(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
09 January 2025 (09.01.2025)

WIPO | PCT

(10) International Publication Number
WO 2025/008533 A1

(51) International Patent Classification:
B66C 13/02 (2006.01)

(21) International Application Number:
PCT/EP2024/069091

(22) International Filing Date:
05 July 2024 (05.07.2024)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2035273 05 July 2023 (05.07.2023) NL

(71) Applicant: **ITREC B.V.** [NL/NL]; 2, Admiraal Trompstraat, 3115 HH SCHIEDAM (NL).

(72) Inventors: **BOONTJES, Lucas**; c/o 2, Admiraal Trompstraat, 3115 HH SCHIEDAM (NL). **KROMDIJK, Harmen Jan**; c/o 2, Admiraal Trompstraat, 3115 HH SCHIEDAM (NL). **WETERINGS, Hendrikus Jacobus**; c/o 2, Admiraal Trompstraat, 3115 HH SCHIEDAM (NL).

(74) Agent: **EP&C**; P.O. Box 3241, 2280 GE Rijswijk (NL).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CV, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IQ, IR, IS, IT, JM, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, MG, MK, MN, MU, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, WS, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, CV, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SC, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, ME, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *in black and white; the international application as filed contained color or greyscale and is available for download from PATENTSCOPE*

(54) **Title:** HEAVE COMPENSATOR FOR OFFSHORE CRANE, OFFSHORE CRANE, VESSEL AND HOISTING METHOD

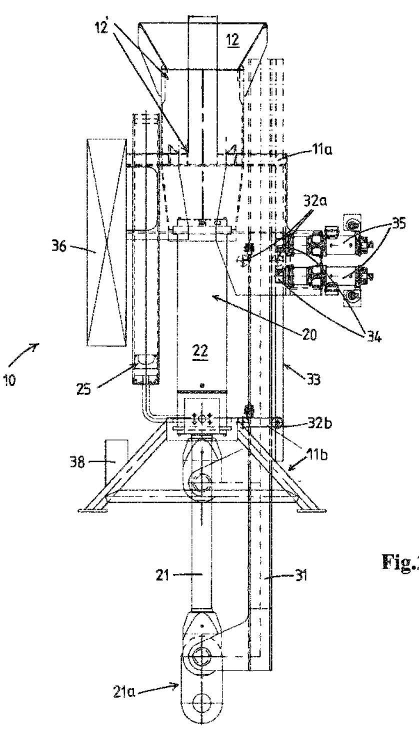

Fig.2

(57) Abstract: An offshore crane and a heave compensator (10) suspended in-line from a lower block, and to a method for hoisting an object. The heave compensator comprises a frame (11a, 11b) to be suspended in-line from the lower block, a vertical passive heave compensation system and a vertical active heave compensation system. The passive heave compensation system comprises a vertical passive cylinder (20) having a downward extending piston rod (21), medium-separators (25) and multiple pressurized gas tanks (26a-t). The vertical active heave compensation system comprises a vertical column (31) connected to the downward extending piston rod and extending vertically parallel to the passive cylinder, wherein the vertical column is vertically guided by the frame, and wherein a vertical rack (33) is mounted to the vertical column and one or more pinions (34) and associated electric motors (35) are supported by the frame.

WO 2025/008533 A1

HEAVE COMPENSATOR FOR OFFSHORE CRANE, OFFSHORE CRANE, VESSEL AND HOISTING METHOD

The present invention relates to an offshore crane with a heave compensator.

In the field of installation of offshore wind turbines one approach envisages that a vessel is used both for transportation of the wind turbine, or components thereof, between an onshore location and the offshore location and for installation of the wind turbine, or components thereof, at the offshore location. So, for example, the vessel is loaded with monopiles, commonly stored horizontally on deck, at the onshore location and then sails to the offshore windfarm. There the crane of the vessel is used for upending the monopile and to install the monopile, e.g. further making use of a monopile gripper to accurately position the monopile. In another example, the foundation is already installed and the vessel is loaded with the mast, nacelle, and blades of the wind turbine. The vessel sails to the windfarm and then the crane is used to install the mast on the foundation, followed by installation of the nacelle, and then the installation of the blades. Alternative installation processes are known as well.

Another approach in the field of installation of offshore wind turbines envisages that a dedicated installation vessel is positioned at the offshore location, the installation vessel having a crane configured for handling of the wind turbine and/or components thereof. A feeder vessel is then used for shuttling between an onshore location and the offshore location in order to supply wind turbine components. For example, a jack-up type or semi-submersible type installation vessel is positioned at the offshore location. The feeder vessel, e.g. self-propelled or a towed barge, is then used, for example, for supply of monopiles or other foundations.

A drawback of the “feeder vessel approach” is the need for offloading the wind turbine components from the feeder vessel. Herein, commonly, the feeder vessel is floating and therefore subject to wave-induced heave motion. On the other hand, the crane on the installation vessel is not, in a jack-up vessel, or hardly, in a semi-submersible vessel or with a different response, subject to heave motion. In this approach, the relative motions in combination with the large weight of the object to be hoisted can be problematic. For example, offloading a monopile in horizontal orientation from the feeder vessel can be difficult, taking into account the enormous weight and dimensions, e.g. a length over 80 meters, a diameter of over 8 meters, e.g. up to 12 – 13 meters, and a weight of over 2000 tonnes.

Proposals have been made to provide the feeder vessel with a heave motion compensated carrier that is configured to support the wind turbine component thereon that is to be offloaded by the crane. The carrier is supported on the hull of the feeder vessel by means of a heave motion compensating support system. Examples of these proposals are presented in WO2022/238152 and WO2020/011679.

The present invention aims to provide a solution, wherein a crane on the installation vessel is provided with a heave motion system. Such a crane can be used instead of, or in addition to a heave motion compensated carrier on a feeder vessel. For example, the carrier with the object is able to carry out rotations, while the heave compensator of the crane is provided to compensate for all types of heave.

The first aspect of the invention provides an offshore crane according to claim 1 and 11, a vessel according to claim 9, a heave compensator according to claim 10 and a method according to claim 12.

The inventive offshore crane is suitable for use on a vessel for handling an object, e.g. a wind turbine component, e.g. an installation vessel for offloading objects such as wind turbine components from a feeder vessel, such as from a barge. Commonly, the objects such as monopiles or rotor blades are horizontally supported on the feeder vessel. The object can also be a monopile for forming a foundation, e.g. for a substation, drilling platform(s) or even as foundation for a viaduct or the like.

For example, the feeder vessel is moved into reach of the inventive offshore crane, e.g. mounted on an installation vessel, which is already present at the offshore location where the wind turbine is to be installed.

For example, monopile main design drivers such as turbines of up to 15 megawatts with rotor diameters of up to 230 metres, resistant to extreme wind loads, especially those driven by hurricanes or typhoons, operable in water depths of up to 65 metres and with wave loads in the Atlantic and Pacific Oceans lead to monopile design requirements with bottom diameters between 8 and 11 metres, lengths of up to 120 metres and wall thicknesses up to 150 millimetres. The final weight of such monopiles can reach up to 2500 tonnes, i.e. 2.500.000 kg.
The crane comprises a hoist cable extending between a hoist winch and a lower block, suspended from the hoist cable. In embodiments furthermore an upper block is provided

between the winch and the lower block, the upper block e.g. being provided at a distal end of a crane boom or crane jib.

The heave compensator comprises a vertical passive heave compensation system and an active heave compensation system, preferably a vertical rack-and-pinion active heave compensation system.

The vertical passive heave compensation system comprises a vertical passive cylinder having a cylinder body, a piston and a vertically downwards extending piston rod, the piston delimiting a lower rod-side chamber and an upper piston-side chamber of the passive cylinder. The cylinder body may have dimensions in the order of about 1 meter in diameter and 4,5 meter in length. The diameter of the piston rod may be in the order of 50cm. Advantageously, the cylinder body is supported by the frame. Advantageously, the vertical passive cylinder is provided with a cap, preferably a hydraulic cap, in particular an end buffer.

The vertical passive heave compensation system comprises one or more medium-separators each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the rod-side chamber of the passive cylinder.

In embodiments, multiple medium-separators are provided in parallel. This is in particular advantageous when the rod-side chamber of the passive cylinder has a large volume, requiring a large volume of hydraulic fluid from the one or more medium-separators.

In alternative embodiments, multiple medium-separators are provided, each associated with a set of pressurized gas tanks having the same pressure.

The vertical passive heave compensation system further comprises multiple pressurized gas tanks, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator.

It is conceivable that the passive heave compensation system has multiple pressurized gas tanks, wherein the gas pressure of the individual gas tanks is adjustable depending on the type of hoisting operation. For example, all gas tanks can have the same pressure in one operation, and for another operation pressures in gas tanks are adjusted to create distinct sets of tanks, each set having gas tanks having the same pressure.
Advantageously, the stiffness of the passive heave compensation system is increased during hoisting, and/ or decreased during lowering. For a low stiffness a low-pressure set of tanks is

connected to the medium-separator feeding the rod-side chamber of the passive cylinder, and for a high stiffness a high-pressure set of tanks is connected.

In an alternative embodiment as in claim 11, the passive heave compensation system has a vertically downwards extending piston rod supported by the frame. In addition, the vertical column of the active heave compensation system is connected to the cylinder body. In such an embodiment, the hydraulic-side chamber of the medium-separator is connected to the upper piston-side chamber of the passive cylinder.

The inventive heave compensator further comprises an active heave compensation system, embodied as a vertical rack-and-pinion active heave compensation system. Alternative active heave compensation systems are known, e.g. winch and cable based. The active heave compensation system is e.g. used to improve accuracy of the heave compensator. In particular, a hydraulic system is less accurate due to oil compression. A rack-and-pinion based system is thus inherently more accurate. The active heave compensation system is e.g. used during the connection of the object to the heave compensator, e.g. a spreader suspended from the heave compensator.

The vertical active heave compensation system is a rack-and-pinion system, comprising a vertical column and extending vertically parallel to the passive cylinder, wherein the vertical column is vertically guided by the frame, and wherein a vertical rack is mounted to the vertical column. Advantageously, the vertical column is connected to the downward extending piston rod. Alternatively, the vertical column is connected to the cylinder body.

The active heave compensation system further comprises one or more pinions and associated electric motors. Both the pinions and one or more electric motors are supported by the frame. Preferably, each pinion has an associated electric motor. Upon operation of the electric motor and pinion the rack is allowed to move in a vertical direction relative to the frame. With the frame supporting the passive cylinder and the rack being connected to the piston rod, this thus provides active heave compensation.

Such electrically active heave compensation is advantageous as the storage and return of energy is more efficient than hydraulics, and/ or in that electric control is more accurate and/ or /faster. In addition, it is possible to gain energy back, or in other words, the motor can be used as a generator. This way batteries can be charged, or a supercapacitor can advantageously be applied.

Advantageously, a clutch is provided between the electric motors and the pinions, allowing the pinions to be disconnected from their drive so they run freely. Furthermore, a clutch can provide improved control of the pinions.

Advantageously, the frame furthermore supports one or more column guides to guide the vertically extending column relative the frame. The advantage of the guides is in particular apparent when considering the length of the vertical column which can be 8-12 meters and is only connected to the downward extending piston rod – and engaged by the pistons. Hence, a set of upper and lower guides provides addition support for the vertical column.

