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(54) **VESSELS WITH ROLL DAMPING MECHANISM**

WASSERFAHRZEUGE MIT ROLLDÄMPFUNGSMECHANISMUS

NAVIRES ÉQUIPÉS D'UN MÉCANISME D'AMORTISSEMENT EN ROULIS

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(73) Proprietor: **Itrec B.V.**  
**3115 HH Schiedam (NL)**

(72) Inventors:  
• **BEREZNITSKI, Alexel**  
**2625 JP Delft (NL)**

• **VAN HEERD, Ferdinand**  
**2645 JN Delfgauw (NL)**  
• **ROODENBURG, Joop**  
**2612 HA Delft (NL)**

(74) Representative: **De Grave-Wolterink, Isabelle**  
**Exter Polak & Charlouis B.V. (EP&C)**  
**P.O. Box 3241**  
**2280 GE Rijswijk (NL)**

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## Description

**[0001]** The invention relates to a monohull heavy lift crane vessel and to a monohull offshore drilling vessel.

**[0002]** Heavy lift cranes of the type mentioned in the preamble of claim 1 have already been commercially available from the applicant for decades, in particular for installation on a vessel, such as for example a cargo vessel, a tender ship used in the offshore industry, etc. Such a monohull vessel with a heavy lift crane is e.g. suitable to support the construction and maintenance of offshore surface and sub-sea oil and gas field development facilities. A heavy lift mast crane with a lift capacity of 3000 ton has been built by the applicant for the Sapura 3000, a heavy lift and pipelay vessel.

**[0003]** In general a heavy lift crane vessel is provided with a water ballast system that allows to compensate for static heel caused by the weight of the jib and possible suspended load during lifting operations, in particular when overboarding a load. Such a water ballast system usually comprises water ballast tanks and associated pumps in the hull of the vessel. In general the pump capacity forms a limitation on the ballast transfer and in practice limits the slew speed of the jib of the crane.

**[0004]** It is known to stabilize a crane vessel additionally by an active roll damping mechanism. Such a mechanism actively suppresses rolling motion. Rolling motion is the rotational movement about the ship's longitudinal axis, which is generated by a wave-excited moment that periodically opposes a moment on the ship. With crane vessels even small roll moments can produce large roll excursions as a result of the load suspending from the heavy lift crane.

**[0005]** An example of an active roll damping mechanism based on the use of a Voith Schneider Propellor is described in US 2007/0123120. A disadvantage of this active roll damping mechanism is its limited capacity for vessels with heavy lift cranes, in particular for heavy lift cranes with a lift capacity of 1500 tons or more.

**[0006]** EP 1304289 discloses moving a train of masses along an U-shaped rail.

**[0007]** It is an object of the present invention is to provide a monohull vessel with a heavy lift crane, the vessel being equipped with an improved active roll damping mechanism.

**[0008]** This object is achieved by equipping the heavy lift crane vessel with an active roll damping mechanism comprising a solid roll damping ballast which is movable in the transverse direction of the hull, a sensor detecting the rolling motion of the hull, and a drive and control system operable to cause and control the movements of the solid roll damping ballast in response to the detections of the sensor to provide roll stabilization.

**[0009]** Thus, active roll stabilization is accomplished by producing a counteracting moment by means of actively controlled solid ballast. A sensor detects the rolling motion and a drive and control system controls the counteracting moment as required.

**[0010]** The mechanism can be used in dynamic mode, wherein the reciprocal transverse motion of the solid ballast is matched to counteract the sea wave induced rolling motion of the vessel, and in a static or semi-static mode, wherein the solid ballast is used to counteract heel induced by the jib or a (light) load suspended from the crane (e.g. during slewing).

**[0011]** The vessel provided with a heavy lift crane may operate at a high slew speed of the jib due to its active roll damping mechanism. Obviously the "slower" water ballast may simultaneous be used to counteract heel of the vessel during slewing of the jib (e.g. with a light load).

**[0012]** The present invention also relates to a monohull offshore drilling vessel for use in the offshore oil and gas drilling industry. This vessel according to the invention is equipped with an active roll damping mechanism comprising a solid roll damping ballast which is movable in the transverse direction of the hull, a sensor detecting the rolling motion of the hull, and a drive and control system operable to cause and control the movements of the solid roll damping ballast in response to the detections of the sensor to provide roll stabilization.

**[0013]** It will be appreciated that the inventive monohull offshore drilling vessel can also be provided with one or more features disclosed herein with reference to a monohull heavy crane vessel and vice versa.

**[0014]** It is noted that the French nuclear powered aircraft carrier Charles De Gaulle is equipped with a computerised, integrated stabilisation system designed to maintain stabilisation to within 0.5 degrees of horizontal, allowing aircraft to be operated up to Sea State 5/6. As well as the carrier's two pairs of active stabilising fins and twin rudders, the system has two computer controlled compensation units which consist of two straight rail tracks for trains carrying 22 tonnes of deadweight. These tracks run transversely below the flight deck. This system is designed to compensate for wind and heel and control roll, yaw and surge. A further development of this air craft carrier stabilisation system is disclosed in US 6,349,660. A further development of this system for small vessel having a train of ballast bodies mounted on U-shaped tracks is disclosed in EP 1304289.

**[0015]** The heavy lift crane vessel according to the invention preferably has a mast crane with a maximum hoisting capacity of at least 3000 tons, more preferably having a hoisting capacity of 5000 tons or more.

**[0016]** The height of the mast of the crane preferably exceeds 75 meters, while the length of the jib may exceed 75m.

**[0017]** The radius of a hoisting cable guided by a hoisting cable guide at the outer end of the jib, which may be referred to as the whip hoist, may be up to 122 m.

**[0018]** The monohull vessel with a mast crane according to the invention is preferably suitable to handle large subsea modules, e.g. modules up to 600 tons at 3000 meters water depth.

**[0019]** In a preferred embodiment of the invention, the crane is provided at the stern of the vessel.

**[0020]** Preferably the heavy lift crane vessel is prepared to also accommodate S-lay pipelaying equipment or equipped with such equipment.

**[0021]** In a preferred embodiment, the vessel according to the invention is further provided with dynamic positioning means, which are preferably operable together with the active roll damping mechanism during hoisting or drilling operations.

**[0022]** The active roll damping mechanism according to the invention comprises a solid roll damping ballast which is movable in the transverse direction of the hull.

**[0023]** For the heavy lift crane vessel the total mass of the roll damping ballast preferably is between 500 and 2500 tons, more preferably between 1000 and 2000 tons, e.g. 1000 or 1500 tons.

**[0024]** For the drilling vessel the total mass of the roll damping ballast is preferably between 100 and 750 tons, more preferably between 200 and 400 tons, e.g. 300 tons.

**[0025]** Preferably the roll damping mechanism is formed such that a single ballast body is mounted on and guided along a set of associated rail tracks, in contrast to the known aircraft carrier system with a train of ballast bodies being mounted on a set of rail tracks. This allows to avoid any problems associated with the interconnections of the ballast bodies within the train of ballast bodies. Also this allows to displace the centre of gravity of the ballast body as much as possible outwards with respect to the centreline of the vessel, thus obtaining an increased restoring moment.

**[0026]** Preferably a ballast body is embodied as a monolithic metal block, or a set of metal blocks fixed to each other so as to form a single solid body, having a weight of at least 100 tons, in order to arrive at a compact ballast body.

**[0027]** Preferably a ballast body has a height that is greater than its transverse dimension, thereby allowing to displace the centre of gravity of the ballast body as much as possible outwards with respect to the centreline of the vessel, thus obtaining an increased restoring moment.

**[0028]** The wave-excited moment opposed on the crane vessel typically has a wave period of 5-25 seconds. To move such a large solid roll damping ballast at such high frequency, a drive system with a very large power capacity is required, even up to several megawatts. Preferred embodiments have a power capacity of more than 2,5 megawatts, e.g. 3 or 4 megawatts.

**[0029]** When suitably dimensioned the roll damping ballast mechanism is expected to decrease the static heel of a crane vessel provided with a 5000 tons heavy lift mast crane from over 9 degrees to less than 3 degrees with a horizontally extending jib directed transverse with respect to the vessel.

**[0030]** The active roll damping mechanism gives a significant improvement of the crane-vessel performance for light load operations as well as significant improvement of workability in offshore conditions.

**[0031]** The roll damping mechanism can compensate

the static heel caused by slew motion of the crane hoisting light loads significantly. The reaction time of this system is preferably quicker than the slew speed of the crane meaning that the speed of crane operations is not limited by the new anti heel system.

**[0032]** The principle of the mechanism is to create a restoring moment. In case of slewing the crane with light loads this restoring moment will compensate the heel moment caused by the weight of the jib of the crane. In case of roll motions the restoring moment will compensate the roll moment caused by waves.

**[0033]** The active roll damping mechanism on the monohull drilling vessel allows for a significant increase of workability in offshore conditions, e.g. in hostile environment and weather conditions, e.g. obviating the need to employ more expensive semi-submersible drilling vessels.

**[0034]** Further advantageous embodiments are described in the dependent claims and in the following description with reference to the drawing.

**[0035]** In the drawing:

Fig. 1 diagrammatically depicts an offshore vessel with a heavy lift mast crane, which is suitable, inter alia, for laying a pipeline on the seabed,

Fig. 2 shows the hoisting crane at the rear side of the vessel shown in Fig. 1, partially in the form of a cut-away view,

Fig. 3 shows the hoisting crane from Fig. 2 from a different direction,

Fig. 4 shows a view of the hoisting crane shown in Figs. 2 and 3 from above,

Fig. 5 shows a cross-section of the hull of the vessel of figure 1,

Fig. 6 shows a monohull offshore drilling vessel,

Fig. 7 shows a transverse section over the line VII - VII in figure 8,

Fig. 8 shows in plan view of part of the vessel of figure 6,

Fig. 9 shows in plan view the part of figure 8 at a lower deck level,

Fig. 10 shows a longitudinal section of the vessel of figure 6.

