelle à un dispositif de rappel et dans lequel le second câble de levage (13), au moins lorsqu'il est raccordé à la charge (9), en parallèle au premier câble (11), est ajustable par rapport au premier câble de levage (11) pour la compensation de pilonnement actif sur la charge (9), et **caractérisé en ce que** l'appareil comprend un capteur (27, 29, 31, 33) configuré pour détecter au moins l'un parmi la position et/ou le mouvement de la charge (9) par rapport à une référence et dans lequel le second câble (13) est raccordé de manière opérationnelle à un organe de commande (35) qui est raccordé, à son tour, au capteur (27, 29, 31, 33) et est configuré pour ajuster le second câble de levage (13) en réponse à un ou plusieurs signaux provenant du capteur (27, 29, 31, 33) pour compenser, en particulier réduire, au moins une partie de la force de rappel de compensation de pilonnement passif du premier câble (11) pour la compensation de pilonnement actif sur la charge (9).
11. Appareil selon la revendication 10, dans lequel la référence comprend au moins un élément du groupe comprenant une position prédéterminée de la charge (9), un mouvement de la charge (9), une force de tension du premier câble de levage (11), une force de rappel du premier câble de levage (11), la première force de levage du premier câble de levage (11) et une force de tension du second câble de levage (13).
12. Appareil selon l'une quelconque des revendications 10 à 11, comprenant un dispositif de levage (3, 5, 5A, 5B, 21, 23), par exemple une grue ou un ensemble de treuil, fournissant à la fois les premier et second câbles de levage (11, 13), dans lequel en particulier le premier câble (11) est un câble de levage principal et le second câble (13) est un câble auxiliaire.
13. Appareil selon l'une quelconque des revendications

10 à 13, l'appareil étant configuré pour être au moins partiellement suspendu à un système de levage et suspendre à son tour la charge (9) par rapport à une base, dans lequel en particulier au moins l'un des premier et second câbles de levage (11, 13) s'étend entre la base et la charge (9), et dans lequel l'appareil et la charge (9) peuvent être fixés de manière mobile ensemble afin de former un ensemble intégré, et dans lequel facultativement l'appareil comprend une source de puissance et/ou un raccordement à une source de puissance externe tel qu'un véhicule commandé à distance.

14. Bâtiment (1) comprenant au moins un appareil selon l'une quelconque des revendications 10 à 13.
15. Bâtiment (1) selon la revendication 14, comprenant plusieurs appareils selon la revendication 12, en particulier deux de ces appareils, et étant configuré pour réaliser le procédé selon la revendication 9.

