Method and means to direct an anchored floating structure against the direction of the waves in open sea

The present invention relates to a method and means to direct a floating structure against the direction of the waves, where said structure is anchored or moored to a buoy at its fore end (in front of the midship area). A floating structure may here include any kind of ship, vessel, boat or floating construction that is designed for use in open waters.

Oil and gas quantities exploited from underground reservoirs at sea, for instance at The North Sea, are at present commonly transported to installations ashore as refinery and storage tanks by means of pipelines arranged on the seabed. In addition, significant quantities of oil and gas are transported by ship, in particular oil and gas produced at small, distant fields that are not brought into communication with the existing pipe system on the sea bed.

While using ship for this kind of transport, it involves that the ship is connected or moored to a buoy that is anchored close to a platform or a subsea storage installation where the oil or the gas is stored, the oil or the gas being transferred from the storage installation to the ship by means of one or more pipe lines arranged through the buoy.

Gradually, storage- and production ships have been employed for storage and production of oil and gas from small fields at sea, or fields where the depths of the sea makes the use of installations resting on the sea bed inconvenient or impossible. Ships of this kind are anchored by means of a turret that most commonly is arranged in the foreship of the ship hull.

In bad weather with strong winds, sea currents and heavy seas, the forces acting on the ship, buoy and moorings may become extremely strong. In particular, strong forces act upon ships that are allowed to swing freely about a mooring point (buoy, anchor or the like) with large amplitudes from one side to the other.

In open sea (see a subsequent paragraph), the dominant forces acting on a ship that is moored to swing freely, normally are sustained by wave forces, and the larger the amplitude of the swinging motion becomes, the more the ship will be influenced by the waves. This is followed by large horizontal movements and forces and also heave and roll motions that cause heavy loads resulting in wear and damage of ship and mooring.

Previously, it is known to direct an anchored ship against the direction of the waves by means of side thrusters arranged in the aft end of the ship. However, such installations are expensive, and represent additional costs in connection with maintenance and repair works.

Furthermore, it is common knowledge in connection with boats, in particular in connection with small fishing boats equipped for fishing with lines or nets, to employ a spanker. A spanker is a sail that is supported by a mast at the aft end of a boat, and it serves to keep the boat against the direction of the wind, and to reduce the rolling motion of the boat. When hauling fishing gears as nets or lines it is important to keep the boat against the direction of the wind to avoid that the boat drifts across the fishing gear.

Thus, a spanker is a sail that is arranged in a direction normally (except when sailing) parallel with the boat.

While a ship is anchored or moored to a buoy or the like in open sea to load or to produce oil or gas, the primary task is to keep the ship against the direction of the waves in a stable manner, as previously mentioned, to avoid that the ship starts swinging (yaw motions) with large amplitudes that may cause heavy loads in the moorings. In addition, large amplitudes of rolling motion may be avoided when the ship is positioned with little directional variations.

The present invention provides a method and a device that bring a solution to this matter. According to the present invention, the method is characterised in that the floating structure is provided with a wind rudder at its aft end that is adjusted versus the wind direction in such a manner that the floating structure is directed against the direction of the waves, as defined in the accompanying independent claim 1.

Furthermore, according to the invention the device is characterised in the arrangement of a turnable, preferably positively driven, wind rudder that is adapted to be adjusted in any desired angular position according to the length axis of the ship, as defined in the accompanying claim 2. The dependent claims 3 and 4 describe advantageous features of the invention.

In the following, the invention is described in detail with reference to drawings that illustrate embodiments thereof in which:

Fig. 1 shows in side and top view, a ship provided with a wind rudder according to the invention,

Fig. 2 shows one embodiment of a wind rudder included in the invention,

Fig. 3 illustrates one theoretical situation for a ship moored by means of a turret, as shown in Fig. 1, where the wind and the waves are coming towards the ship at different directions,

Fig. 4 shows, based upon model experiments, a graphic presentation of:

a) the yaw motion of a model boat as wind direction versus the direction of sea current and waves is 20 degrees, and where the model boat is not provided with a wind rudder, and

b) the yaw motion of the same model boat as above, as wind direction versus the direction of sea current and waves is 20 degrees, and where the boat is provided with a wind rudder arranged at an angle of 30 degrees with the length axis of the boat.