**[0036]** Figure 1 shows an offshore heavy lift crane vessel 1 which is also suitable, inter alia, for laying a pipeline on the seabed.

**[0037]** The vessel 1 has a monohull 2 with a working deck 3 and, at the front of the hull 2, a superstructure 4 for crew accommodation, etc.

**[0038]** The vessel 1 is equipped with a water ballast system, e.g. including anti-roll tanks 12. Water ballast systems are known in the art, e.g. the open-bottom tank system which reduces roll by modifying the roll resonance period.

**[0039]** In this example the vessel 1 has a length of 180 meters and a beam of 46 meters.

**[0040]** The vessel 1 in this example is also provided

with a pipeline-laying installation, here of the S-lay type, with one or more welding stations on the working deck 3, for coupling pipeline sections 9a in a substantially horizontal orientation. On the working deck 3 there are also what are known as tensioners 8 for carrying the weight of the pipeline 9 which is hanging downwards from the vessel 1. The vessel may also be equipped with another type of pipeline-laying installation, e.g. a (rigid) reel lay installation.

**[0041]** Furthermore, the vessel 1 has a stinger 5 which projects outside the hull 2 of the vessel 1 at the rear side of the vessel 1, engages on the hull 2 at an engagement point such that it can pivot about a substantially horizontal pivot structure 6 and forms a downwardly curved support for pipeline moving towards the seabed.

**[0042]** Furthermore, the vessel 1 has a heavy lift crane 20, in this embodiment disposed in the vicinity of the same side of the hull as the stinger 5, here at the stern of the hull 2, which hoisting crane 20 has a vertical structure fixed to the hull 2. The hoisting crane 20 will be described in more detail below. Here, the crane 20 is disposed above the location where the pipeline 9 leaves the working deck 3, on the longitudinal axis of the vessel 1.

**[0043]** The hoisting crane 20, which is illustrated in detail in Figures 2-4, has a substantially hollow vertical column 21 with a foot 22, which is fixed to the hull 2 of the vessel 1. Furthermore, the column 21 has a top 23.

**[0044]** The hoisting crane 20 has a jib 24, which is illustrated in two different positions in Figure 1. An annular bearing structure 25 extends around the vertical column 21 and guides and carries a jib connection member 26, so that the jib connection member 26, and therefore the jib 24, can rotate about the column 21.

**[0045]** In this case, the jib connection member 26 forms a substantially horizontal pivot axis, so that the jib 24 can also be pivoted up and down. There is at least one drive motor 27 for displacing the jib connection member 26 along the annular bearing structure 25. By way of example, the annular bearing structure 25 comprises one or more guide tracks which extend around the column 21 and on which an annular component 28 of the jib connection member 26 is supported via running wheels. Jib securing supports 29 are arranged on the component 28 at two positions. The drive motor 27 may, for example, drive a pinion which engages with a toothed track around the column 21.

**[0046]** To pivot the jib 24 up and down, there is a topping winch 30 provided with a topping cable 31 which engages on the jib 24.

**[0047]** Furthermore, the hoisting crane 20 comprises a hoisting winch 35 for raising and lowering a load, with an associated hoisting cable 36 and a hoisting hook 37.

**[0048]** At the top 23 of the column 21 there is a top cable guide 40 provided with a cable pulley assembly 41 for the topping cable 31 and a cable pulley assembly 42 for the hoisting cable 36.

**[0049]** One or more cable pulley assemblies 43 for the hoisting cable 36 and a cable pulley assembly 44 for the

topping cable 31 are arranged on the jib 24. The number of cable parts for each cable can be selected as appropriate by the person skilled in the art.

**[0050]** The winches 30 and 35 are in this case disposed in the foot 22 of the vertical column 21, so that the topping cable 31 and the hoisting cable 36 extend from the associated winch 30, 35 upward, through the hollow vertical column 21 to the top cable guide 40 and then towards the cable guides 43, 44 on the jib 24.

**[0051]** The top cable guide 40 has a rotary bearing structure, for example with one or more running tracks around the top of the column 21 and running wheels, engaging on the running tracks, of a structural part on which the cable pulley assemblies are mounted. As a result, the top cable guide 40 can follow rotary movements of the jib about the vertical column 21 and adopt substantially the same angular position as the jib 24.

**[0052]** The top cable guide 40 may have an associated drive motor assembly which ensures that the top cable guide 40 follows the rotary movements of the jib 24 about the column 21, but an embodiment without drive motor assembly is preferred.

**[0053]** The jib winch 31 and the hoisting winch 35 are arranged on a rotatable winch support 50, which is rotatable about a rotation axis substantially parallel with the vertical column 21. The movable winch support 50, which is mounted movably with respect to the vertical column 21. The winch support 50 here is located in the vertical crane structure, preferably in the region of the foot 22 under the circular cross section part of the column 21, and is mechanically decoupled from the top cable guide 40. The support 50 could e.g. also be arranged in the hull of the vessel below the column, e.g. the foot could have an extension which extends into the hull.

**[0054]** In the example shown, the winch support 50 is a substantially circular platform which at its circumference is mounted in an annular bearing 51, with the winches 31, 35 arranged on the platform. The annular bearing 51 is in this case such that the platform can rotate about a vertical axis which coincides with the axis of rotation of the top cable guide. The bearing can have any appropriate design including trolleys running along a circular track.

**[0055]** The rotatable winch support 50 has an associated drive motor assembly 52 for moving the winch support 50, in such a manner that the winch support 50 maintains a substantially constant orientation with respect to the jib 24 in the event of rotary movements of the jib 24 about the vertical column 21. The orientation of the winch support 50 with respect to the top cable guide 40 likewise remains substantially constant, since its movements are once again the consequence of rotary movements of the jib 24.

**[0056]** In the embodiment shown, there is an angle sensor 60 for detecting the position of the component 28 of the jib connection member 26 with respect to the vertical column 21, the drive motor assembly 52 of the winch support 50 having associated control means 53 which

are in operative contact with the angle sensor 60.

**[0057]** The winches 31, 35 each have an associated electrical (or electro-hydraulic) winch drive motor assembly 38, 39 which is disposed on the movable winch support 50. The electrical energy required is supplied by generators disposed elsewhere on the vessel, at a distance from the movable winch support 50. One or more sliding contacts (not shown) are provided in the electrical connection between these generators and the winch drive motor assemblies 38, 39.

**[0058]** In a variant which is not shown, the winch support 50 can rotate about a vertical shaft, this shaft being provided with one or more sliding contacts. In such an embodiment, the deep water lowering cable extends through the centre of such shaft.

**[0059]** Via the one or more sliding contacts, a power current supply is preferably fed to the electrical equipment on the winch support 50.

**[0060]** The hoisting crane 20 is provided with a cab 70 for a hoisting crane operator, which cab 70 is in this case carried by the annular bearing structure 25 to which the jib 24 is secured, so that the cab 70 can rotate with the jib about the vertical column 21.

**[0061]** In the cab 70 there are at least control members (not shown) for operating the winch 35 of the hoisting cable 36 and for operating the winch 31 of the topping cable 31. The winch drive motor assemblies 38, 39 have associated control means (not shown) which are in wireless communication with the associated control members in the cab 70. By way of example, a plurality of wireless transmission/reception units are disposed around the vertical column, in or in the vicinity of the path of the cab 70 around the vertical column.

**[0062]** The control means, for example electronic control equipment, for the one or more winches on the winch support 50 are preferably also positioned on this winch support 50.

**[0063]** It can be seen from the figures that, as is preferred, the vertical column 21 has a substantially continuous outer wall. In this case, the horizontal section through the vertical column is substantially circular from the jib connection member to the top 23, with the cross section gradually decreasing towards the top of the column. The foot 22 of the column 21 is substantially rectangular, which has the advantage that the foot 22 can easily be secured (by welding or using bolts) to the longitudinal and cross bulkheads of the hull 2 of the vessel 1. In a variant which is not shown, the vertical column is partly or completely a framework of bars.

**[0064]** It can be seen from Figure 1 that a load-bearing connecting structure 80, which holds the stinger in a desired position, extends between the vertical structure of the hoisting crane 20 at a location above the point of engagement 6 of the stinger 5 on the vessel hull 2 (in this case in the vicinity of the annular bearing structure for the jib 24), and the stinger 5, at a location remote from the point of engagement 6 of the stinger 5 on the vessel hull 2.

**[0065]** The vessel 1 can be used to lay a pipeline 9, but also for hoisting work, such as the hoisting work carried out, for example, in the offshore industry when installing platforms, underwater installations, etc.

5 **[0066]** In figure 5 a cross-section of the vessel 1 is shown. In the hull of the vessel, preferably below the main deck 100 on the between deck 120 as shown here, the vessel has a room 101 wherein the roll damping mechanism is located. This mechanism here includes a number of solid ballast bodies 110 which are displaceable in a reciprocable manner in the transverse direction of the hull.

10 **[0067]** As can be seen the transverse distance for travel of the solid ballast bodies 110 is at least 10 meters to either side of the centreline of the vessel, more preferably at least 15 meters. As is even more preferred the entire beam of the vessel with the exception of the outer compartments of the vessels hull is made available for the travel of the solid ballast bodies 110.