In embodiments, the frame of the heave compensator comprises:

- a top frame supporting the cylinder body of the passive cylinder and one or more pinions and associated electric motors, and preferably also upper column guides;
- a landing frame mounted to the cylinder body of the passive cylinder and preferably also comprising lower column guides.

The active heave compensation system further comprises a battery to provide power to the one or more electric motors. Advantageously, in embodiments a supercapacitor is provided to accept and deliver power from and to the electric motor when functioning as an electric generator.

In embodiments, a spreader is provided which is configured for lifting wind turbine parts such as monopiles, blades or nacelles, which spreader is connectable/ suspendable or connected to/ suspended from the heave compensator to suspend from the heave compensator, see for example WO2021156508.

In embodiments, a sensor and a control system are provided using information of the sensor to control the active heave compensation system. The active heave compensation system is advantageously applied to increase the accuracy of the passive heave compensation system.

The active heave compensation system may further comprise a position sensor to determine the distance between the object and the heave compensator, and a control system using information of the position sensor to control the active heave compensation system. For example, the distance sensor is placed on the crane or on the vessel.
The sensor is e.g. a position sensor or a distance sensor (optical, radar, laser, mechanical means etc.) that measures the distance to the deck. Advantageously a Motion Reference Unit (MRU) is applied. MRU’s are high-tech devices capable of measuring movement in all six

degrees of freedom – roll, pitch, yaw, surge, sway, and heave. They are vital components in monitoring movement for ships, helidecks, offshore gangways, cranks and winches, sonars, and more. The sensor is preferably provided on the heave compensator, but other locations are also conceivable.

The heave compensator of the first aspect of the invention comprises a frame. In embodiments, the heave compensator is configured:

- with the passive cylinder vertically oriented at a central position,
- flanked by two opposite banks of vertically oriented pressurized gas tanks, e.g. each bank comprising a set of one of more pressurized gas tanks having the same pressure; and
- the one or more vertically oriented medium-separators between the banks of gas tanks at one side of the passive cylinder, and
- wherein the vertical column, rack and pinions of the active heave compensation system are provided between the banks of gas tanks at a side of the passive cylinder opposite the one or more medium-separators, and
- wherein the battery of the active heave compensation system is provided adjacent the one or more vertically oriented medium-separators.

Alternatively, the heave compensator is configured:

- with the passive cylinder vertically oriented at a central position,
- flanked by two vertical columns, rack and pinions of the active heave compensation system are provided symmetrically between the banks of gas tanks at opposite sides of the passive cylinder.

For example, the passive cylinder is still flanked by two opposite banks of vertically oriented pressurized gas tanks, e.g. each bank comprising a set of one of more pressurized gas tanks having the same pressure. It is also conceivable that there is just one bank of gas tanks. The one or more vertically oriented medium-separators and the battery of the active heave compensation system are provided e.g. adjacent the vertically oriented pressurized gas tanks or adjacent the vertical columns.

In embodiments, distinct sets of pressurized gas tanks are provided, each set comprising one of more pressurized gas tanks having the same pressure. It is conceivable that there is a high-pressure set of tanks, a medium-pressure set of tanks and a low-pressure set of tanks, wherein the sets are selectively connectable to the medium-separator. With multiple sets of pressurized gas tanks, a passive heave compensation system is provided having distinct stiffness properties.

The inventive heave compensator is suspended in-line from the lower block, e.g. via a connector.

In embodiments, the lower block is provided with a connector and the heave compensator comprises a connector guidance funnel. Advantageously, an operable mechanism is provided, e.g. above the funnel, which operable mechanism is configured to, in a connection process, engage the connector of the lower block in a vertical engagement motion and to releasably lock the lower block to the heave compensator so as to suspend the heave compensator from the lower block, and in a disconnection process to unlock the lower block from the heave compensator and disengage the heave compensator and the connector.

In alternative embodiments, the heave compensator is provided with a connector and the lower block comprises a connector guidance funnel and an operable mechanism above the funnel which operable mechanism is configured to, in a connection process, engage the connector of the heave compensator in a vertical engagement motion and to releasably lock the heave compensator to the lower block so as to suspend the heave compensator from the lower block, and in a disconnection process to unlock the heave compensator from the lower block and disengage the lower block and the connector.

The invention further relates to an installation vessel, e.g. for the installation of objects such as wind turbine components, comprising an offshore crane as described above.

The invention further relates to a hoisting method for objects wherein use is made of an installation vessel comprising a crane as described above. Preferably, the hoisting method comprises the steps of:

a) providing the object on a feeder vessel susceptible to heave;
b) providing the heave compensator of the offshore crane in the vicinity of the object;
c) connecting the object to the heave compensator;
d) operating the passive heave compensation system;
e) hoisting the object.

In embodiments, during step b) the heave compensator is used to bring the hook/spreader at fixed distance above load. The pressure in passive cylinder is relatively low, while active heave compensation is provided with the rack-and-pinion.

In embodiments, prior to step c) the method furthermore comprises the steps of:

- connecting a spreader to the heave compensator to suspend from the heave compensator;
- providing a position sensor to determine the distance between the object and the spreader;
- using information from the position sensor to operate the active heave compensation system so as to maintain a stable distance between the spreader and the object to facilitate the connection of the object to the spreader.

This is a possible use of the active heave compensation system.

In embodiments wherein distinct sets of pressurized gas tanks are provided, each set comprising one of more pressurized gas tanks having the same pressure, during step d) first one set of tanks is connected to the medium-separator, followed by another set of tanks. For example, first a low-pressure set is connected, followed by a high-pressure set of tanks. Or alternatively, first a low-pressure set is connected, followed by a medium-pressure set of tanks and finally a high-pressure set of tanks. Advantageously, the pressure is increased to about 90% of the load.

In a fast lift off function the object is pulled up quickly, at about $0.5 m/s^2$, which requires a sudden need of about 100t of extra traction. This is done by a combination of the rack-and-pinion drive and an additional high-pressure gas cylinder switched on to actuate the passive heave cylinder.

In embodiments, prior to step d), the method comprises the step of providing a position sensor to determine the distance between the object and the spreader; and during step d) using information from the position sensor to operate the active heave compensation system as a brake mechanism for the upward motion of the piston rod of the passive cylinder, in particular when high-pressure tanks are connected to the gas-side chamber of the medium-separator to enable fast lifting. This is an alternative possible use of the active heave compensation system. In embodiments, both uses of the active heave compensation system are applied during hoisting.

A second aspect of the invention relates to an offshore crane for use on a vessel for handling an object, e.g. a wind turbine component, wherein the crane comprises a hoist cable extending between a hoist winch and a lower block, wherein a heave compensator is mounted to the lower block, and wherein the object can be suspended from the heave compensator, the heave compensator comprising a frame;

the heave compensator further comprises a vertical heave compensation system with:

- one or more vertical cylinders each having a cylinder body supported by the frame, a piston and a vertically upwards extending piston rod, the piston delimiting an upper rod-side chamber and a lower piston-side chamber of the cylinder;
- one or more medium-separators each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the piston-side chamber of the cylinder;
- multiple pressurized gas tanks, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator;

wherein the heave compensator further comprises a vertical load connector, wherein the vertical load connector is at a lower end thereof provided with a lifting tool, e.g. a lifting hook, wherein the one or more piston rods are connected to the vertical load connecter, such that the vertical load connector is configured to move vertically with respect to the frame when the one or more piston rods are extended or retracted.

The heave compensator may act like a passive heave compensator. The heave compensator is mounted to the lower block and not suspended therefrom via cables. Due to the heave compensator being integral with the frame there will be no double pendulum motion which increases the stability of the load. Furthermore, by integrating the heave compensator with the lower block the total length between the crane boom tip and the load may be reduced which also increases the stability of the load with respect to the crane.

In an embodiment, the heave compensator furthermore comprises an active heave compensation system which comprises a vertical rack which is mounted to the vertical load connector, one or more pinions and on or more associated electric motors supported by the frame, and a battery which is configured to provided power to the one or more electric motors. The rack and pinion can be operated to provide an active heave compensation for the heave compensator, providing both active and passive heave compensation.

In an alternative embodiment, the active heave compensation system comprises:

- a vertical column connected to the upward extending piston rod and extending vertically parallel to the cylinder, wherein the vertical column is vertically guided by the frame, and wherein a vertical rack is mounted to the vertical column;

- one or more pinions and associated electric motors, supported by the frame;
- a battery to provide power to the one or more electric motors.

In an alternative embodiment, the active heave compensation system comprises one or more pump devices which are configured to extend and retract the upward extending piston rod. Preferably, the crane and/pr the heave compensator comprises one or more sensors that measure the position and movement of the load with respect to the lower block, wherein the measurement data is transmitted to a control system that is configured to operate the pump devices.

In an embodiment, the frame comprises a vertical guiding structure which extends vertically along a majority of the length of the frame, wherein the vertical guiding structure is configured to guide the vertical load connector when the vertical load connector moves vertically with respect to the frame.

In an embodiment, an umbilical is connected to the heave compensator to provide the active heave compensation system with electrical power, wherein the umbilical extends from the crane to the vertical active heave compensation system.

In an embodiment, all components of the heave compensation system are housed at least partly inside of the frame.

In an embodiment, the lifting tool is pivotably connected to the vertical load connector.

In an embodiment, the heave compensation system comprises two vertical heave cylinders, two medium-separators and two pressurized gas tanks, wherein the two pressurized gas tanks are under the same pressure.

In an embodiment, the one or more piston rods are connected to a connection frame, and the vertical load connector is connected to the connection frame, wherein - when the piston rods are extended or retracted - the connection frame and thus the vertical load connector are also moved vertically.

In an embodiment, the frame, vertical cylinders, medium separators, and pressurized tanks define a central receiving opening which is configured to receive the vertical load connector. The heave compensator has a retracted and an extended position, wherein - in the retracted position - the vertical load connector is substantially located inside of the frame and along the vertical cylinders and pressurised tanks.

In an embodiment, the frame can be connected to the lower block via a pinned connection, which allows for a quick connection and disconnection.

In an embodiment, the heave compensator is configured to be used underwater, e.g. the compensator can be submerged up to 300m water depth.

A third aspect of the invention relates to an offshore crane for use on a vessel for handling an object, e.g. a pile hammer, the crane comprising a hoist cable extending between a hoist winch and a lower block, wherein a main lifting tool, preferably an exchangeable tool, e.g. a crane hook, is connected to the lower block, and wherein the crane further comprises a secondary lifting tool, e.g. a damping tool or heave compensation tool, wherein an the object can be suspended from the main lifting tool or from the secondary lifting tool, wherein the secondary lifting tool comprises:

- one or more vertical cylinders each cylinder comprising a piston and a vertically downward extending piston rod, each piston of the respective cylinder delimiting a lower rod-side chamber and an upper piston-side chamber of the cylinder,
- a lower hoist frame, wherein the lower hoist frame is only suspended from a lower end of the one or more piston rod, wherein the lower hoist frame is configured to support the object, e.g. the object can be suspended from the lower hoist frame.

The crane comprises both a main lifting tool and the secondary lifting tool simultaneously, wherein an object can be selectively suspended from the main lifting tool and the secondary lifting tool. Depending on the current lifting operation, either the main lifting tool or the secondary lifting tool will be required, because both these tools are simultaneously connected to the lower block it allows for a quick switching of tools, thus decreasing the operational time.