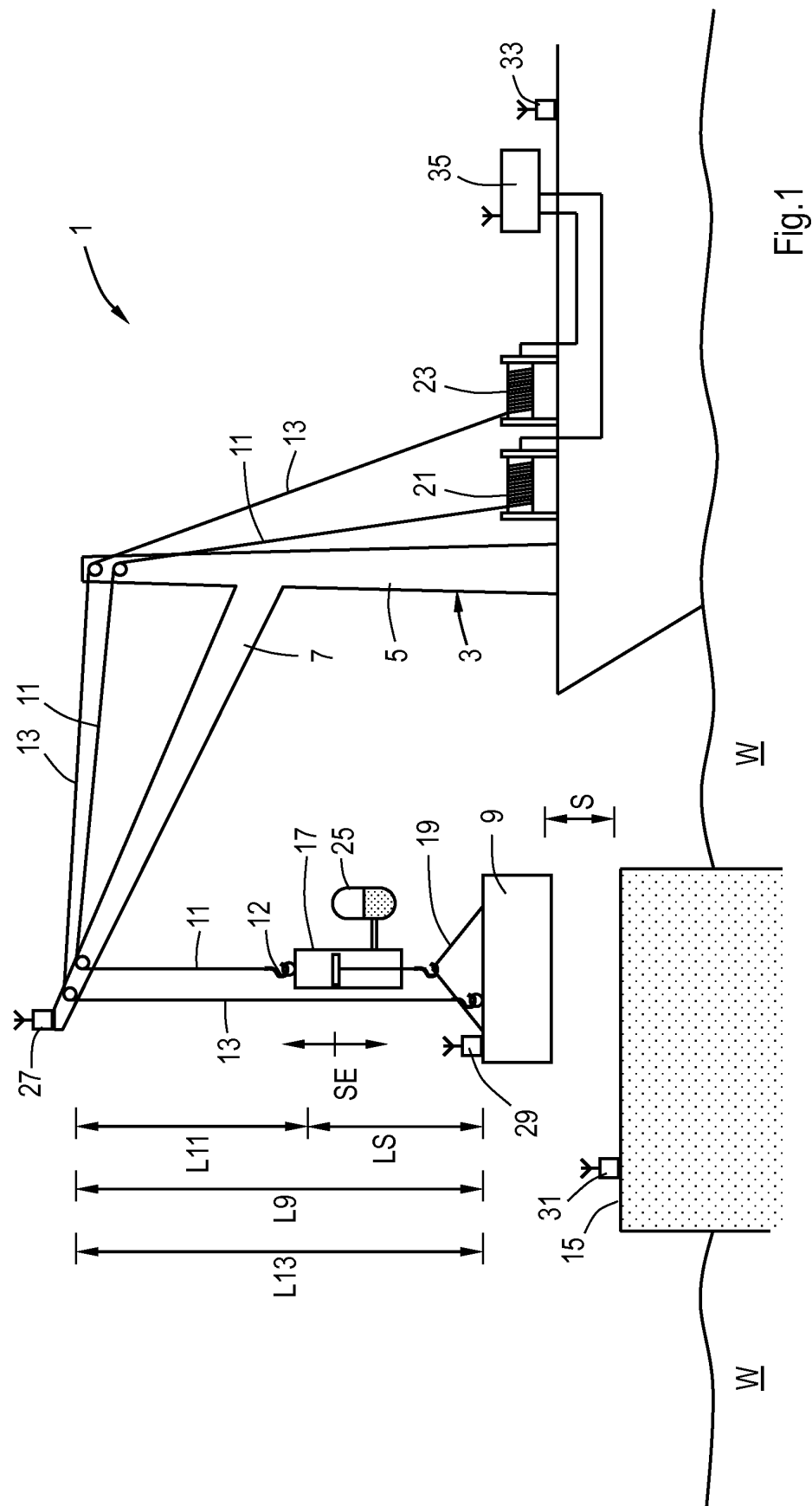
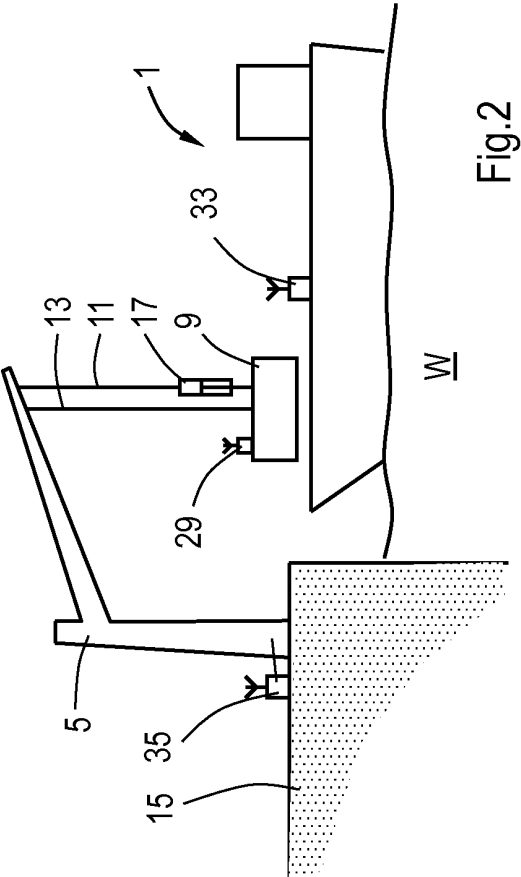
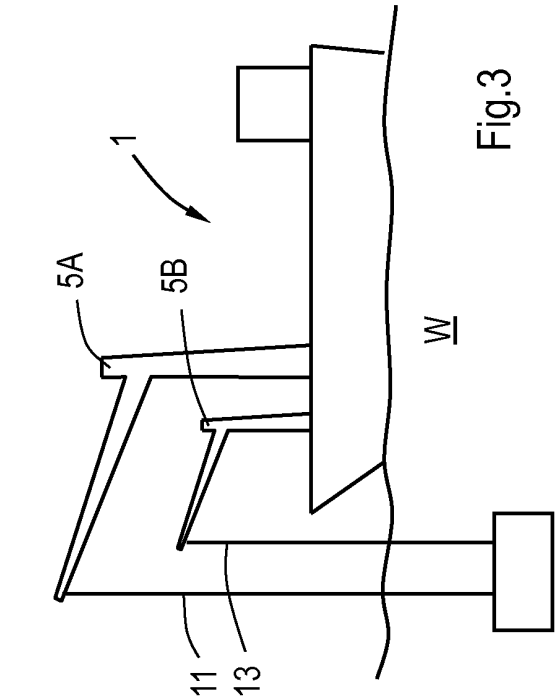