15 **[0068]** Preferably, the ballast body 110 is a solid metal block, or a number of solid metal blocks or plates. Alternatively, the ballast body includes a length of cable or chain, e.g. for underwater operations. In an alternative embodiment, the ballast body comprises vessel related equipment or supplies (spare parts etc.).

20 **[0069]** Here each ballast body 110 is equipped with rollers 111, and the vessel has one or more straight tracks extending transverse relative to the vessel and having opposed ends near the sides of the hull. Obviously other guide and bearing arrangements than one or more tracks and rollers on the ballast body can be envisaged.

25 **[0070]** The drive for each of the ballast bodies 110 in this example comprises two winches 115 and a cable arrangement with cables 116, 117 that allow displacing the ballast body in both directions. The winch 115 preferably is a winch with a drum having a double helical groove for the cables. For example each winch has a capacity of 400 kW. Preferably multiple ballast bodies and associated drives are placed side by side in the room, e.g. 4 or 5 of such ballast bodies.

30 **[0071]** Each ballast body here is equipped with dampers at its opposed transverse side, e.g. oleo dampers, preferably having a stroke of more than 0.25 meters.

35 **[0072]** The hull is further equipped with water ballast tanks 125 and roll damping water tanks 128.

40 **[0073]** The drive for the one or more ballast bodies further includes a control system operable to cause and control the movements of the solid roll damping ballast bodies in response to the detections of the sensor to provide roll stabilization.

45 **[0074]** It will be appreciated that the roll damping mechanism can also be employed in a semi-static mode, wherein the one or more ballast bodies are positioned to counter a more or less static or slow changing heel caused by a load on the vessel, e.g. to counter the heel induced by slewing the jib of the crane, with or without a load being suspended from the crane. It is noted that a heavy lift crane may have a jib of such a weight that slew-

ing the jib to a position transverse to the vessel induces a significant heel that may then be compensated (partly or entirely) by suitable semi-static operation of the roll damping mechanism.

**[0075]** An example of a monohull offshore drilling vessel equipped with a roll damping mechanism according to the invention will now be elucidated with reference to figures 6-10. It will be appreciated that the roll damping mechanism is of the same basic design as the roll damping mechanism explained with reference to the heavy lift crane vessel, and that features, e.g. preferred features, thereof may be included in the embodiment for the drilling vessel.

**[0076]** The drilling vessel 200 in general is suitable for offshore drilling, e.g. for oil and gas exploration, well servicing and/or other drilling related activities (e.g. servicing and/or placement of subsea equipment).

**[0077]** The hull 202 has crew quarters and a bridge 203 on the bow side, here with helicopter platform.

**[0078]** The vessel includes a water ballast system, preferably configured to allow for roll motion suppression, e.g. including anti-roll tanks 207.

**[0079]** As is preferred the hull 202 of the vessel 200 has a moonpool 205, preferably centred on the longitudinal axis of the vessel.

**[0080]** In this example, effectively above the moonpool 205, a multiple firing line hoist system 210 is mounted on the hull 202 so that - as preferred - a forward portion and a rear portion of the moonpool 205 are accessible at the front and the rear of the system 210. It will be appreciated that a single firing line hoist system can also be present on an alternative version of the vessel.

**[0081]** In this example, as is preferred, the multiple firing line hoist system 210 comprises:

- a mast 211 having a top side and a base, which in this example as a transverse girder, is connected to the hull of the drilling vessel, wherein the mast 211 has a hollow construction with a first side 212 (in this example the rear side) and an opposed second side 213 (in this example the front side),
- a first hoisting device supported by the mast and having load attachment means 214 displaceable along a first firing line 214a, which extends on the outside of and adjacent to the first side of the mast 212;
- a second hoisting device supported by the mast and having load attachment means 215 displaceable along a second firing line 215a, which on the outside of and adjacent to the second side 213 of the mast.

**[0082]** The first and second hoisting devices each include one or more cables and one or more associated winches to manipulate the position of each of the load attachment devices relative to the mast. The winches are preferably located in the mast 211, most preferably in the base of the mast, but other location are also possible.

**[0083]** Details of the mast 211 and the hoisting devices

can be derived from US 6,763,898 which is incorporated herein by reference.

**[0084]** A BOP storage is present, preferably in the hull of the vessel adjacent the moonpool 205.

**[0085]** The first hoisting device here is adapted for raising and lowering the BOP to the seabed. The vessel includes a riser storage not shown in the drawing.

**[0086]** One or more working decks are preferably provided near the mast, e.g. at the rear and the front of the mast, which allow to cover a portion of the moonpool 205. A working deck may be mobile and/or include mobile deck portions.

**[0087]** In this example the vessel 200 is provided with a rotary drilling drive, namely a top drive 216, at the front side of the mast, so that drilling is possible via the front firing line 215a. It will be appreciated that a rotary drilling drive could also (or as alternative) be located at the rear side of the mast. Similar the riser storage and handling system could be arranged at the front side of the mast is desired.

**[0088]** In figure 7 a cross-section of the vessel 1 is shown, generally just aft of the moonpool 205. In the hull of the vessel, below the main deck, the vessel has a room 250 wherein the roll damping mechanism is located. This mechanism here includes two solid ballast bodies 260 which are arranged side by side and are displaceable in transverse direction of the hull.

**[0089]** As can be seen the transverse distance for travel of the solid ballast bodies 260 is at least 5 meters to either side of the centerline of the vessel, more preferably at least 7,5 meters, in this example 9 metres. The figures 7,8 show the bodies 260 also in their extreme positions 260' and 260".

**[0090]** Preferably, the ballast body 260 is a solid metal block, or a number of solid metal blocks or plates. In this example each ballast body weighs between 100 and 200 tons, e.g. 150 tons.

**[0091]** Here each ballast body 260 is equipped with bottom rollers 261 that run on associated rail tracks 262 of the vessel, said tracks being straight and having opposed ends at opposite side of the room 250 in the vessel. As is preferred, also one or more rail tracks are fitted above the path of the ballast body, and the ballast body is provided with upper rollers that run on said upper rail tracks 263. These rail tracks are visible in figure 10.

**[0092]** The drive for each of the ballast bodies 260 in this example comprises a winch 270 and a cable arrangement with cables 271, 272 that allow displacing the ballast body in both directions. The winch 270 is preferably arranged at a level below the associated path of the ballast body as is shown in figure 7. The winch may have a drum having a double helical groove for the cables. For example each winch has a capacity of several 100 kW's.

**[0093]** The drive for the one or more ballast bodies 260 further includes a winch control system operable to cause and control the movements of the winches for the solid roll damping ballast bodies in response to the detections of one or more suitable sensors to provide roll stabiliza-

tion.

**[0094]** It is noted that a sensor to detect rolling motion is any sensor or sensor system, e.g. including one or more sensor and an associated computer, that allows to provide relevant control information to suitably control the operation of the drive means for the solid roll damping ballast bodies. It can e.g. be an angle detecting sensor, e.g. including one or more gyroscopic sensors that provide angle information of the vessel, but can also be a sensor that measures or interprets actual wave-motion, e.g. wave height, wave period (such as infrared and radar based sensor systems), and may include also e.g. a sensor system that makes use of previously stored data on wave patterns, e.g. specific to the region where the vessel is employed (e.g. based on measurements from buoys). The sensor system may also make use of wind speed and/or wind direction measurements, or other parameters affecting the motion (not limited to rolling motion) of the vessel.

**[0095]** Each ballast body here is equipped with dampers at its opposed transverse side, e.g. oleo dampers, preferably having a stroke of more than 0.25 meters.

**[0096]** Operation of the roll damping mechanism in the vessel 200 allows to reduce the roll of the drilling vessel and so allows to increase the workability of the vessel, e.g. when drilling operations are performed in adverse conditions.

**[0097]** A particular advantage e.g. arises when handling the BOP or similar equipment. As is known in the art Blow Out Preventers are often bulky and very heavy pieces of equipment. Handling such a BOP, e.g. in order to bring it from its storage position into the firing line or vice versa is greatly facilitated when the roll damping mechanism is in operation, thereby reducing roll of the vessel.

**[0098]** In general the operation of the roll damping mechanism with movable ballast bodies allows to precisely control the load on the drill string during drilling and may contribute to the effect of a heave compensator acting on said drill string.

**[0099]** The active use of the roll damping mechanism on the drilling vessel also is of advantage during the assembly (and possible also disassembly) of a riser string, wherein riser sections are connected end-to-end. As the suspended riser string will in general have a vertical orientation, rolling motion of the vessel causes an alignment error between the suspended riser and a new riser section to be connected to the riser string. Many connectors on riser sections only allow for a small alignment error, and in general the connection process will be hindered by the rolling motion. Use of the roll damping mechanism during this process will reduce or alleviate any alignment error and thus be beneficial to an efficient process.

**[0100]** In general the roll damping mechanism allows for the deployment of monohull drilling vessel in geographical areas wherein up till now large and expensive semi-submersible drilling vessels were required in order to obtain a stable drilling situation.

**[0101]** For each of the vessels shown in the drawings - as is preferred - the roll damping mechanism is formed such that a single ballast body is mounted on and guided along a set of associated rail tracks. This allows to displace the centre of gravity of the ballast body as much as possible outwards with respect to the centreline of the vessel, thus obtaining an increased restoring moment.

**[0102]** Also for each of the vessels shown in the drawings - as is preferred - a ballast body is embodied as a monolithic metal block, or a set of metal blocks fixed to each other so as to form a single solid body, having a weight of at least 100 tons, in order to arrive at a compact ballast body.

**[0103]** Also for each of the vessels shown in the drawings - as is preferred - a ballast body has a height that is greater than its transverse dimension, thereby allowing to displace the centre of gravity of the ballast body as much as possible outwards with respect to the centreline of the vessel, thus obtaining an increased restoring moment.