In an embodiment, the secondary lifting tool is embodied as a damping tool, wherein the one or more vertical cylinders of the damping tool are filled with a compressible liquid or gas and/or comprises an overpressure relief valve. When the object vertically moves, e.g. suddenly, relative to the lower block, the fluid or gas will be compressed and/or expelled which causes a damping effect. For example, hydraulic liquid can leave the chamber via the pressure relief valve, e.g. via a throttle.

Such a damping tool is especially beneficial for use during pile driving, wherein a pile hammer will be suspended from the lower hoist frame. One of the problems that may sometime occur during pile driving is a so called pile-run. This cause huge instantaneous forces on the entire crane. By using the damping tool these forces will be, comparatively, more gradually introduced to the crane.

In an embodiment, the lower hoist frame is annular, e.g. rectangular, and comprises a central opening.

In an embodiment, the lower hoist frame is dimensioned such that the main lifting tool is, in a top-down projection, located within the central opening of the lower hoist frame. This allows the main lifting tool to be used to lift an object while the lower hoist frame is simultaneously present.

In an embodiment, the secondary lifting tool comprises four cylinders, which are all connected to the lower block and each at their lower end connected to the lower hoist frame.

In an embodiment, the lower hoist frame has a rectangular shape, wherein the four cylinders are arranged at or in the proximity of a respective corner of the rectangular lower hoist frame.

In an embodiment, the one or more cylinders are connected to the lower block via a multi-axis coupling.

In an embodiment, the secondary lifting tool is a heave compensation tool, wherein the heave compensation tool comprises:

- one or more medium-separators each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the rod-side chamber of the cylinder;
- one or more pressurized gas tanks mounted to the lower block, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator.

In an embodiment, the heave compensation tool is an active heave compensation tool which is provided with one or more pump devices which are configured to extend and retract the piston rods of the one or more vertical cylinders, whereby operating the one or more pump devices the lower hoist frame can be lowered or raised compared to the lower block. Preferably, the crane and/or heave compensator comprises one or more sensors that measure the position and movement of the load with respect to the lower block, wherein the measurement data is transmitted to a control system that is configured to operate the pump devices.

In an embodiment, the lower frame has an active position and a raised parking position, wherein - in the active position – the lower hoist frame is at a vertical distance below the main hoisting tool and configured to hoist an object. In the parking position, the lower hoist frame is located at a raised position above at least part of the main hoisting tool, such that the main hoisting tool can be used for hoisting an object without interference of the lower hoist frame. An actuator may be present to move the lower frame between the active position and the raised parking position and/or vice versa. In an embodiment, the cylinders are configured to controllably move the lower frame between the active position and the raised parking position and/or vice versa.

In an embodiment, the crane is configured to provide active heave compensation to the lower block, e.g. wherein the hoist winch(es) are spooled to hoist or lower or lift the lower block, e.g. wherein a control system provides active heave compensation to the lower block.

The third aspect of the invention also relates to a method for the installation of a monopile in the seabed, wherein use is made of the offshore crane. The method comprising the following steps

- connecting the monopile to the main lifting tool;
- lifting the monopile onto the seabed in an upright position;
- disconnecting the main lifting tool from the monopile;
- connecting a pile hammer to the lower hoist frame of the damping tool;
- driving the monopile into the seabed using the pile hammer supported by the damping tool.

A fourth aspect of the invention relates to an offshore crane for use on a vessel for handling an object, e.g. a wind turbine component, the crane comprising a hoist cable extending between a hoist winch and a lower block assembly, the crane further comprises a heave compensator,

wherein the heave compensator comprises a heave cylinder assembly arranged horizontal on, e.g. inside of, the lower block assembly, wherein the heave cylinder assembly comprises one or more heave cylinders, each having a cylinder body, a piston, and a piston rod, wherein the heave cylinder assembly is connected to a first tilt bracket and to a second tilt bracket, wherein the first and second tilt brackets are each tiltable mounted to the lower block assembly,

wherein a first and second connection rod each have a bracket end which is respectively connected to the first and second tilt bracket, wherein the first and second connection rods are each at a frame-end thereof connected to a connection frame located below the lower block assembly,

wherein the connection frame is configured to be connected or connected to a load connector from which a load can be suspended, e.g. via a spreader,

wherein the first and second tilt brackets are each pivotably connected to the lower block assembly around a tilt bracket pivot axis, such that when the one or more horizontal heave cylinders are extended or retracted the tilt bracket pivots around the tilt bracket pivot axis thereby moving the connection rods up and down, such that the connection frame and thus the load connector and load are moved in a substantial vertical direction.

The heave cylinder assembly is configured to move the load connector and load in a substantial vertical direction, thereby providing heave compensation. Normally heave compensators comprise vertically oriented cylinders. By having horizontally oriented cylinders the total height of the heave compensator is significantly reduced, this has multiple advantages. The distance between the load and the crane boom tip can be reduced, the pendulum length is thus reduced, which in turn reduces the swinging motion of the load with respect to the crane, leading to a more stable load. Furthermore, the reduced length of the heave compensator also reduces the required crane height or increases the lifting height of the crane compared to a heave compensator having vertically oriented cylinders.

In an embodiment, the one or more heave cylinders each comprise rod-side chamber and a piston-side chamber delimited by the piston,

wherein the horizontal heave assembly further comprises:

- one or more medium-separators each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the piston-side chamber of the cylinder,
- multiple pressurized gas tanks, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator.

In an embodiment, the heave cylinder assembly comprises a synchronisation system which is configured to synchronise the rotation of the first and second tilt brackets. If the rotation of the first and second tilt brackets is not synchronised, it could occur that the connection frame becomes slanted.

In an embodiment, the horizontal heave cylinder assembly comprises a single horizontal heave cylinder, wherein the cylinder body is pivotably connected to one of the first or second tilt bracket and wherein the piston rod is connected to the other of the first or second tilt bracket. When the piston rod is extended the piston rod will push against the first or second tilt bracket, while the cylinder body also pushes against the other tilt bracket, this causes the first and second tilt brackets to rotate around the respective first and second tilt axes. In this embodiment, the single horizontal heave cylinder is movable supported by the lower block.

In an alternative embodiment, the horizontal heave cylinder assembly comprises a first and second horizontal heave cylinder, wherein the cylinder body of both the first and second horizontal heave cylinders are connected to the lower block assembly, and wherein the piston rod of the first and second horizontal heave cylinders are pivotably connected to the first and second tilt bracket respectively. Preferably, the synchronisation system is configured to synchronise the extension and retraction of the piston rod of the first and second cylinders.

In an embodiment, the synchronisation system is configured to operate the first and second horizontal heave cylinders on the basis of position control, such that the first and second horizontal cylinders extend and retract the same distance and simultaneously.

In an embodiment, the synchronisation system comprises:
- a first line connected to the piston-side chamber of the first cylinder,
- a second line connected to the piston-side chamber of the second cylinder,
- a rotary flow divider having a first pump device and a second pump device on a common rotary shaft, the first pump device connected to the first line and the second pump device connected to the second line.

For example, the first and second lines extend between the cylinder and a medium-separator.

In an embodiment, the one or more pressurised gas tanks are connected to the lower block in a horizontal orientation, e.g. wherein one or more, preferably two, pressurised gas tanks are arranged on each side of the lower block. By horizontally orienting the pressurized gas tanks, the height of the heave compensator is reduced.

In an embodiment, the lower block assembly comprises two parallel lower block panels spaced at a distance to define a space between the panels, wherein the lower block panels are connected to each other by lower block connection members, e.g. lower and upper plates, wherein the horizontal heave cylinder and tilt brackets are arranged in the space between the lower block panels. Preferably, the one or more pressurised gas tanks are arranged on the outside of the lower block panels.

In an embodiment, the connection frame comprises a load connector structure, e.g. as in WO2020/055249. The load connector structure allows for a quick and easy connection between the connection frame and the load connector, e.g. lifting hook.

In an embodiment, wherein the first and second connection rod comprise one or more rods, preferably two rods.

In an embodiment, the crane further comprises a spreader, e.g. configured for lifting wind turbine parts such as a monopile, blade or nacelle, which spreader is connectable or connected to the load connector to suspend from the heave compensator.

In an embodiment, a sensor and control system are provided, wherein the sensor is configured to measure the position and/or movement of the load and the lower block, and wherein the control system is configured to operate the heave compensator based on the information provided by the sensor to maintain a stable distance between the load and the lower block.

The fourth aspect of the invention also relates to a method for hoisting an object wherein use is made of a heave compensator as described herein.

The invention is further elucidated in relation to the drawings, in which:
Fig. 1 is a front view of a compensator with a spreader and monopile;
Fig. 2 is a detailed cross-sectional view of the heave compensator of fig. 1;
Fig. 3 is a schematic representation of the inventive heave compensator;
Fig. 4 is a front view on the heave compensator of fig 1 in a rest position on deck;
Fig. 5 is a bottom view on the heave compensator of fig 1;
Fig. 6 is a cross-sectional view of a central part of the heave compensator of fig 1.
Figs. 7a-b show a front and side view of a heave compensator;
Fig. 8 shows an isometric view of a heave compensator,

Figs. 9a-c show different positions of a heave compensator with horizontally oriented cylinders.

In fig. 1 a heave compensator 10 is shown. It is not shown how the heave compensator 10 is suspended from an offshore crane, in-line with a lower block of a hoist system of the offshore crane. It is common general knowledge to provide a crane with a hoist system comprising a hoist cable extending between a hoist winch and a lower block.

The heave compensator 10 is provided with a frame 11a, 11b and can be suspended in-line from the not-shown lower block. In the shown embodiment the heave compensator 10 can be suspended when a connector provided on the lower block, not show, is locked to the connector guidance funnel 12 provided at the heave compensator 10, here at a top frame 11a. Such a system is generally known as a quick connector system, e.g. as disclosed in WO2020/055249. Advantageously, an operable mechanism is provided, e.g. above the funnel 12, which operable mechanism is configured to, in a connection process, engage the connector of the lower block in a vertical engagement motion and to releasably lock the lower block to the heave compensator so as to suspend the heave compensator from the lower block, and in a disconnection process to unlock the lower block from the heave compensator and disengage the heave compensator and the connector.

The diameter of a top part of the funnel is e.g. up to 2 meters.

In fig. 2 further details of the quick connector interface 12’ are visible. Also, the top frame 11a with the connector guidance funnel 12 and the landing frame 11b supporting the have compensator are shown in more detail.

Alternative systems wherein the heave compensator is provided with a connector and the lower block with a connector funnel are also conceivable.

Any alternative connection system allowing the suspension of the heave compensator 10 from the lower block of the hoist system of the crane is conceivable.

In fig. 1 an object 1, here a portion of a monopile, is suspended from the heave compensator 10, here via a spreader 2. The spreader is connected to a lower end 21a of piston rod 21 of a vertical passive heave compensation system of the heave compensator 10. The spreader 2 comprises a first set of cables 2a to be connected to the lower end 21a of the piston rod 21, a spreader frame 2b and a second set of cables 2c to connect to object, here monopile 1, to the spreader frame. In fig. 1 two positions of the piston rod are indicated: the connected monopile 1 is shown in a lower position of the piston rod, while parts of the spreader 2 connected to the lower end 21a of the piston rod are also shown in an upper position of the piston rod.