As mentioned above, Fig. 1 shows a ship 1, in side and top view. At its fore end the ship is provided with a turret 4 that is arranged in the hull for turning motion and that is moored to the sea bed by means of anchor lines 3 (not further shown). Thus, the ship is arranged to turn or swing freely about the turret.

One essential feature according to the invention, is that there is arranged a turnable wind rudder at the aft end of the ship, where said rudder extends above the deck or possible installations at the deck. The wind rudder 5 is preferably driven by means of an electric or a hydraulic motor and is adapted to be turned into any desirable position (angle) relative to the longitudinal axis of the ship. The cross section of the rudder should suitably have the shape of a wing profile or a droplet as shown in the drawing, to achieve an increased "lift" and a reduced air resistance. On the other hand, other shapes may be employed, such as a planar or approximately a planar shape.

Fig. 2 shows the cross section of an alternatively shaped rudder having such a form that an approximate lifting surface effect is achieved for wind directions coming in from both sides of the ship. The following symbols are used in this figure:

α_R = Rudder direction relative to vessel

β = Wind direction relative to vessel

τ = Wind direction relative to rudder

c = Direction of fore fin relative to rudder direction

d = Direction of aft fin relative to rudder direction

FR = Lift force from rudder

DR = Drag force from rudder

In Fig. 2a the rudder is shaped to sustain a "lift" to the port side (PS in the figure) as the wind comes from the port side of the ship. Fig. 2b shows in an inverted situation, the shape of the rudder-profile as the wind comes from the starboard side of the ship, and as a "lift" to the starboard side is desired. Such a profile sustains a large "lift" even at an attack angle of 0 degrees, and represents a maximum force in its transverse direction at approximately 8-15 degrees depending on the shape of the profile.

The rudder is divided into three hinged sections that may be swung with respect to each other, in a manner that allows the centreline of the profile to form a curve that characterises the form of a wing. It has a main section 10 that is allowed to turn about the mast 11 supported by the ship 1. The foremost section 8 of the profile, "leading edge", is allowed to turn about an axis 9. The rear section 7, "trailing edge", is allowed to turn about axis 6. Both axis 6 and 9 are fixed to the main section 10.

Waves in open sea are mainly generated by wind, and generally, under strong windy conditions (gale and stronger), the direction of the waves will be similar to the wind direction within a band of angles of 15 to 20 degrees to both sides. This angle may become larger under weak wind conditions because of so called "old sea".

Sea currents are also mainly generated by the wind. This wind generated current will, as a result of the rotation of the earth, advance at a direction up to 20 degrees with respect to the direction of the wind. However, there may be contributions to this current caused by tidal, global- (the Gulf current) and local currents. In such matters the angle between the current and the waves may become up to 40-60 degrees, even under strong wind conditions.

As wind and current generally act at an angle that differs from the wave direction, a ship not being provided with a wind rudder will be oriented at an averaged direction that differs from the wave direction. The wave forces will then be significant as the waves, as mentioned above, will cause heavy loads in the transverse direction of the ship. Moreover, waves vary a lot in the course of time, and thus the ship will perform large yaw motions that cause heavy dynamic loads on the mooring.