## Claims

1. A monohull vessel with a heavy lift crane (20), the crane comprising:

- a substantially hollow vertical column (21) with a foot (22) which is fixed to the hull and with a top (23),
- a jib (24), which has a reach beyond the hull of the vessel,
- a jib connection member (26) rotatable about the column (21), the jib connection member forming a substantially horizontal pivot axis so that the jib can be pivoted up and down,
- topping means (30, 31) for pivoting the jib (24) up and down, comprising a jib winch (30) and a jib hoisting cable (31)
- one or more hoisting cable guides (43) on the jib of the hoisting crane;
- hoisting means (35,36) for hoisting a load, comprising a hoisting winch (35) and an associated hoisting cable (36) which extends from the winch to a hoisting cable guide on the jib,

wherein the vessel is provided with a water ballast system, and

wherein the vessel further comprises an active roll damping mechanism,

**characterized in that**

the active roll damping mechanism comprises:

- a solid roll damping ballast (110) which is movable in the transverse direction of the hull, which is embodied as a monolithic metal block, or a set of metal blocks fixed to each other so as to form a single solid body, having a weight of at

- least 100 tons  
 - a sensor detecting the rolling motion of the hull,  
 - a drive and control system (115) operable to cause and control the movements of the solid roll damping ballast in response to the detections of the sensor to provide roll stabilization.
2. A monohull offshore drilling vessel (200), the vessel comprising:
- a drilling structure (211) with one or more drilling stations allowing subsea drilling operations to be performed from the vessel,
- characterized in that**  
 the vessel is equipped with an active roll damping mechanism comprising:
- a solid roll damping ballast (260) which is movable in the transverse direction of the hull, which is embodied as a monolithic metal block, or a set of metal blocks fixed to each other so as to form a single solid body, having a weight of at least 100 tons  
 - a sensor detecting the rolling motion of the hull,  
 - a drive and control system (270) operable to cause and control the movements of the solid roll damping ballast in response to the detections of the sensor to provide roll stabilization,
3. Vessel according to claim 1, wherein the solid roll damping ballast (110) has a total mass of at least 800 ton, preferably between 1000 and 3000 tons, e.g. a mass of 2000 tons.
4. Vessel according to claim 2, wherein the solid roll damping ballast (260) has a total mass between 100 and 750 tons, more preferably between 200 and 400 tons.
5. Vessel according to one or more of the preceding claims, wherein the vessel (1;200) is provided with dynamic positioning means.
6. Vessel according to one or more of the preceding claims, wherein the roll damping mechanism is such that a single ballast body (110;260) is mounted on and guided along a set of associated rail tracks.
7. Vessel according to one or more of the preceding claims, wherein a ballast body (110;260) has a height that is greater than its dimension in transverse direction of the vessel, e.g. a height between 1,5 and 4 metres.
8. Vessel according to claim 1, wherein the heavy lift crane is capable of hoisting a load of at least 5000 tons.
9. Vessel according to claim 1, wherein the crane further comprises a top cable guide (40) provided at the top (23) of the vertical column; the top cable guide (40) comprising a rotary bearing structure, so that the top cable guide can follow rotary movements of the jib about the vertical column and adopts substantially the same angular position as the jib.
10. Vessel according to claim 1, wherein the hoisting winch (35) is disposed in the column, preferably in the vicinity of the foot of the vertical column (21), so that the hoisting cable extends from the winch through the hollow vertical column to the top cable guide and then to a hoisting cable guide on the jib.
11. Vessel according to claim 1, wherein the jib winch (31) and the hoisting winch (35) are arranged on a rotatable winch support (50), which is rotatable about a rotation axis substantially parallel with the vertical column (21, 22), such that the winch support (50) is mounted movable with respect to the vertical column (21,22); the winch support (50) having an associated drive motor assembly (52) for moving the winch support (50), in such a manner that the winch support (50) maintains a substantially constant orientation with respect to the jib (24) in the event of rotary movements of the jib about the vertical column (21,22)
12. Vessel according to claim 1, wherein the vertical column (21) has a substantially continuous outer wall, and wherein preferably the horizontal section through the vertical column (21) is substantially circular, and in which the cross section preferably decreases gradually towards the top of the column.
13. Vessel according to claim 1, in which the foot of the column (21) is substantially rectangular.
14. Vessel according to claim 2, wherein the vessel comprises a moonpool (205) and multiple firing line hoist system arranged at the moonpool, preferably above a moonpool so that portions of the moonpool extend at two opposed sides of the hoist system, wherein the system (210) comprises:
- a mast (211) having a top side and a base, e.g. a transverse girder, which is connected to the hull of the drilling vessel, wherein the mast (211) has a hollow construction with a first side (212) and an opposed second side (213),  
 - a first hoisting device supported by the mast and having load attachment means (214) displaceable along a first firing line (214a), which extends on the outside of and adjacent to the first side of the mast (212);  
 - a second hoisting device supported by the mast and having load attachment means (215) dis-



placeable along a second firing line (215a), which on the outside of and adjacent to the second side (213) of the mast, and

wherein preferably the roll damping mechanism (260,270) is disposed in a room (250) below deck of the vessel, preferably adjacent the moonpool (205).

15. A method for operating a monohull crane vessel (1) according to claim 1, wherein the roll damping mechanism is used to counter heel induced by slewing of the jib
16. A method for subsea drilling wherein use is made of a vessel (200) according to claim 2 and the roll damping mechanism is used to counter roll during a drilling operation and/or during a BOP handling operation.

#### Patentansprüche

1. Einrumpfschiff mit einem Schwerlastkran (20), wobei der Kran umfasst:

- eine im wesentlichen hohle, vertikale Säule (21) mit einem Fuß (22), der an dem Rumpf befestigt ist, und mit einer Spitze (23),
- einen Ausleger (24), der eine Reichweite über den Rumpf des Schiffes hinaus hat,
- ein Ausleger-Verbindungselement (26), das um die Säule (21) drehbar ist, wobei das Ausleger-Verbindungselement eine im wesentlichen horizontale Schwenkachse bildet, so dass der Ausleger nach oben und nach unten geschwenkt werden kann,
- Hebeeinrichtungen (30, 31) zum Schwenken des Auslegers (24) nach oben und nach unten, umfassend eine Auslegerwinde (30) und ein Auslegerhebeseil (31),
- wenigstens eine Hebeseilführung (43) an dem Ausleger des Hebekrans und
- Hebeeinrichtungen (35, 36) zum Heben einer Last, umfassend eine Hebewinde (35) und ein zugehöriges Hebeseil (36), das sich von der Winde zu einer Hebeseilführung an dem Ausleger erstreckt,

wobei das Schiff mit einem Wasserballastsystem ausgestattet ist und das Schiff weiterhin einen aktiven Rolldämpfungsmechanismus umfasst,

**dadurch gekennzeichnet, dass** der aktive Rolldämpfungsmechanismus umfasst:

- einen massiven Rolldämpfungsballast (110), der in der Querrichtung des Rumpfes beweglich ist und als monolithischer Metallblock oder ein Satz von Metallblöcken ausgeführt ist, die an-

einander befestigt sind, um so einen einzigen massiven Körper auszubilden, der ein Gewicht von wenigstens 100 Tonnen hat,

- einen Sensor, der die Rollbewegung des Rumpfes erfasst, und
- ein Antriebs- und Steuersystem (115), das betätigt werden kann, um die Bewegungen des massiven Rolldämpfungsballastes in Erwiderung auf die Erfassungen des Sensors zu bewirken und zu steuern, um eine Rollstabilisierung zu erzeugen.

2. Einrumpfhochseebohrschiff (200), wobei das Schiff umfasst:

- eine Bohrstruktur (211) mit wenigstens einer Bohrstation, die eine Ausführung von Unterseebohrvorgängen von dem Schiff aus gestattet,

**dadurch gekennzeichnet, dass** das Schiff mit einem aktiven Rolldämpfungsmechanismus ausgestattet ist, der umfasst:

- einen massiven Rolldämpfungsballast (260), der in der Querrichtung des Rumpfes beweglich ist und als monolithischer Metallblock oder ein Satz von Metallblöcken ausgeführt ist, die aneinander befestigt sind, um so einen einzigen massiven Körper auszubilden, der ein Gewicht von wenigstens 100 Tonnen hat,
- einen Sensor, der die Rollbewegung des Rumpfes erfasst, und
- ein Antriebs- und Steuersystem (270), das betätigt werden kann, um die Bewegungen des massiven Rolldämpfungsballastes in Erwiderung auf die Erfassungen des Sensors zu bewirken und zu steuern, um eine Rollstabilisierung zu erzeugen.

3. Schiff nach Anspruch 1, bei dem der massive Rolldämpfungsballast (110) eine Gesamtmasse von wenigstens 800 Tonnen, vorzugsweise zwischen 1.000 und 3.000 Tonnen, wie etwa eine Masse von 2.000 Tonnen hat.

4. Schiff nach Anspruch 2, bei dem der massive Rolldämpfungsballast (260) eine Gesamtmasse zwischen 100 und 750 Tonnen, vorzugsweise jedoch zwischen 200 und 400 Tonnen hat.

5. Schiff nach wenigstens einem der vorhergehenden Ansprüche, wobei das Schiff (1; 200) mit dynamischen Positioniereinrichtungen ausgestattet ist.