In Fig. 2 the heave compensator 10 is shown in further detail. The heave compensator 10 comprises a vertical passive heave compensation system with a vertical passive cylinder 20 having a cylinder body 22 supported by the frame, here a landing frame 11b and a top frame 11a.

The vertical passive heave compensation system further comprises a piston 23, visible in fig. 3, and a vertically downwards extending piston rod 21. As shown in fig. 3, the piston delimiting a lower rod-side chamber 23a and an upper piston-side chamber 23b of the passive cylinder.

In view of the capacity of the heave compensator, the cylinder body as shown has a diameter of over 1 meter and a length of about 4,5 meter. The diameter of the piston rod is in the order of 50 cm. The stroke length of the piston rod suffices for its use as heave compensation system for the purpose of hoisting heavy loads under heave susceptible circumstances. The piston is able to translate in a vertical direction at a speed of up to 1 m/sec, more advantageously up to 0,75 m/sec.

The vertical passive heave compensation system further comprises one or more medium-separators 25, shown in detail in fig. 3, each having a hydraulic-side chamber 25a and a gas-side chamber 25b, which hydraulic-side chamber is connected to the rod-side chamber 23a of the passive cylinder. The volume of the hydraulic-side chamber of the medium-separator is e.g. in the order of 2500 litres. As visible in the top view in fig. 6, in this embodiment two medium-separators 25 are provided. The hydraulic pressure generated in the medium-separator is advantageously variable, and can e.g. be in the order of 330 bar.

The connection between the hydraulic-side chamber 25a of the medium-separator 25 and the rod-side chamber 23a of the passive cylinder allows the transfer of hydraulic fluid, advantageously at flow rates of up to 30.000 litres/ minute.

The pressure in the medium-separator 25 is generated by multiple pressurized gas tanks 26a-26t, e.g. comprising nitrogen, N_2, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator. In figs. 1 and 4 only five of these gas tanks are visible, in fig. 6 all tanks 26a-26t are visible. In fig. 3 two gas tanks 26a, 26b and associated gas tank valves 26a’, 26b’ are schematically shown. As visible in the top view in fig. 6, in this embodiment 20 gas tanks 26a-26t are provided. For example, each gas tank has a volume between 1000 -1500 litres.

The heave compensator further comprises a vertical active heave compensation system with a vertical column 31 connected to the downward extending piston rod 21 and extending vertically parallel to the passive cylinder 20. The vertical column 31 is vertically guided by the frame, in particular by upper column guides 32a supported by top frame 11a and lower column guides 21b supported by landing frame 11b.

A vertical rack 33 is mounted to the vertical column 31. The vertical active heave compensation system further comprises one or more pinions 34 and associated electric motors 35, supported by the frame, here by top frame 11a. A battery 36 is provided to supply power to the one or more electric motors. It is conceivable that in addition a supercapacitor is provided.

In the shown embodiment, four pinions are provided with associated motors, having an exemplary capacity of 100kW each. The battery may have a capacity of up to 500 kWh.

As shown in figs. 1, 2, 4 and 5 a utility unit 38 is advantageously provided at the landing frame 11b, for providing connections for battery charging and gas pressurizing. Here, on deck a power unit 39, here a 40ft deck container for HPU (hydraulic power unit) is provided, which can be connected to the utility unit 38.

In fig. 4 the heave compensator 10 is shown in a parking position, e.g. for charging the battery. The funnel 12 is ready to receive a connector of a lower block to be suspended in-line from the lower block. A bottom end of the downward extending piston rod 21a, suitable for connection of a spreader as visible in fig. 1, rests on deck.

The total height of the heave compensator as shown in fig. 4 can exceed 10 meters, e.g. up to 13 meters. The dimensions of the landing frame 11a are e.g. 6 x 6 meters, e.g. 6,5 x 6,5 meters.

Figures 7a-b, show an alternative heave compensator according to the second aspect of the invention. The compensator is shown in fully extended state.

The lower block 100 is suspended from a hoist cable 101 which passes over one or more sheaves of the lower block. A heave compensator 102 is mounted to the lower block 100. The heave compensator 102 is configured to support and object and provide at least a passive heave compensation.

The heave compensator 102 comprises a frame 103. The lower block 100 is secured to the frame, e.g. so that the frame 103 cannot move relative to the lower block 100.

The heave compensator 102 further comprises a vertical passive heave compensation system.

The vertical passive heave compensation system comprises two vertical cylinders 104. Each cylinder has a cylinder body 104a supported by the frame 103, a piston and a vertically downwards extending piston rod 104b, the piston delimiting a lower rod-side chamber and an upper piston-side chamber of the passive cylinder.

The vertical heave compensation system further comprises one or more, e.g. two, medium-separators, not shown, each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the piston-side chamber of the passive cylinder.

The vertical passive heave compensation system further comprises one or more, e.g. two, pressurized gas tanks 105, each tank is connected via a respective gas tank valve to the gas-side chamber of the medium-separator.

A vertical load connector 106 is connected to the two piston rods via a transverse connection frame 107. A lifting hook 108 is pivotable connect to the lower end of the vertical load connector.

The vertical load connector 106 is configured to move vertically with respect to the frame 102 when the two piston rods 104b are extended or retracted.

The frame 103 comprises a vertical guiding structure 109 which extends vertically along a majority of the length of the frame 103. The vertical guiding structure 109 guides the vertical load connector 106 when the vertical load connector moves vertically with respect to the frame 103.

All components of the heave compensation system 103 are housed at least partly inside of the frame 102.

The frame 102, vertical cylinders 104, medium separators, and pressurized tanks 105 define a central receiving opening which is configured to receive the vertical load connector 106.

The heave compensator has a retracted and extended position, the extended position is shown in figures 7a-b, wherein in the retracted position the vertical load connector is for its majority located inside of the frame and along the vertical cylinders and pressurised tanks.

The frame 102 can be connected to the lower block 100 via a pinned connection, which allows for a quick connection and disconnection.

Figure 8 shows an example of third aspect wherein a lower block 200 is suspended by a hoist cable 201 which extends between a hoist winch and the lower block 200.

A crane hook 202 is connected to the lower block 200 and is configured to support a load 203 when desired.

In the shown embodiment, the crane is provided with a secondary lifting tool which is embodied as a damping tool. The damping tool has four vertical cylinders 210 which are connected to the lower block 200. Each vertical cylinder comprises a piston 210a and a vertically downward extending piston rod 210b. Each piston 210a of the respective cylinder delimits a lower rod-side chamber and an upper piston-side chamber of the cylinder,

In an embodiment, the one or more vertical cylinders of the damping tool are filled with a compressible liquid or gas and/or comprises an overpressure relief valve.

In an alternative embodiment not shown, the secondary lifting tool is a heave compensator tool, wherein the heave compensator comprises:

- one or more medium-separators each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the rod-side chamber of the cylinder 210a;
- one or more pressurized gas tanks mounted to the lower block 200, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator.

A lower hoist frame 211 is only suspended from the lower ends of the four piston rods 210b.

The lower hoist frame 211 is annular, here shown as rectangular, and defines a central opening wherein the four vertical cylinders 210 are arranged at a respective corner of the rectangular hoist frame 211. In a top-down projection, the crane hook 203 is located within the central opening of the lower hoist frame 211.

Damping tool cables 212 extend from each corner of the rectangular lower hoist frame 211 towards a central connection point of the pile hammer 203. Alternatively, the damping tool cables extend towards different connection points of a load or a spreader.

In an embodiment not shown, the four vertical cylinders 210 are each connected to the lower block 200 via a multi-axis coupling, e.g. allowing the cylinders to swivel.

Figure 8 shows the lower frame 211 in the active position, wherein the lower hoist frame 211 is at a vertical distance below the crane hook 202 and configured to hoist an object 203. In the parking position, the lower hoist frame 211 is located at a vertical position above the crane hook 202, such that the crane hook can be used for hoisting an object without interference of the lower hoist frame.

The third aspect of the invention also relates to a method for the installation of a monopile in the seabed, wherein use is made of an offshore crane. The method comprising the following steps:

- connecting the monopile to the crane hook 202, e.g. via a monopile lifting tool;
- lifting the monopile onto the seabed in an upright position;
- disconnecting the crane hook 202 and possibly the monopile liftin from the monopile;
- connecting a pile hammer 203 to the lower hoist frame 211 of the damping tool;
- driving the monopile into the seabed using the pile hammer 203 supported by the damping tool.

Figures 9a-c show heave compensator 300 comprising a heave cylinder assembly 301 which is horizontally arranged inside of the lower block assembly 302 (dashed line). The lower block assembly 302 is connected to hoist cables 303 which extend between the hoist winch and the lower block assembly.

The heave cylinder assembly 301 comprises multiple, here two, horizontally oriented heave cylinders 304. Each heave cylinder comprises a cylinder body 304a, a piston 304b, and a piston rod 304c. The cylinder bodies 304a of both the first and second heave cylinders 304 are connected to the lower block assembly 302. The piston rod 304c of the first and second heave cylinder 304 are pivotably connected to a first tilt bracket 305a and second tilt bracket respectively 305b.

A first and second connection rod 306a, 306b each have a bracket end that is respectively connected to the first and second tilt bracket 305a, 305b. The first and second connection rod 306a, 306b are each at a frame-end thereof connected to a connection frame 307.

The connection frame 307 is connected to a load connector 308 from which a load can be suspended, here shown as a hoisting hook 308.

The first and second tilt brackets 305a, 305b are both pivotably connected to the lower block assembly 302 at opposite ends thereof around a tilt bracket pivot axis 309a, 309b, such that when the first and second heave cylinders 304 are extended or retracted the tilt bracket pivots 305a, 305b around the tilt bracket pivot axis 309a, 309b thereby moving the connection rods 306a, 306b up and down, such that the connection frame 307 and thus the load connector and load are moved in a substantial vertical direction.

Figure 9a shows the heave compensator in the lowest position of the connection frame 307, here the piston rods 304c are not extended.

Figure 9b shows the heave compensator in the highest position of the connection frame 307, here the piston rods 304c have been extended such that the first and second tilt brackets 305a, 305b are rotated around the tilt bracket pivot axis 309a, 309b. This pivots the connection point between the tilt brackets 305a, 305b and the connections rods 306a, 306 upwards, such that the connection frame is also moved upwards.

In an embodiment not shown, the two heave cylinders 304 each comprise a lower rod-side chamber and an upper piston-side chamber delimited by the piston,
wherein the horizontal heave assembly further comprises:

- one or more medium-separators each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the rod-side chamber of the passive cylinder,
- multiple pressurized gas tanks, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator.

In an embodiment, the horizontal heave cylinder assembly comprises a synchronisation system which is configured to synchronise the rotation of the first and second tilt brackets. If the rotation of the first and second tilt brackets is not synchronised, it could occur that the connection frame 307 becomes slanted.

In an embodiment, the synchronisation system is configured to operate the first and second heave cylinders on the basis of position control, such that the first and second horizontal cylinders extend and retract the same distance and simultaneously.