Fig. 3 illustrates a theoretical situation where a ship is moored by means of a turret, as shown in Fig. 1, and where the wind and the waves are coming towards the ship at

different directions, as indicated by arrows. The symbols in this figure are as follows:

Fs	=	Transversal component of wind force on vessel
Fc	=	Transversal component of current loads on vessel
Fw	=	Transversal component of wave force on vessel
Ds	=	Longitudinal component of wind force on vessel
Dc	=	Longitudinal component of current loads on vessel
Dw	=	Longitudinal component of wave force on vessel
Ft	=	Turret mooring force
γ	=	Vessel direction relative to wave heading
Ms	=	Yaw turning moment of wind force on vessel
Mc	=	Yaw turning moment of current loads on vessel
Mw	=	Yaw turning moment of wave forces on vessel
FR	=	Transversal ship component of wind force on wind rudder
DR	=	Longitudinal component of wind force on wind rudder
CDG	=	Centre of gravity of vessel

The force arrows as indicated by F_W, F_C, and F_S represent the transversal components of the forces originated by waves, current and wind respectively, that act upon the ship. F_R and D_R represent the transversal and longitudinal components of the wind forces acting on the wind rudder.

The longitudinal components of the wind, wave and current forces that act on the ship are similarly indicated by the force arrow marked $D_S+D_W+D_C$. Wind, waves and current will in addition cause yaw force of momentum (about the vertical axis of the ship), as represented in the Figure by an arrow marked $M_S+M_W+M_C$ that acts about the centre of gravity (COG) of the ship. The magnitude of the forces and the force of momentums that act on the ship depend on the shape of the ship both below and above the sea level, and on the relative direction between respectively the ship and wind, waves and current.

The mooring force, marked by F_R, acts through the centre of the turret. The forces of momentum acting in connection with turret mooring systems are generally of such a small magnitude that they can be neglected.

A ship may be defined as being moored in a directionally unstable manner, if it is altered from one initial position to an another position significantly different from said initial position, by the influence of a minor transversal force (disturbance). This feature is characteristic for a static unstable situation. A dynamic unstable situation is characterised by that the ship will start turning (yaw) with an increasing amplitude if the ship is given a small transversal disturbance (influenced by a force in a limited period of time).

The forces that may generate an unstable behaviour of the ship may be originated by wind, waves, current or other kinds of influence that acts on the ship. A moored ship is stable or unstable, with respect to its direction, in dependence of the coefficients of transversal forces and torques that are originated by wind, waves and current together with the location of the turret and its mooring forces. The dynamic directional stability criterion is in addition determined by the moment of inertia of the ship with respect to yaw motions and transversal movements of the ship.

The magnitude of the forces originated by waves, wind and current that act on the ship are depending on the geometry of the ship and its averaged direction with respect to the direction of waves, wind and current. In a given situation, if the ship is directionally unstable, large yaw motions must be anticipated, as mentioned above. If, in case the ship is directionally stable, the feedback force (from wind, current and waves) will generally be small in comparison with the inertia forces of the ship. Thus, the response period for the yaw motion will become long, 100 seconds and more, depending on the wind-, current- and wave forces. This implies, in addition, that if one force component (e.g. the wave force) alters in magnitude or direction, the direction of the ship may alter significantly. In particular the yaw motion will be influenced by (slowly varying) wave forces.

As the wind often acts in a direction that differs with respect to the direction of the waves, and also represents the most dominant force influencing the direction of the ship, the averaged direction of a ship not provided with a wind rudder will mainly be determined by the direction of the wind. Thus, the direction of the ship will be somewhat biased with respect to the direction of the waves. This is an unfavourable situation as waves

coming against the bow of a ship at a biased direction cause large dynamic forces that generate yaw motions, resulting in very high and dynamic loads in the mooring lines of the anchored ship. Waves coming against the ship at an oblique angle may in addition cause large roll motions of the ship.

The use of one or more wind rudders will according to the invention provide a force that acts in a direction that is inverse as to the sum of the forces FW, FC and FS, and that contributes to the following:

-improve the directional stability of the ship as the rudder acts to augment the "yaw angle spring stiffness" of the ship, an augmentation in the forces that will turn the ship back to an averaged direction after a swing-out, and

-alter the averaged direction of the ship in such a manner that the direction of the waves versus the bow will be straight from ahead, whereby the dynamic forces that both influence the yaw angles of the ship and the averaged wave load will be decreased.