6. Schiff nach wenigstens einem der vorhergehenden Ansprüche, bei dem der Rolldämpfungsmechanismus derart beschaffen ist, dass ein einziger Ballastkörper (110; 260) auf einem Satz zugehöriger Füh-

- runngsschienen angebracht und entlang derselben geführt ist.
7. Schiff nach wenigstens einem der vorhergehenden Ansprüche, bei dem ein Ballastkörper (110; 260) eine Höhe hat, die größer ist als dessen Abmessung in Querrichtung des Schiffes, wie etwa eine Höhe zwischen 1,5 und 4 Metern. 5
8. Schiff nach Anspruch 1, bei dem der Schwerlastkran in der Lage ist, eine Last von wenigstens 5.000 Tonnen zu heben. 10
9. Schiff nach Anspruch 1, bei dem der Kran weiterhin eine obere Seilführung (40) umfasst, die an der Spitze (23) der vertikalen Säule vorgesehen ist; wobei die obere Seilführung (40) eine Drehlagerstruktur umfasst, so dass die obere Seilführung Drehbewegungen des Auslegers um die vertikale Säule folgen kann, und im wesentlichen dieselbe Winkelstellung einnimmt wie der Ausleger. 15 20
10. Schiff nach Anspruch 1, bei dem die Hebewinde (35) in der Säule vorzugsweise in der Nähe des Fußes der vertikalen Säule (21) angeordnet ist, so dass sich das Hebeseil von der Winde durch die hohle vertikale Säule zu der oberen Seilführung und dann zu einer Hebeseilführung an dem Ausleger erstreckt. 25
11. Schiff nach Anspruch 1, bei dem die Auslegerwinde (31) und die Hebewinde (35) auf einer drehbaren Windenhalterung (50) angebracht sind, die um eine Drehachse im wesentlichen parallel zu der vertikalen Säule (21, 22) derart drehbar ist, dass die Windenhalterung (50) beweglich im Bezug auf die vertikale Säule (21, 22) angebracht ist; wobei die Windenhalterung (50) eine zugehörige Motorantriebsanordnung (52) zum Bewegen der Windenhalterung (50) derart hat, dass die Windenhalterung (50) eine im wesentlichen konstante Ausrichtung im Bezug auf den Ausleger (24) für den Fall von Drehbewegungen des Auslegers um die vertikale Säule (21, 22) beibehält. 30 35 40
12. Schiff nach Anspruch 1, bei dem die vertikale Säule (21) eine im wesentlichen kontinuierliche Außenwand hat und bei der vorzugsweise der horizontale Schnitt durch die vertikale Säule (21) im wesentlichen kreisförmig ist, wobei sich der Querschnitt vorzugsweise allmählich zur Spitze der Säule verringert. 45 50
13. Schiff nach Anspruch 1, bei dem der Fuß der Säule (21) im wesentlichen rechteckig ist. 55
14. Schiff nach Anspruch 2, wobei das Schiff ein Moonpool (205) und ein Mehrfachschießleitungs-Hebesystem umfasst, das an dem Moonpool vorzugsweise über dem Moonpool derart angeordnet ist, dass sich Abschnitte des Moonpools auf zwei gegenüberliegenden Seiten des Hebeseystems erstrecken, wobei das System (210) umfasst:
- einen Mast (211) der eine Oberseite und eine Basis, wie etwa eine Querstrebe, hat, die mit dem Rumpf des Bohrschiffes verbunden ist, wobei der Mast (211) einen hohlen Aufbau mit einer ersten Seite (212) und einer gegenüberliegenden zweiten Seite (213) hat,
  - eine erste Hebevorrichtung, die von dem Mast gehalten ist und eine Lastenanbringungseinrichtung (214) hat, die entlang einer ersten Schießleitung (214a) verschiebbar ist, die sich auf der Außenseite der ersten Seite des Mastes (212) und benachbart dazu erstreckt; und
  - eine zweite Hebevorrichtung, die von dem Mast gehalten ist und eine Lastanbringungseinrichtung (215) hat, die entlang einer zweiten Schießleitung (215a) verschiebbar ist, die sich auf der Außenseite der zweiten Seite (213) des Mastes und benachbart dazu erstreckt, wobei vorzugsweise der Rolldämpfungsmechanismus (260, 270) in einem Raum (250) unter Deck des Schiffes, vorzugsweise benachbart dem Moonpool (205), angeordnet ist.
15. Verfahren zum Betreiben eines Einrumpfkran Schiffes (1) nach Anspruch 1, bei dem der Rolldämpfungsmechanismus dazu verwendet wird, einer Krängung entgegenzuwirken, die durch das Schwenken des Auslegers verursacht wird. 30 35
16. Verfahren für das Unterseebohren, bei dem von einem Schiff (200) nach Anspruch 2 Gebrauch gemacht wird und der Rolldämpfungsmechanismus verwendet wird, um einem Rollen während des Bohrvorgangs und/oder eines BOP-Handhabungsvorgangs entgegenzuwirken. 40

#### Revendications

1. Navire monocoque avec une grue de levage pour colis lourd (20), la grue comprenant :
- une colonne verticale sensiblement creuse (21) avec un pied (22) qui est fixé sur la coque et avec une partie supérieure (23),
  - une flèche (24) qui a une portée au-delà de la coque du navire,
  - un élément de raccordement de flèche (26) pouvant tourner autour de la colonne (21), l'élément de raccordement de flèche formant un axe de pivot sensiblement horizontal de sorte que la flèche peut être pivotée vers le haut et vers le bas,

des moyens de surélévation (30, 31) pour faire pivoter la flèche (24) vers le haut et vers le bas, comprenant un treuil de flèche (30) et un câble de levage de flèche (31),

un ou plusieurs guides de câble de levage (43) sur la flèche de la grue de levage ;

des moyens de levage (35, 36) pour lever une charge, comprenant un treuil de levage (35) et un câble de levage (36) associé qui s'étend à partir du câble jusqu'à un guide de câble de levage sur la flèche,

dans lequel le navire est prévu avec un système de lest liquide, et

dans lequel le navire comprend en outre un mécanisme d'amortissement au roulis actif,

**caractérisé en ce que :**

le mécanisme d'amortissement au roulis actif comprend :

un lest d'amortissement au roulis solide (110) qui est mobile dans la direction transversale de la coque, qui est mis en oeuvre sous la forme d'un bloc de métal monolithique, ou un ensemble de blocs de métal fixés entre eux afin de former un corps solide unique, ayant un poids d'au moins 100 tonnes,

un capteur détectant le mouvement de roulis de la coque,

un système d'entraînement et de contrôle (115) pouvant fonctionner pour provoquer et contrôler les mouvements du lest d'amortissement au roulis solide en réponse aux détections du capteur afin de fournir la stabilisation au roulis.

**2. Navire monocoque de forage (200), le navire comprenant :**

une structure de forage (211) avec une ou plusieurs stations de forage permettant de réaliser des opérations de forage sous-marines depuis le navire,

**caractérisé en ce que :**

le navire est équipé d'un mécanisme d'amortissement au roulis actif comprenant :

un lest d'amortissement au roulis solide (260) qui est mobile dans la direction transversale de la coque, qui est mis en oeuvre sous la forme d'un bloc de métal monolithique, ou d'un ensemble de blocs de métal fixés entre eux afin de former un corps solide unique, ayant un poids d'au moins 100 tonnes,

un détecteur détectant le mouvement de roulis de la coque,

un système d'entraînement et de contrôle (270)

pouvant fonctionner pour provoquer et contrôler les mouvements du lest d'amortissement au roulis solide en réponse aux détections du capteur pour fournir la stabilisation au roulis.

**3.** Navire selon la revendication 1, dans lequel le lest d'amortissement au roulis solide (110) a une masse totale d'au moins 800 tonnes, de préférence entre 1 000 et 3 000 tonnes, par exemple une masse de 2 000 tonnes.

**4.** Navire selon la revendication 2, dans lequel le lest d'amortissement au roulis solide (260) a une masse totale comprise entre 100 et 750 tonnes, encore de préférence entre 200 et 400 tonnes.

**5.** Navire selon une ou plusieurs des revendications précédentes, dans lequel le navire (1 ; 200) est prévu avec des moyens de positionnement dynamiques.

**6.** Navire selon une ou plusieurs des revendications précédentes, dans lequel le mécanisme d'amortissement au roulis est tel, qu'un corps de lest unique (110 ; 260) est monté sur et guidé le long d'un ensemble de rails associés.

**7.** Navire selon une ou plusieurs des revendications précédentes, dans lequel un corps de lest (110 ; 260) a une hauteur qui est supérieure à sa dimension dans le sens transversal du navire, par exemple une hauteur comprise entre 1,5 et 4 mètres.

**8.** Navire selon la revendication 1, dans lequel la grue de levage pour coulis lourd est capable de lever une charge d'au moins 5 000 tonnes.

**9.** Navire selon la revendication 1, dans lequel la grue comprend en outre un guide de câble supérieur (40) prévu au niveau de la partie supérieure (23) de la colonne verticale ; le guide de câble supérieur (40) comprenant une structure de palier rotative, de sorte que le guide de câble supérieur peut suivre les mouvements rotatifs de la flèche autour de la colonne verticale et adopte sensiblement la même position angulaire que la flèche.

**10.** Navire selon la revendication 1, dans lequel le treuil de levage (35) est disposé dans la colonne, de préférence à proximité du pied de la colonne verticale (21), de sorte que le câble de levage s'étend à partir du treuil en passant par la colonne verticale creuse jusqu'au guide de câble supérieur et ensuite jusqu'à un guide de câble de levage sur la flèche.