The lower block assembly 302 comprises two parallel lower block panels 310 spaced at a distance to define a space between the panels 310, wherein the lower block panels are connected to each other by lower block connection members, e.g. lower and upper plates. As shown in figures 9a,b, the horizontal heave cylinders 304 and tilt brackets 305a, 305b are arranged in the space between the lower block panels.

Four pressurised gas tanks 310 are connected to the lower block in a horizontal orientation.

Two pressurised gas tanks 310 are arranged on each side of the lower block assembly 302.

In an embodiment, the connection frame 307 is configured to comprise a load connector guidance structure, e.g. a funnel, see WO2020/055249. The load connector guidance structure allows for a quick and easy connection between the connection frame and the load connector, e.g. lifting hook.

In a not shown embodiment, the crane further comprises a spreader configured for lifting wind turbine parts such as a monopile, blade or nacelle, which spreader is connectable or connected to the load connector 308 to suspend from the heave compensator.

In an embodiment, a sensor and control system are provided, wherein the sensor is configured to measure the position and/or movement of the load and the lower block, and wherein the control system is configured to operate the heave compensator based on the information provided by the sensor to maintain a stable distance between the load and the lower block.

CLAIMS

1. Offshore crane for use on a vessel for handling an object (1), e.g. a wind turbine component, the crane comprising a hoist cable extending between a hoist winch and a lower block, wherein a heave compensator (10) is suspended in-line from the lower block, and wherein the object can be suspended from the heave compensator, e.g. via a spreader,

the heave compensator comprising a frame,

the heave compensator further comprising a vertical passive heave compensation system with:

- a vertical passive cylinder (20) having a cylinder body (22) supported by the frame (11a, 11b), a piston (23) and a vertically downwards extending piston rod (21), the piston delimiting a lower rod-side chamber (23a) and an upper piston-side chamber (23b) of the passive cylinder,
- one or more medium-separators (25) each having a hydraulic-side chamber (25a) and a gas-side chamber (25b), which hydraulic-side chamber is connected to the rod-side chamber (23a) of the passive cylinder,
- multiple pressurized gas tanks (26a-26t), each tank selectively connectable via a respective gas tank valve (26a’, 26b’) to the gas-side chamber (25b) of the medium-separator (25),

the heave compensator further comprising a vertical active heave compensation system with:

- a vertical column (31) connected to the downward extending piston rod and extending vertically parallel to the passive cylinder (20), wherein the vertical column is vertically guided by the frame, and wherein a vertical rack is mounted to the vertical column,
- one or more pinions (34) and associated electric motors (35), supported by the frame,
- a battery (36) to provide power to the one or more electric motors (35).

2. Offshore crane according to claim 1, wherein the heave compensator is configured:

- with the passive cylinder (20) vertically oriented at a central position,
- flanked by two opposite banks of vertically oriented pressurized gas tanks, e.g. each bank comprising a set of one of more pressurized gas tanks having the same pressure; and

- the one or more vertically oriented medium-separators between the banks of gas tanks at one side of the passive cylinder, and
- wherein the vertical column, rack and pinions of the active heave compensation system are provided between the banks of gas tanks at a side of the passive cylinder opposite the one or more medium-separators, and
- wherein the battery of the active heave compensation system is provided adjacent the one or more vertically oriented medium-separators.

3. Offshore crane according to one or more of the preceding claims, wherein distinct sets of pressurized gas tanks are provided, each set comprising one of more pressurized gas tanks having the same pressure.

4. Offshore crane according to one or more of the preceding claims, wherein the frame of the heave compensator comprises:
- a top frame (11a) suspended in-line from the lower block, the top frame supporting the cylinder body of the passive cylinder and one or more pinions and associated electric motors, and preferably also upper column guides (32a);
- a landing frame (11b) mounted to the cylinder body of the passive cylinder and preferably also comprising lower column guides (32b).

5. Offshore crane according to one or more of the preceding claims, the lower block is provided with a connector and the heave compensator comprises a connector guidance funnel (12).

6. Offshore crane according to one or more of the preceding claims, wherein a supercapacitor is provided to accept and deliver power from and to the electric motor when functioning as an electric generator.

7. Offshore crane according to one or more of the preceding claims, further comprising a spreader configured for lifting wind turbine parts such as monopiles, blades or nacelles, or for lifting freight containers, which spreader is connectable or connected to the heave compensator to suspend from the heave compensator.

8. Offshore crane according to one or more of the preceding claims, wherein a sensor and control system is provided using the information of the sensor to control the active heave compensation system, e.g. a position sensor to determine the distance between the object and the spreader, and wherein the information of the position sensor is used to operate the

active heave compensation system so as to maintain a stable distance between the spreader and the object to facilitate the connection of the object to the spreader.

9. Vessel, e.g. for the installation of an object, e.g. a wind turbine component, comprising an offshore crane according to one or more of the preceding claims 1-8.

10. A heave compensator configured to be suspended in-line from a lower block of an offshore crane comprising a hoist cable extending between a hoist winch and the lower block, and wherein an object can be suspended from the heave compensator, e.g. via a spreader; the heave compensator comprising a frame;

the heave compensator comprising a vertical passive heave compensation system with:

- a vertical passive cylinder having a cylinder body supported by the frame, a piston and a vertically downwards extending piston rod, the piston delimiting a lower rod-side chamber and an upper piston-side chamber of the passive cylinder;
- one or more medium-separators each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the rod-side chamber of the passive cylinder;
- multiple pressurized gas tanks, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator;

the heave compensator further comprising a vertical active heave compensation system with:

- a vertical column, connected to the downward extending piston rod and extending vertically parallel to the passive cylinder, wherein the vertical column is vertically guided by the frame, and wherein a vertical rack is mounted to the vertical column;
- one or more pinions and associated electric motors, supported by the frame;
- a battery to provide power to the one or more electric motors.

11. Offshore crane for use on a vessel for handling an object, e.g. a wind turbine component, the crane comprising a hoist cable extending between a hoist winch and a lower block, wherein a heave compensator is suspended in-line from the lower block, and wherein the object can be suspended from the heave compensator, e.g. via a spreader; the heave compensator comprising a frame;

the heave compensator comprising a vertical passive heave compensation system with:

- a vertical passive cylinder having a cylinder body, a piston and a vertically downwards extending piston rod supported by the frame, the piston delimiting a lower rod-side chamber and an upper piston-side chamber of the passive cylinder;
- one or more medium-separators each having a hydraulic-side chamber and a gas-side chamber, which hydraulic-side chamber is connected to the upper piston-side chamber of the passive cylinder;
- multiple pressurized gas tanks, each tank selectively connectable via a respective gas tank valve to the gas-side chamber of the medium-separator;

the heave compensator further comprising a vertical active heave compensation system with:

- a vertical column connected to the cylinder body and extending vertically parallel to the passive cylinder, wherein the vertical column is vertically guided by the frame, and wherein a vertical rack is mounted to the vertical column;
- one or more pinions and associated electric motors, supported by the frame;
- a battery to provide power to the one or more electric motors.

12. Hoisting method for an object, e.g. a wind turbine component, wherein use is made of a vessel according to claim 9, comprising the steps of:

a) providing the object on a vessel susceptible to heave;

b) optionally connecting the heave compensator to the crane and providing the heave compensator of the offshore crane in the vicinity of the object;

c) connecting the object to the heave compensator;

d) operating the passive heave compensation system and optionally the active heave compensation system and hoisting the object.

13. Hoisting method according to claim 12, wherein prior to step c) the method furthermore comprises the steps of:

- connecting a spreader to the heave compensator to suspend from the heave compensator;
- providing a position sensor to determine the distance between the object and the spreader;
- using information from the position sensor to operate the active heave compensation system so as to maintain a stable distance between the spreader and the object to facilitate the connection of the object to the spreader.

14. Hoisting method according to claim 12 or 13, wherein distinct sets of pressurized gas tanks are provided, each set comprising one of more pressurized gas tanks having the same

pressure, and wherein during step d) first one set of tanks is connected to the medium-separator, followed by another set of tanks.

15. Hoisting method according to any one or more of claims 11 - 14, wherein prior to step d), the method comprises the step of providing a position sensor to determine the distance between the object and the spreader; and during step d) using information from the position sensor to operate the active heave compensation system as a brake mechanism for the upward motion of the piston rod of the passive cylinder, in particular when high-pressure tanks are connected to the gas-side chamber of the medium-separator to enable fast lifting.