Fig. 1



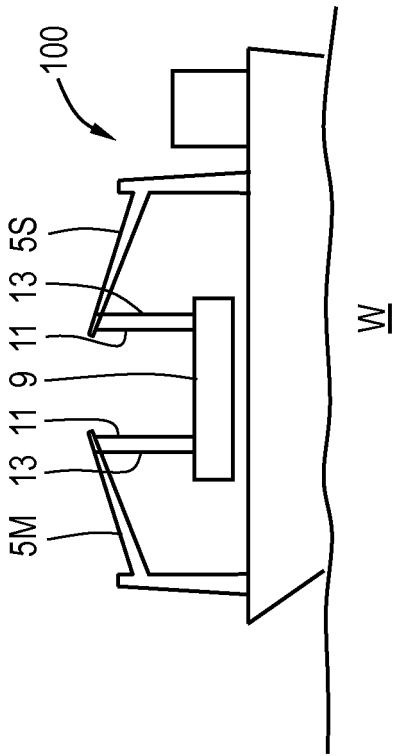


Fig. 4

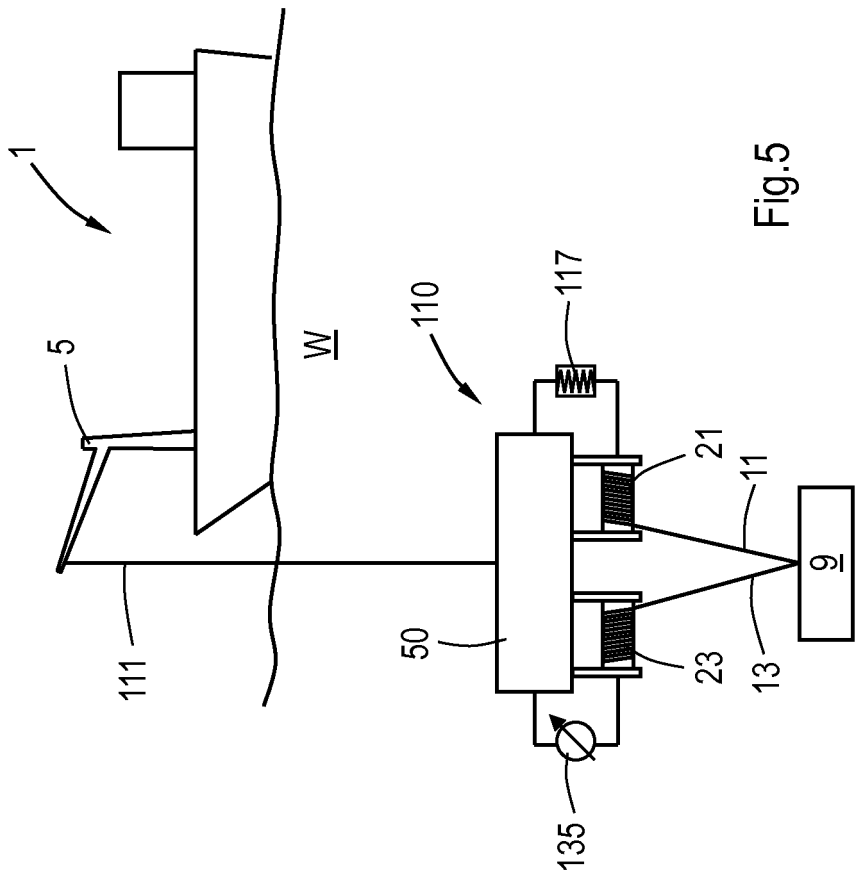


Fig. 5

REFERENCES CITED IN THE DESCRIPTION

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