**11.** Navire selon la revendication 1, dans lequel le treuil de flèche (31) et le treuil de levage (35) sont agencés sur un support de treuil rotatif (50), qui peut tourner autour d'un axe de rotation sensiblement parallèle à

la colonne verticale (21, 22), de sorte que le support de treuil (50) est monté de manière mobile par rapport à la colonne verticale (21, 22) ; le support de treuil (50) ayant un ensemble de moteur d'entraînement (52) associé pour déplacer le support de treuil (50), de sorte que le support de treuil (50) maintient une orientation sensiblement constante par rapport à la flèche (24) en cas de mouvements rotatifs de la flèche autour de la colonne verticale (21, 22).

12. Navire selon la revendication 1, dans lequel la colonne verticale (21) a une paroi externe sensiblement continue, et dans lequel de préférence la section horizontale à travers la colonne verticale (21) est sensiblement circulaire, et dans lequel la section transversale diminue de préférence progressivement vers la partie supérieure de la colonne.

13. Navire selon la revendication 1, dans lequel le pied de la colonne (21) est sensiblement rectangulaire.

14. Navire selon la revendication 2, dans lequel le navire comprend un puits central (205) et un système de levage à plusieurs lignes de tir agencées au niveau du puits central, de préférence au-dessus d'un puits central de sorte que les parties du puits central s'étendent au niveau des deux côtés opposés du système de levage, dans lequel le système (210) comprend :

un mat (211) ayant un côté supérieur et une base, par exemple une poutre transversale, qui est raccordée à la coque du navire de forage, dans lequel le mat (211) a une construction creuse avec un premier côté (212) et un second côté opposé (213),

un premier dispositif de levage supporté par le mat et ayant des moyens de fixation de charge (214) déplaçables le long d'une première ligne de tir (214a), qui s'étend sur l'extérieur de et de manière adjacente au premier côté du mat (212) ;

un second dispositif de levage supporté par le mat et ayant des moyens de fixation de charge (215) déplaçables le long d'une seconde ligne de tir (215a), qui s'étend à l'extérieur de et de manière adjacente au second côté (213) du mat, et

dans lequel, de préférence, le mécanisme d'amortissement au roulis (260, 270) est disposé dans une pièce (250) au-dessous du pont du navire, de préférence adjacente au puits central (205).

15. Procédé pour actionner un navire monocoque à grue (1) selon la revendication 1, dans lequel le mécanisme d'amortissement au roulis est utilisé pour contrer la gîte induite par le pivotement de la flèche.

16. Procédé de forage sous-marin, dans lequel on utilise un navire (200) selon la revendication 2 et le mécanisme d'amortissement au roulis est utilisé pour contrer le roulis pendant une opération de forage et/ou pendant une opération de manipulation de BOP (obturateur anti-éruption).

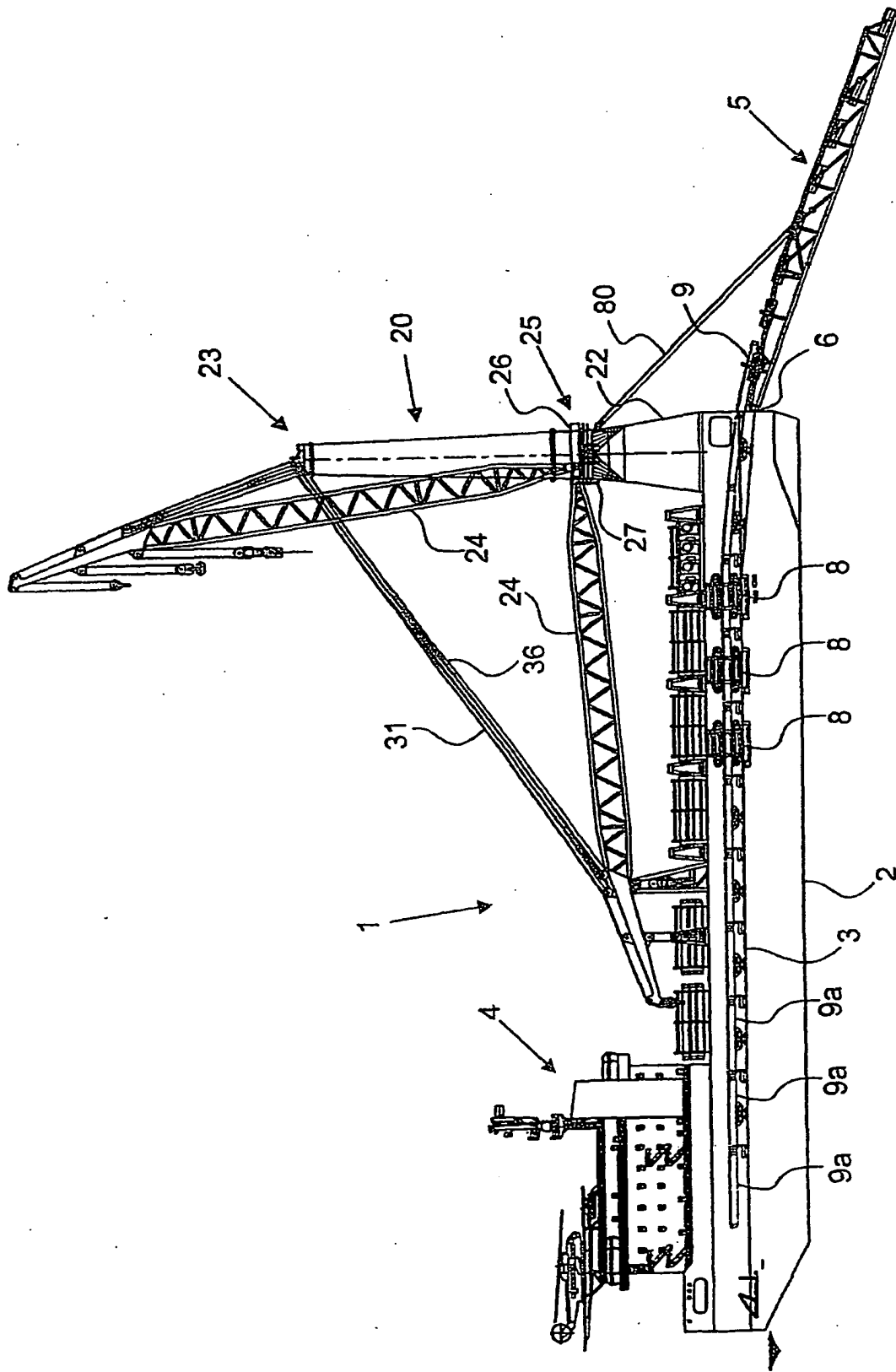
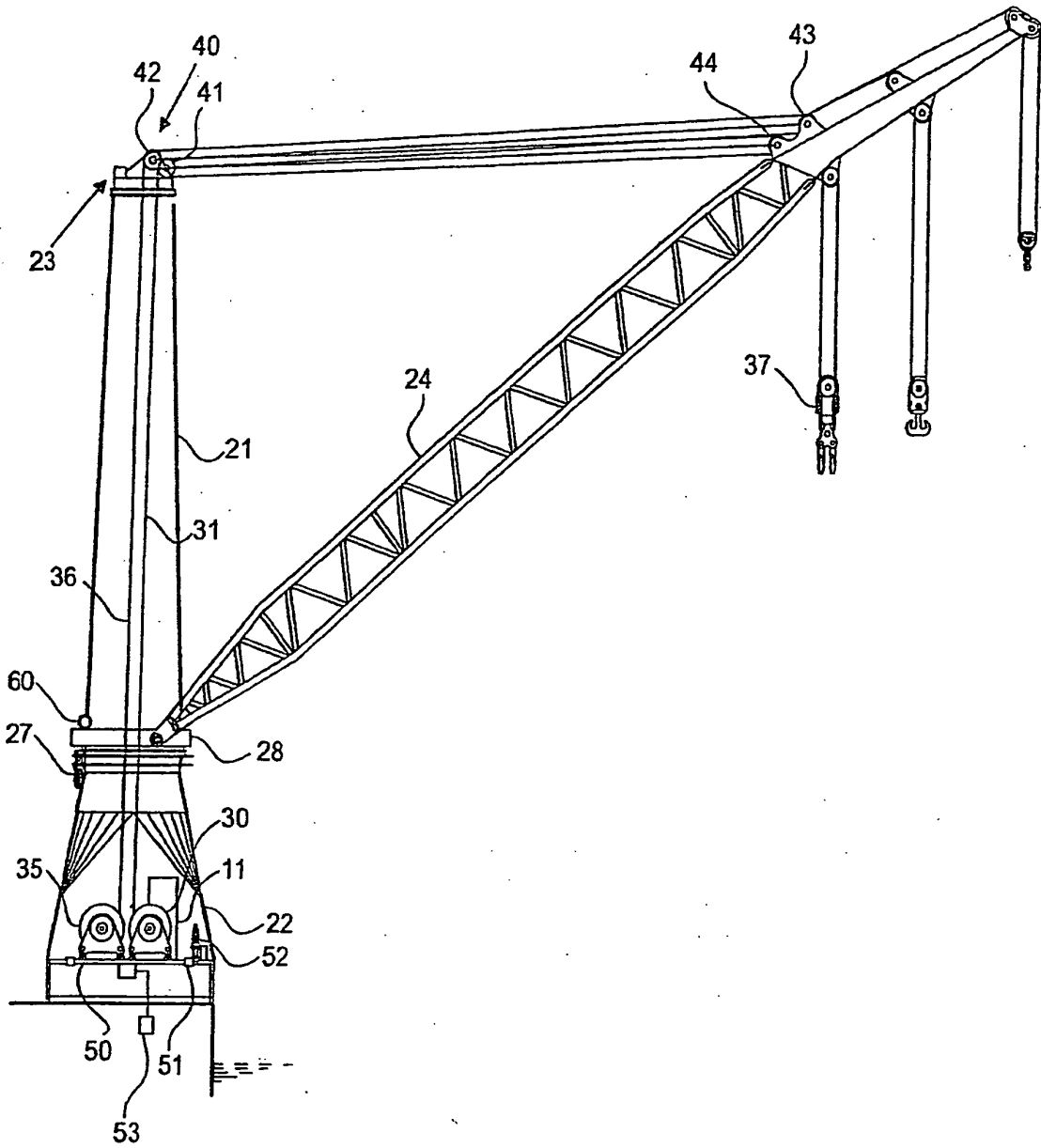
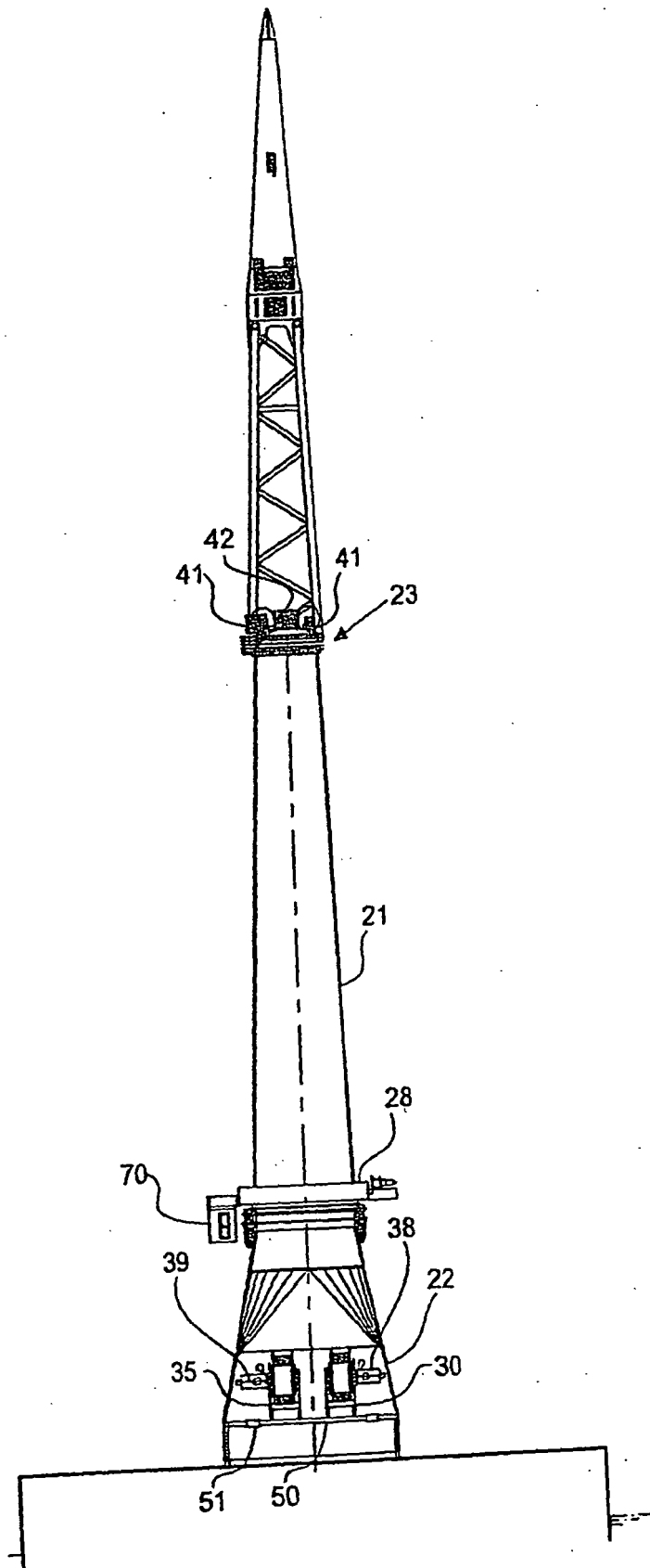