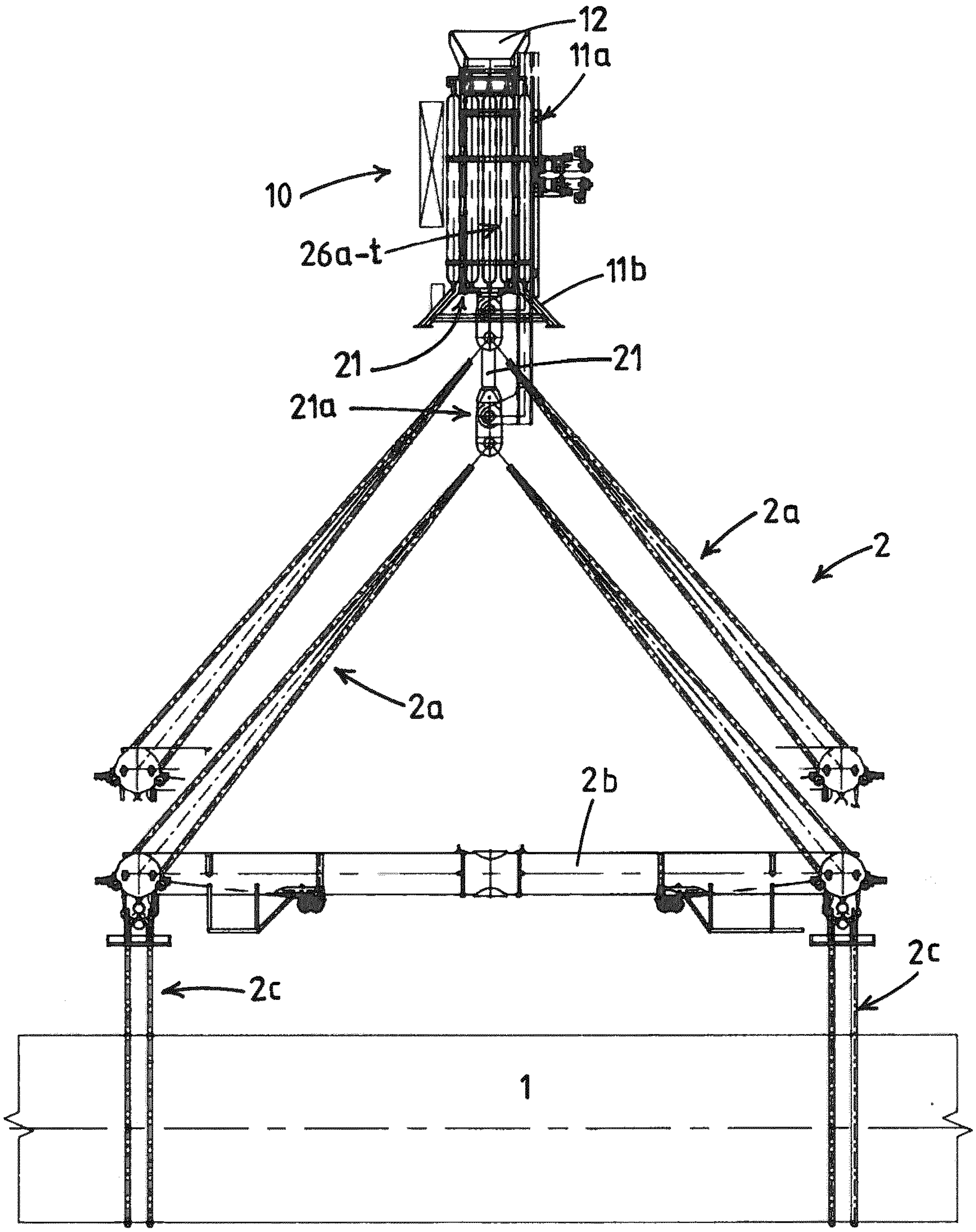

Fig.1

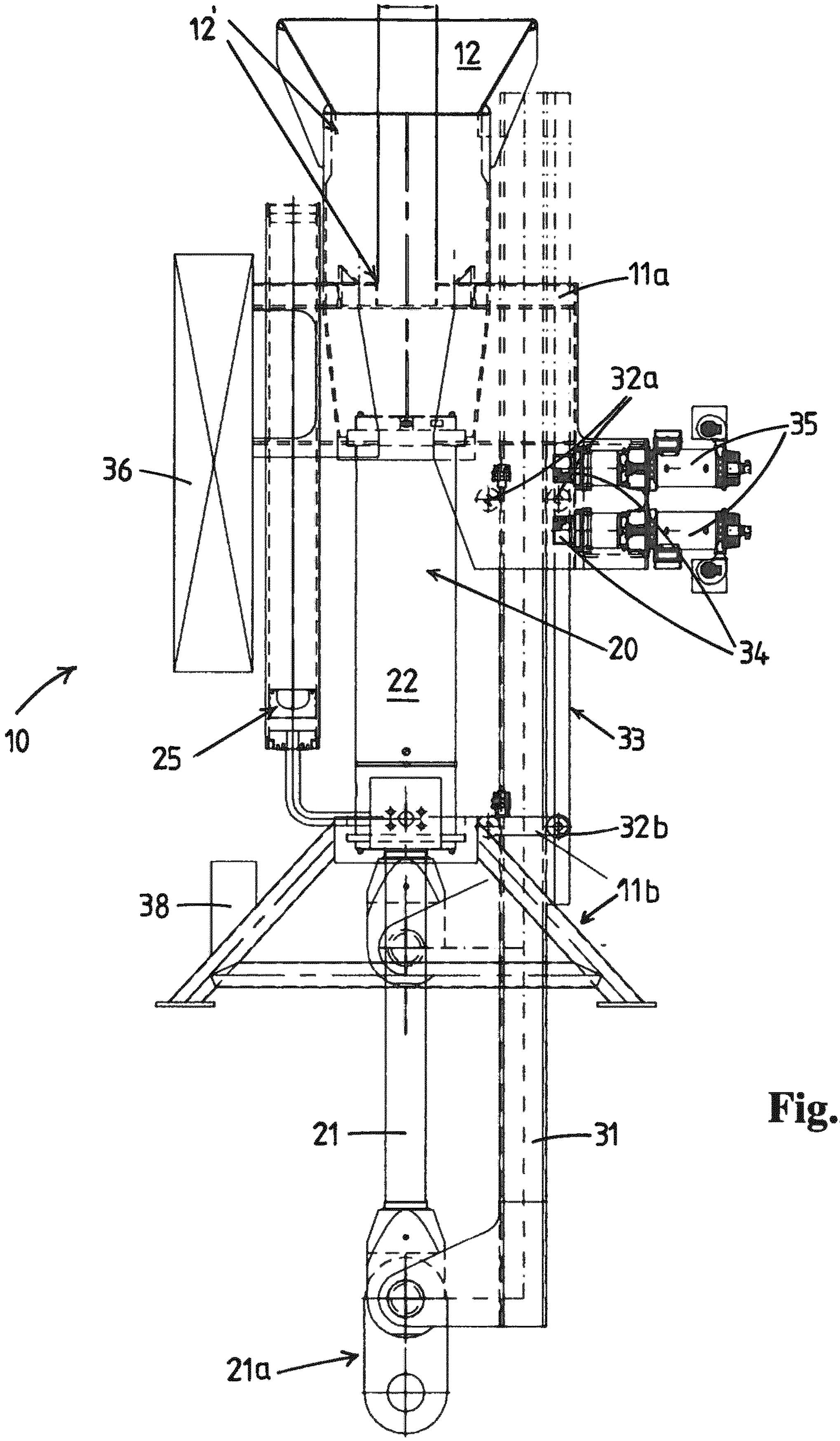

Fig.2

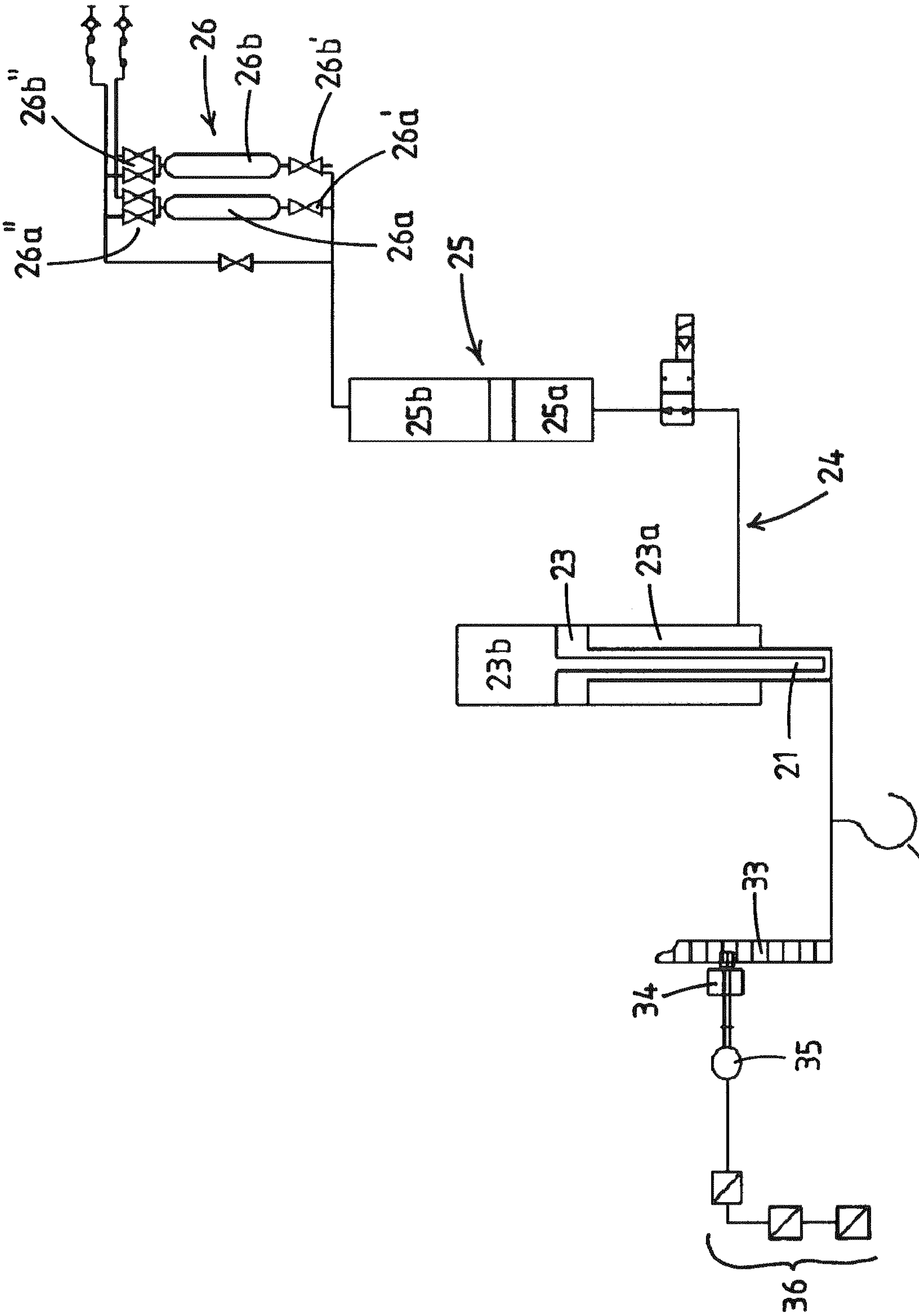
26
26b
26b'
26b''
26a'
26a''
26a
25
25b
25a
24
23
23a
23b
21
21a
33
34
35
36