The wind rudder may be adjusted and controlled in alternative manners, for instance by:

-periodical adjustment of the rudder in accordance with changes in the averaged direction of the ship versus wind and waves, or

-continuous adjustment of the rudder that in addition take into account the yaw motions of the ship, for maximum utilisation of the capacity of the rudder.

Further, the rudder should be dimensioned to sustain a transverse force that is sufficiently strong to keep the bow of the ship up against the waves under the most probable load combinations of wind, waves and current for both loaded and ballasted draught.

Furthermore, the adjustment and the control of the rudder may be performed manually, or automatically in a manner similar to that of a side thruster in a dynamic positioned

ship, that will say by means of data control based on continuous records of for instance the direction of the ship, wind, current and waves.

Experiments were performed with a model boat moored in a turret, and where said boat was provided with a fixed wind rudder according to the invention. The experiments were performed in a model tank where waves propagated at a direction that was 20° versus the direction of the wind, and where the direction of the current was similar to that of the waves. The wind rudder was fixed in a position that formed an angle of 30° with the length axis of the model boat, and had an area that were approximately 20% of the surface water cross sectional area of the boat.

In the course of the experiments, the boat positioned at an averaged angle of 3,3° versus the direction of the waves, thus the angle of attack of the wind versus the wind rudder was 30-20+3,3 = 13,3°. Under these conditions, the maximum yaw angle of the boat was 11,43°, while the minimum yaw angle was -4,1°. In the last mentioned case the angle of attack of the wind versus the wind rudder was 30-20-4,1 = 5,9°, and in the first mentioned case the similar angle was 30-20+11,4 = 21,4°.

Experiments with a model boat not provided with a wind rudder were also carried out. In these experiments the directions for the wind and the waves were the same as above. In this situation, the boat had an averaged angle of 13° versus the direction of the waves. Furthermore, the maximum yaw angle was 28° and the minimum yaw angle was 0,4°.

Fig. 4 a) and b) shows a graphic presentation of the yaw motions of the boat, respectively without and with a wind rudder, as recorded for a period of time under the experiments.

As follows from the values of the digits above and of Fig. 4 a) and b), the yaw motions (the swinging motion from side to side) are substantially smaller for the boat provided with a wind rudder. In this manner, the differences between the largest yaw amplitudes are more than 30%. This reduction of yaw amplitude also resulted in a reduction of the mooring loads, that were measured to be about 25% for the boat provided with a wind rudder. However, as concerns the wind rudder that was applied in the experiments, it

should be mentioned that this rudder was not optimised neither with regards to the size, nor to the shape. Meanwhile, the results of the experiments illustrate the positive influence on the movements and forces that exclusively will be obtained by applying a wind rudder according to the present invention.

Claims

1. Method to direct an anchored floating structure (1) against the direction of the waves, where said structure at its fore end is moored to a buoy or the like,
characterised in that
the floating structure is provided with one or more turnable wind rudders (5) at its aft end that is so adjusted versus the direction of the wind that the floating structure is directed against the direction of the waves in a stable manner.

2. Means to direct an anchored floating structure (1) against the direction of the current- and/or waves, where said structure at its fore end is moored to a buoy or the like,
characterised in that
one or more turnable and preferably positively driven wind rudder(s) are arranged in relation to the aft end of the floating structure (1) and further adapted to be adjusted in any desired angle versus the length axis of the floating structure.

3. Means according to claim 2,
characterised in that
the wind rudder or rudders (5) have wing profile- or droplet like sections.

4. Means according to claims 2 and 3,
characterised in that
the rudder/s (5) are divided into three hinged sections (7, 8, 9) that may be swung with respect to each other in a manner that allows the centreline of the sections to form a camber.