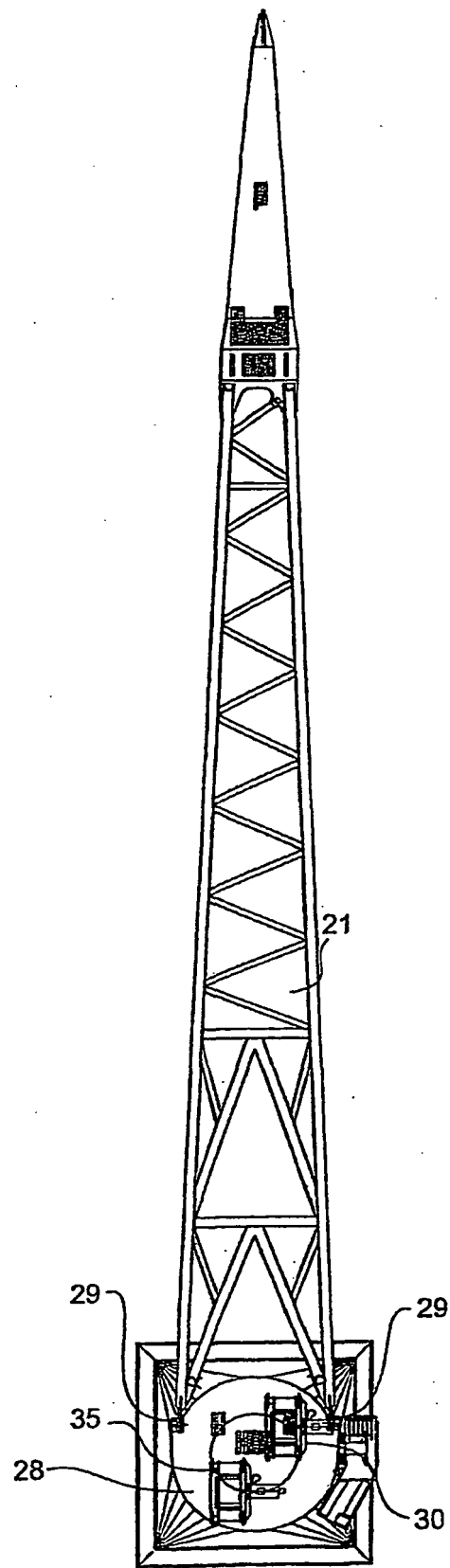
Fig.1



**Fig.2**



**Fig.3**



**Fig.4**



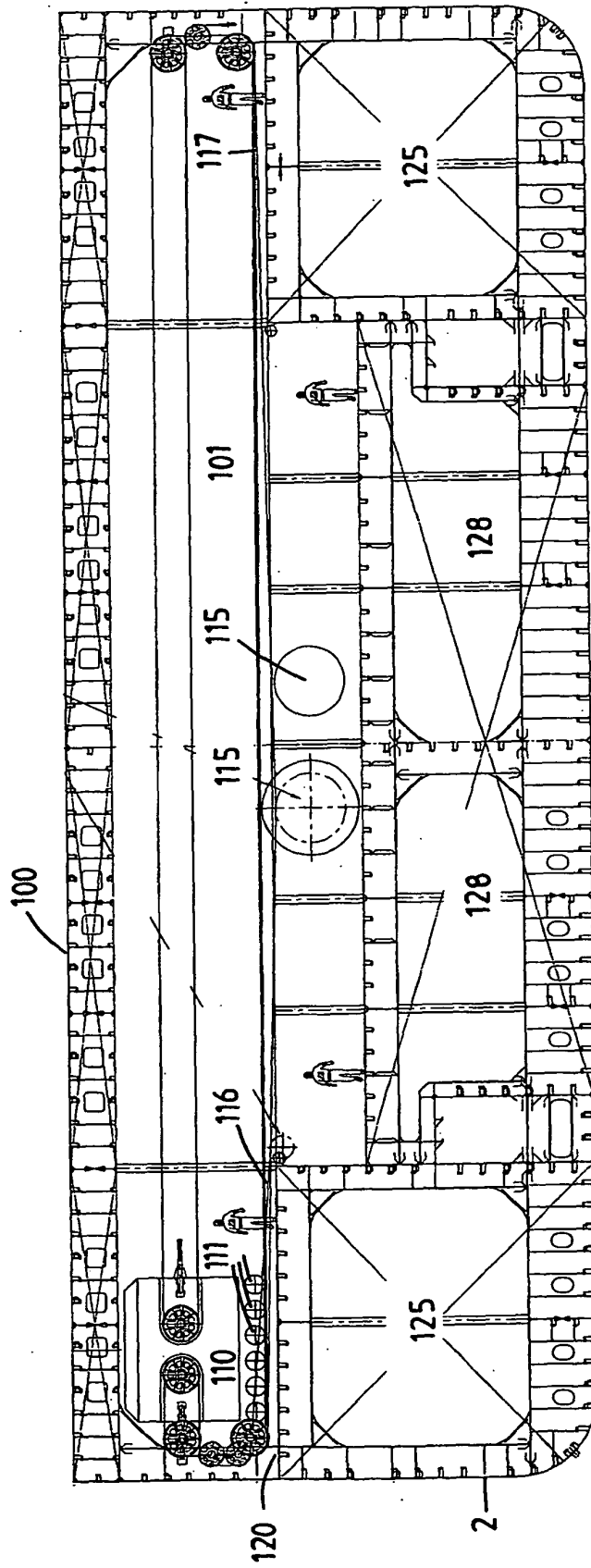


Fig.5

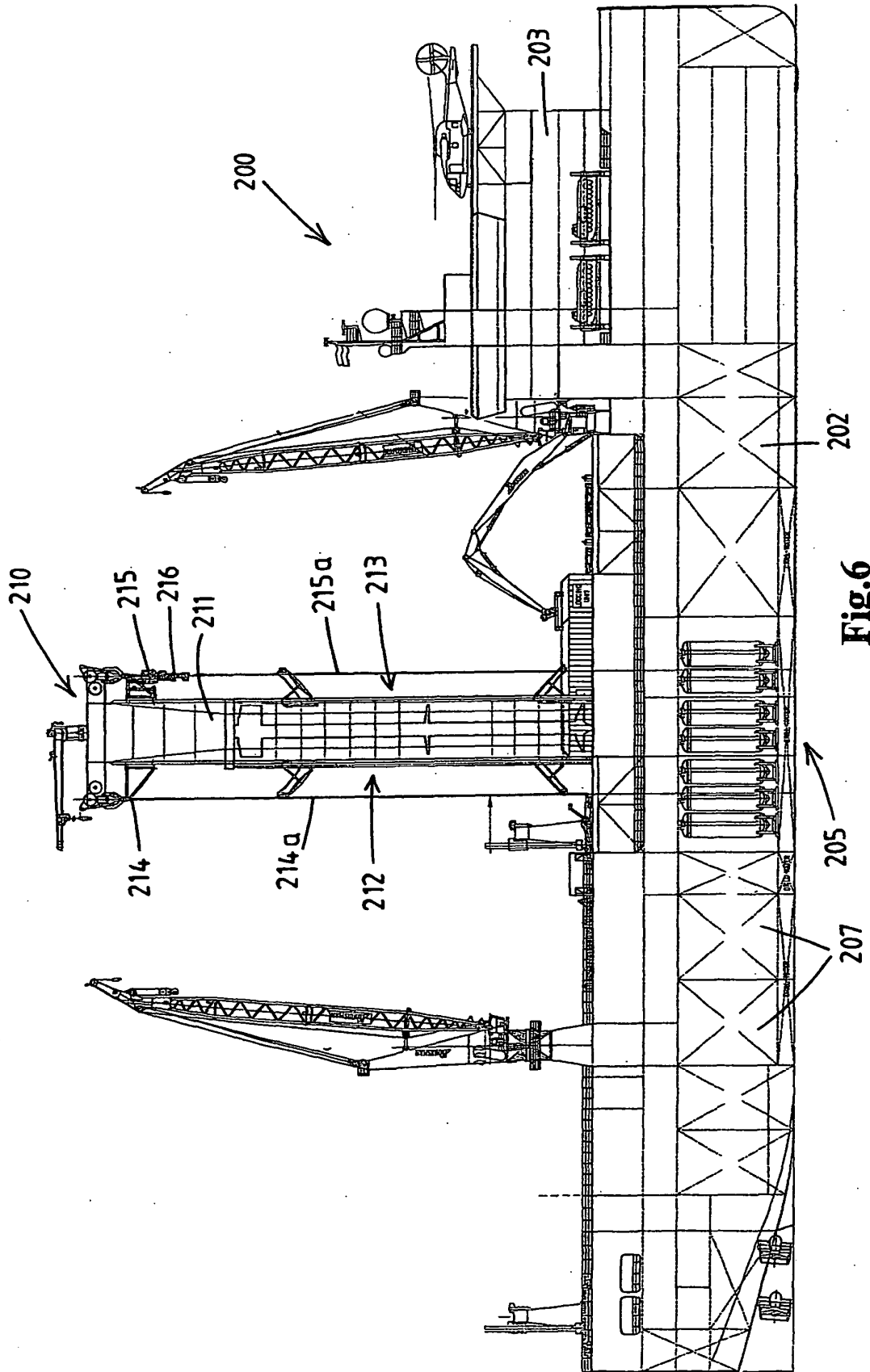
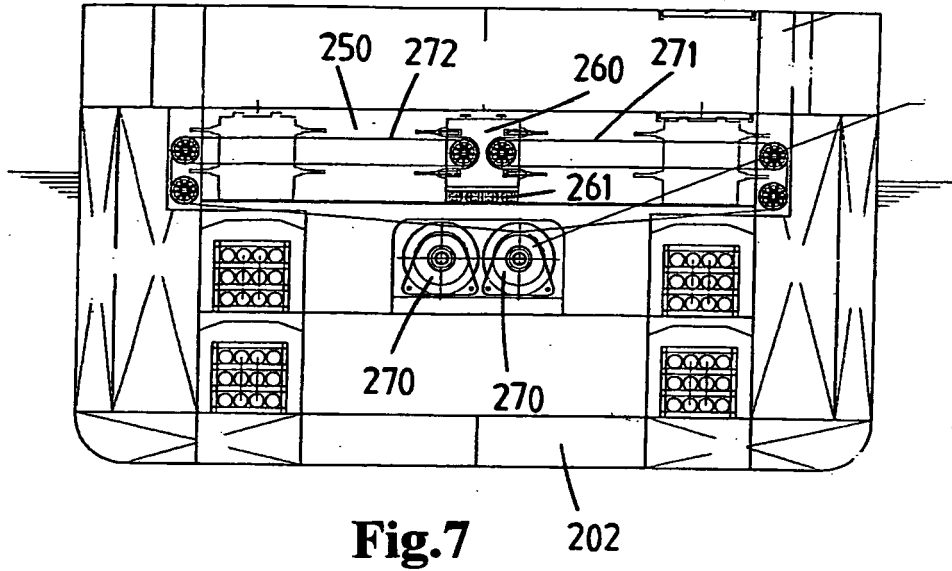
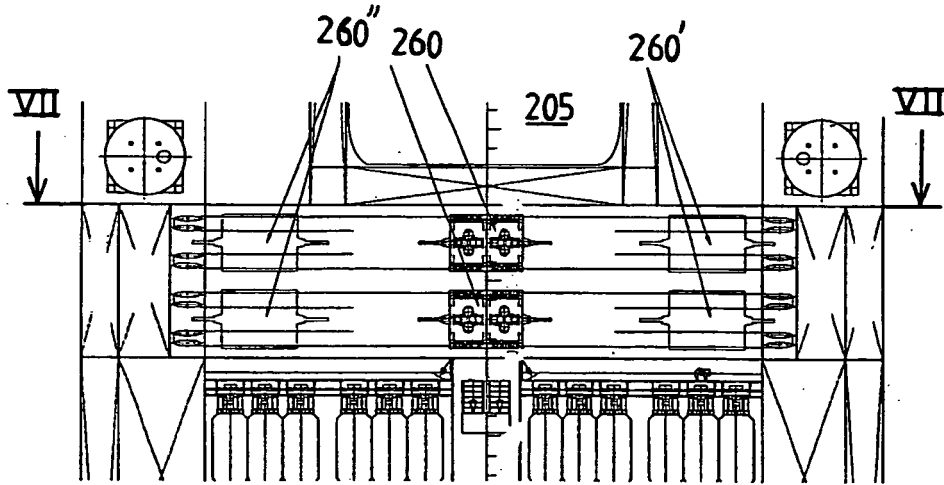