Fig.3

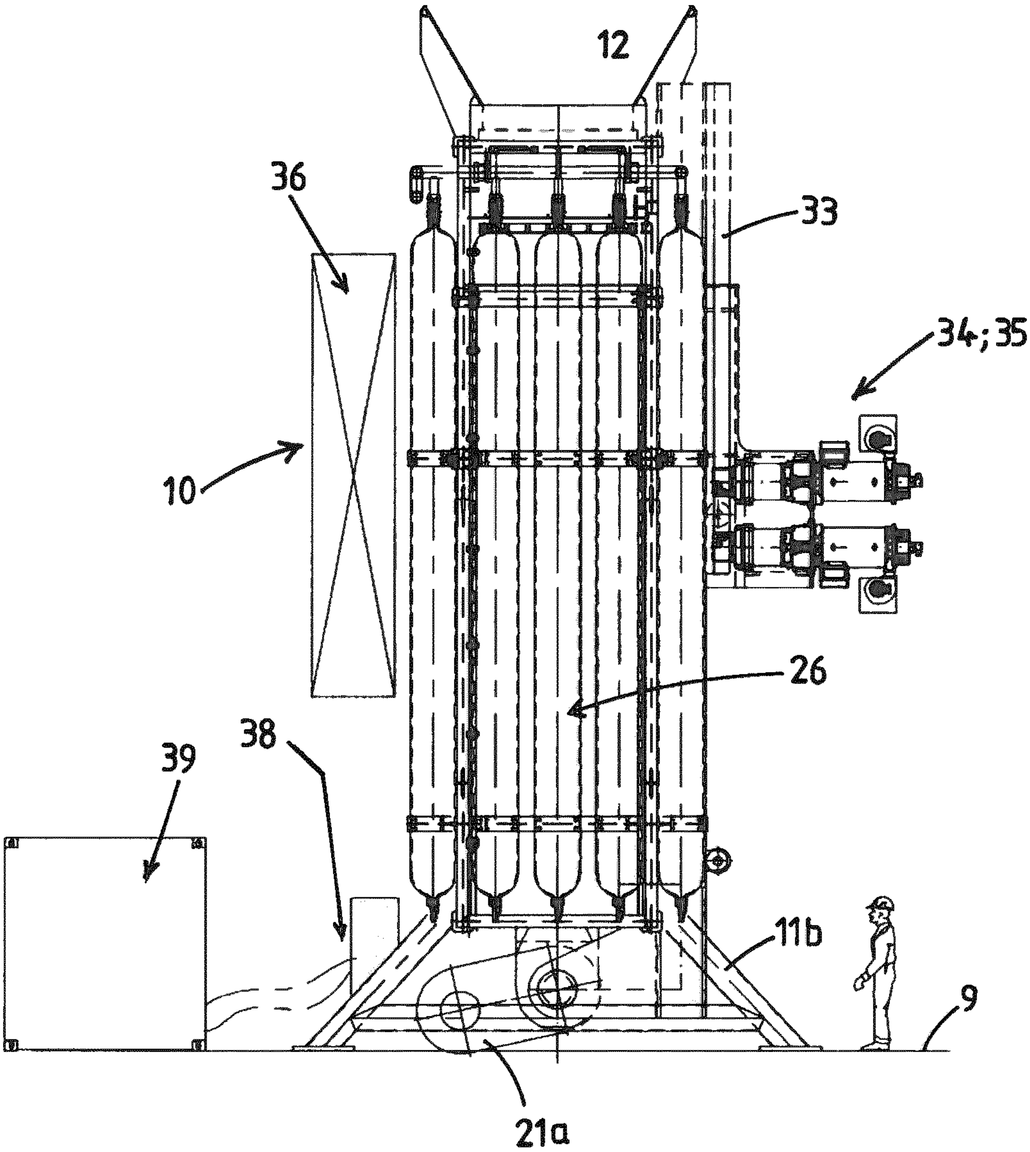

Fig.4

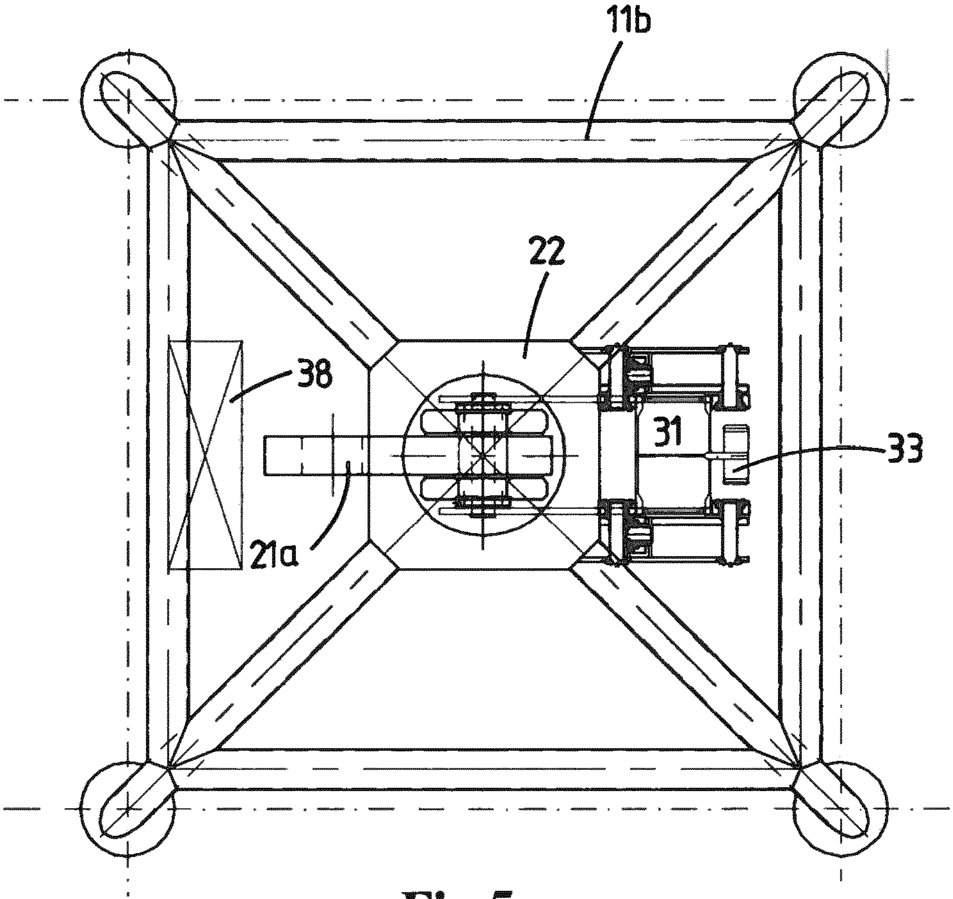

Fig.5

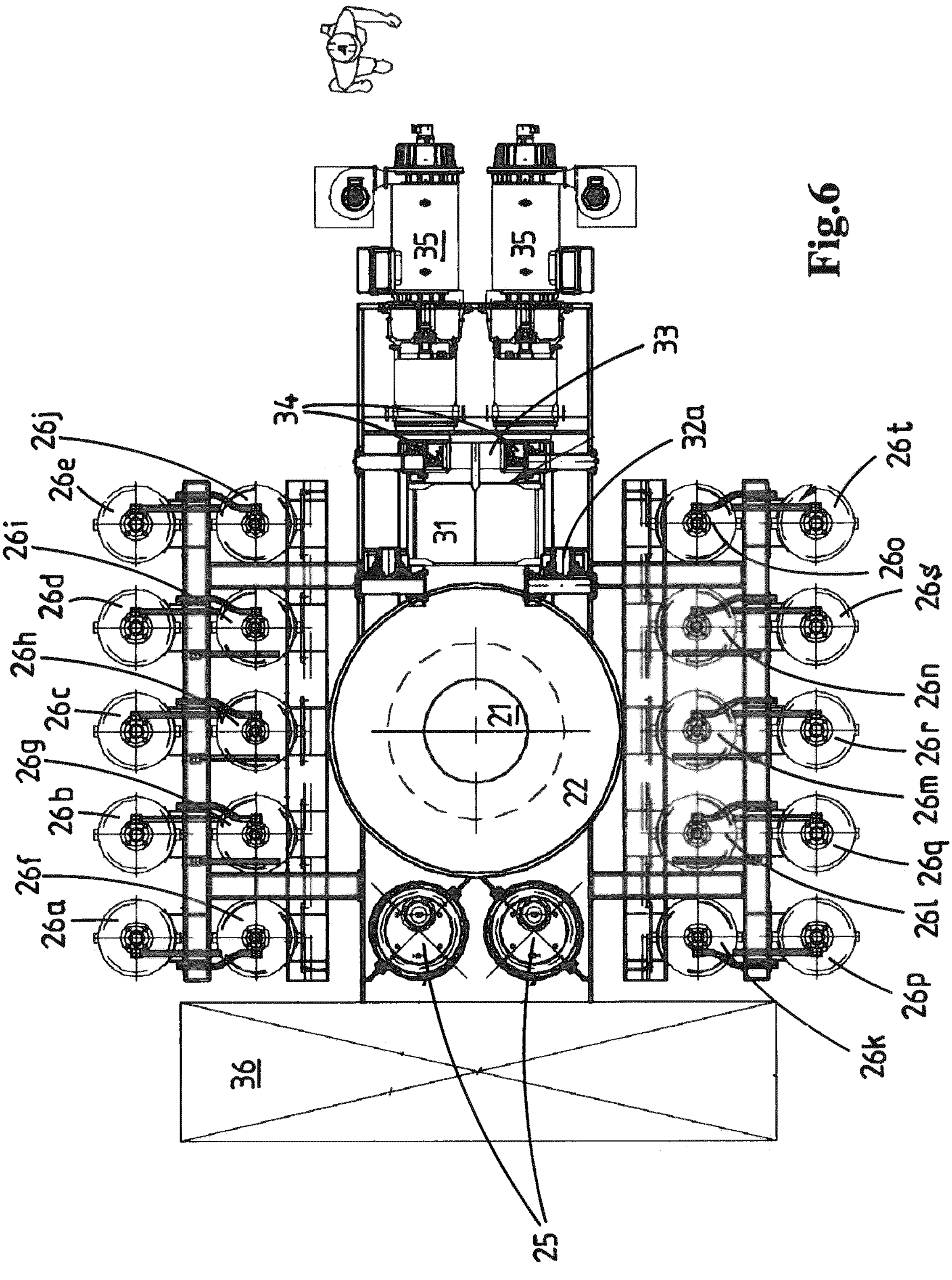
35
35
33
34
32a
31
21
22
25
36
26a
26b
26c
26d
26e
26f
26g
26h
26i
26j
26k
26l
26m
26n
26o
26p
26q
26r
26s
26t

Fig.6

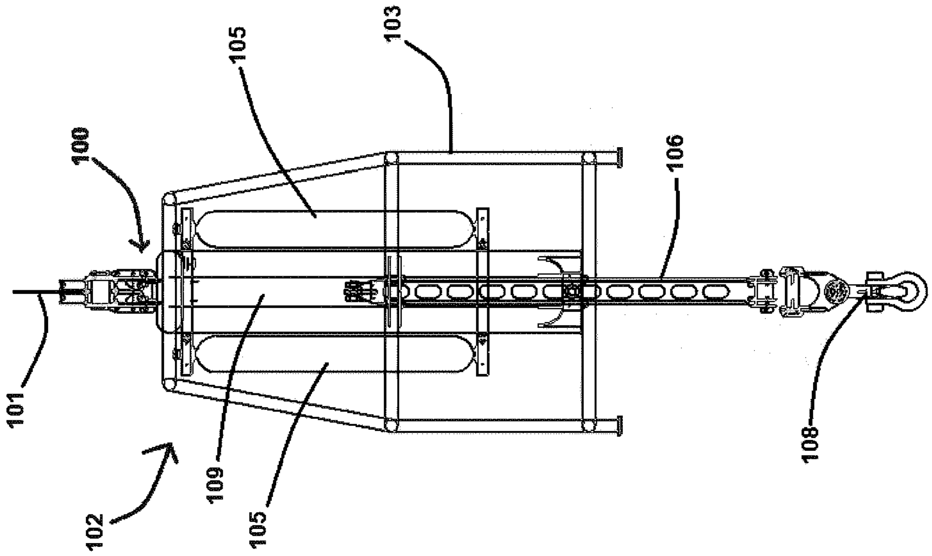
100
101
102
103
105
105
106
108
109

Fig. 7b

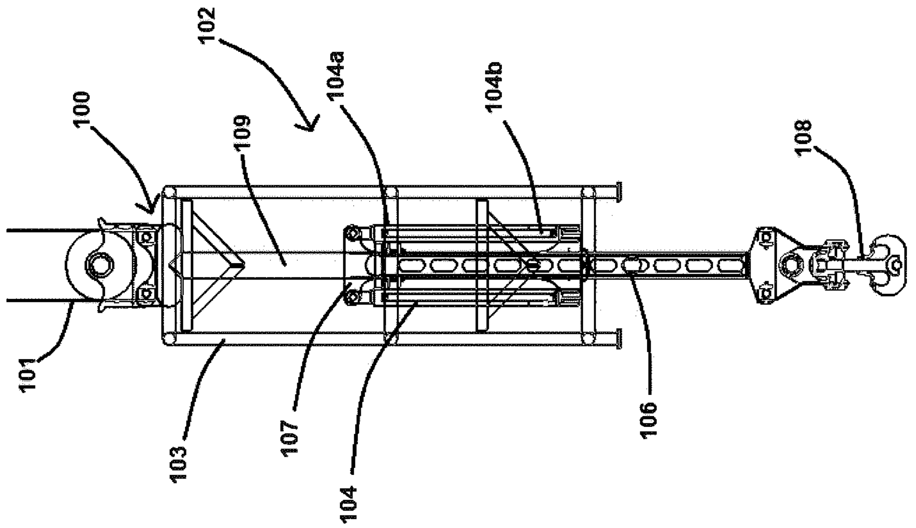
100
101
102
103
104
104a
104b
106
107
108
109

Fig. 7a

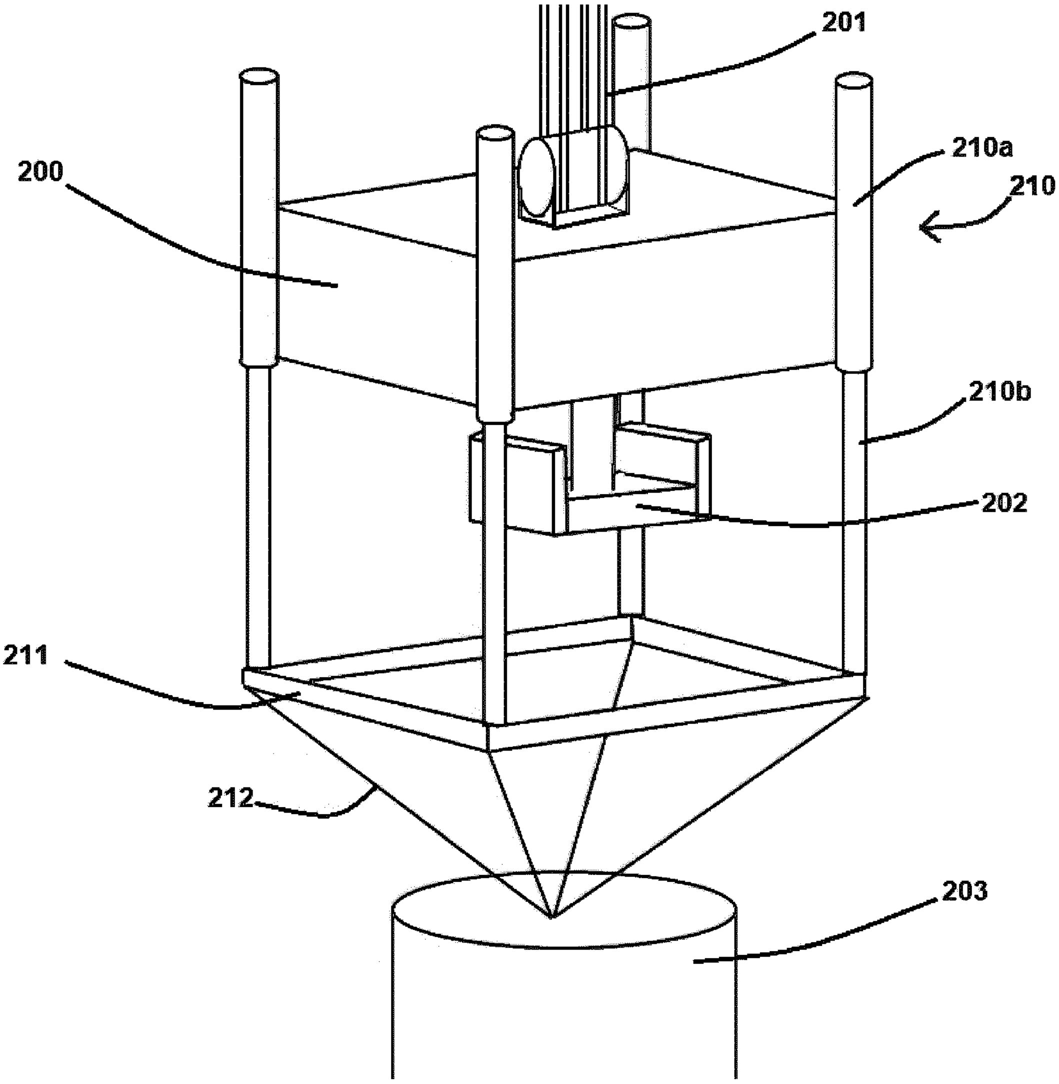

Fig. 8

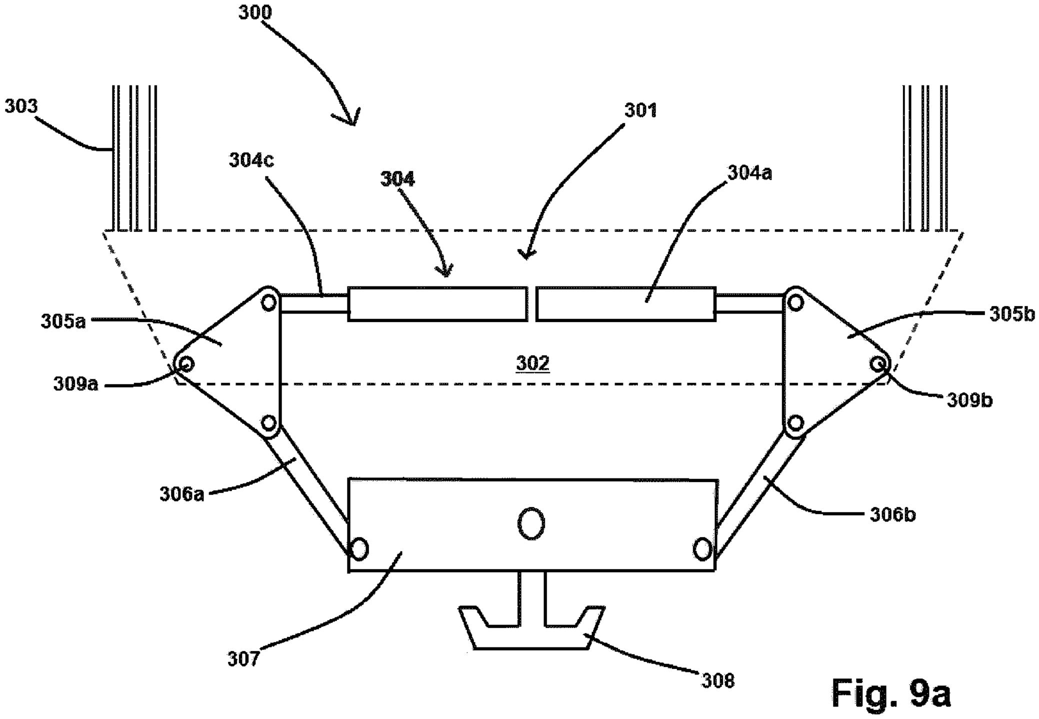
300
303
304c
304
301
304a
305a
302
305b
309a
309b
306a
306b
307
308

Fig. 9a

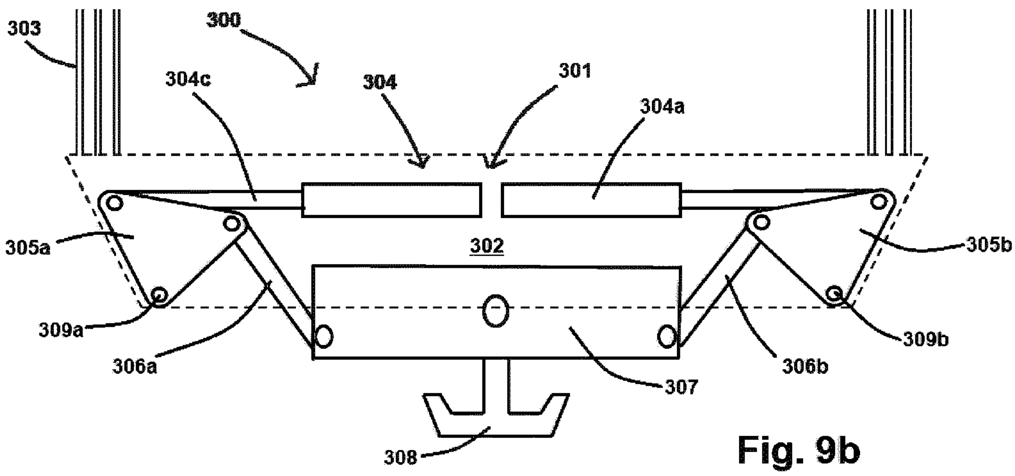
303
300
304c
304
301
304a
305a
302
305b
309a
306a
307
306b
309b
308

Fig. 9b

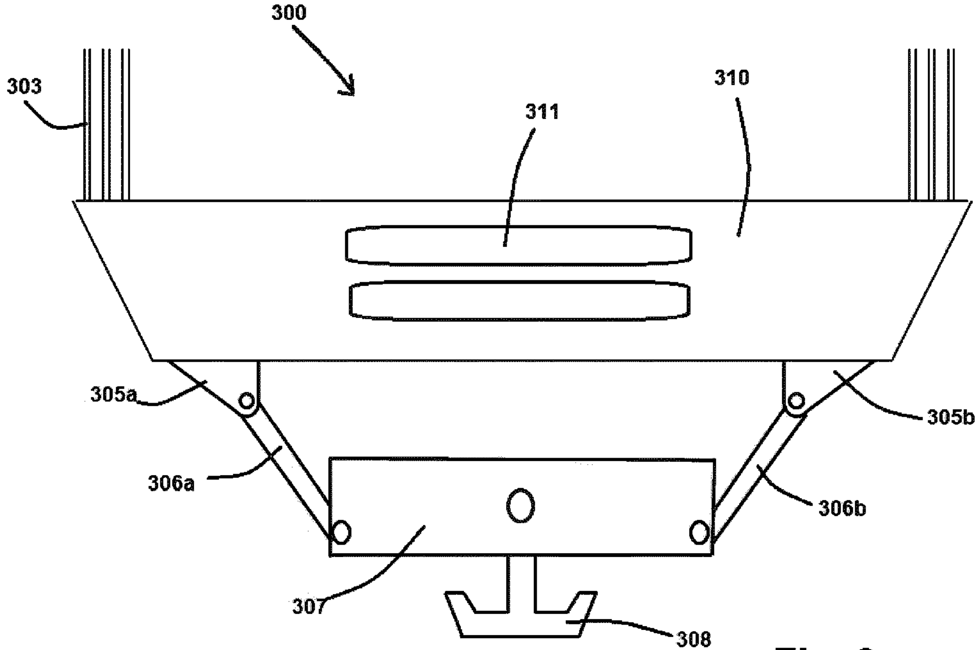

Fig. 9c

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2024/069091

A. CLASSIFICATION OF SUBJECT MATTER
INV. B66C13/02
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
B66C B63B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	NO 343 296 B1 (SAFELINK AS [NO]) 21 January 2019 (2019-01-21) abstract page 8 - page 10 figures -----	1-15
A	DE 10 2017 206595 A1 (BOSCH GMBH ROBERT [DE]) 1 March 2018 (2018-03-01) abstract paragraph [0058] - paragraph [0059] figure 6 -----	1,9-12
A	FR 2 180 557 A1 (INST FRANCAIS DU PETROLE [FR]) 30 November 1973 (1973-11-30) page 6, line 14 - line 30 figure 3 -----	1,9-12

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 September 2024	15/10/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Sheppard, Bruce

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2024/069091

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
NO 343296 B1	21-01-2019	NONE	
DE 102017206595 A1	01-03-2018	DE 102017206595 A1 EP 3290384 A1	01-03-2018 07-03-2018
FR 2180557 A1	30-11-1973	NONE	