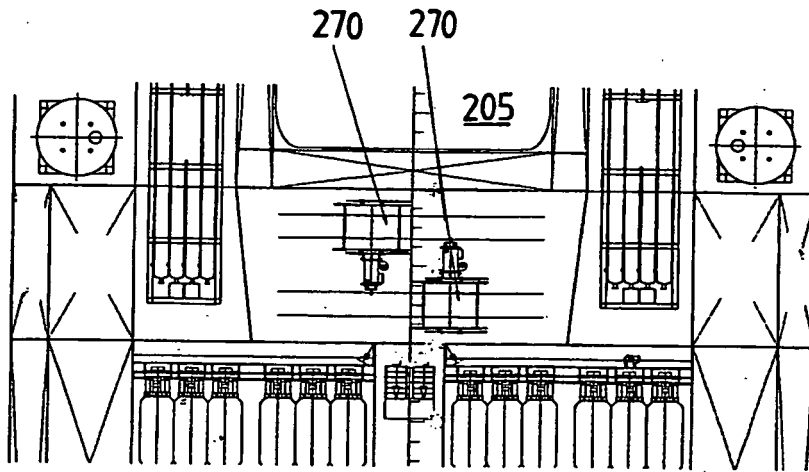
Fig. 6



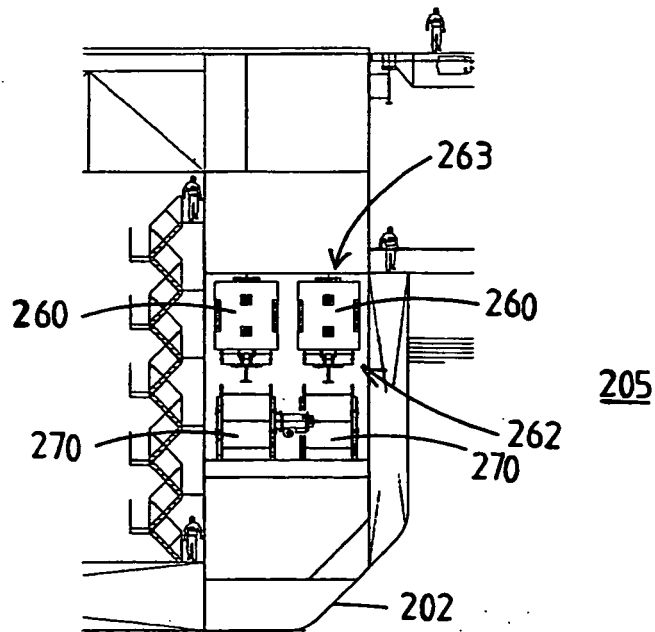
**Fig. 7** 202



**Fig. 8**



**Fig.9**



**Fig.10**

**REFERENCES CITED IN THE DESCRIPTION**

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