

AN ASYMMETRIC MONOHULL VESSEL FOR FLOATING PRODUCTION

Technical Field

5 The present invention relates to a monohull vessel for floating production, which may include storage and offloading functionalities.

Background

10 Floating Production Storage and Offloading (FPSO) operation involves production and processing of hydrocarbons and minerals, e.g., crude oil, water and gas, at sea. A floating vessel is often used for such an operation in deep water. It is also commonly known as floating production. Hydrocarbons produced in the subsea well are transported to the floating vessel via subsea pipeline, riser system, etc. and may be
15 processed by the facilities on the topside of the floating vessel. The floating vessel may be used to store the processed products, e.g., crude oil. The processed products may then be offloaded onto a shuttle tanker. If the operation involves only storage and offloading, it is known as Floating Storage and Offloading (FSO) operation. The hull of an FPSO may be converted from an oil tanker or specially built for the operation. A
20 monohull FPSO is also referred to as a ship-shaped FPSO that commonly has a symmetric hull shaped like a ship. For the operation, the floating vessel is designed to be stationed at a specific location with the required storage capacity and to support large topsides payload with low production downtime.

25 To date, symmetric ship-shaped or monohull FPSOs have been installed extensively in the offshore industry. Global performance design optimisation of conventional monohull FPSOs as shown in Fig. 1 was discussed in a paper titled "FPSO Design to Minimise Operational Downtime due to Adverse Metocean Conditions off North-West Australia" published and presented at Deep Offshore Technology
30 International Conference & Exhibition, held November 27-29, 2012, in Perth, Australia. A conventional monohull FPSO when applied with a large number of deep-water risers hung on one side is suboptimal in terms of load carrying capacity and

ballast and cargo operations, among other deficiencies, due to significant levels of transversely imbalanced riser and structural loads.

The meteorological and oceanography (metocean) environment of FPSOs may
5 be typically characterized by sea waves and swell waves. Sea waves are locally generated in response to wind conditions and swell waves are resulted predominantly from storms in the oceans, e.g., Southern Ocean. Sea waves have typical peak periods between 2 and 7 seconds and wave heights ranging between 0 and 4 metres under non-tropical cyclone forcing. Swells and many severe storms have typical associated peak
10 wave periods in the range of 12 to 18 seconds. Persistent swells are largely responsible for resonant roll motions in many conventional FPSOs.

For example, the Santos Basin offshore Brazil and the North-West Shelf offshore Australia are affected by persistent Southern Ocean swells. In some instances,
15 the swell-induced roll motion amplitudes are greater than 12 degrees under operational metocean conditions. It was noted that actual roll motions observed in the fields often exceeded design predictions and roll motions under operational metocean conditions can be greater than in the severe metocean conditions.

20 Large-amplitude vessel motions induced by long-wave-period swells and severe storms cause problems in the installation and operation of FPSOs, including damage to risers, increased structural fatigue, off-specification production, and frequent process shut-downs. All these problems and issues result in significant downtime during operation and loss in productivity and net present value (NPV) of an FPSO over its
25 lifetime.

In view of the above, it is important to note that the motion characteristics of the floating vessel can have significant impact on both production plant downtime and the mooring and riser systems. Hence, any financial benefits gained during conversion
30 or construction of the floating vessel can be quickly eroded if the hull is not also designed to suit the field environmental conditions and is frequently shutdown resulting in loss of production or high cost of process facility, mooring and riser system repairs.

It is hence important to derive a solution that addresses the abovementioned problems and issues. In other words, the design of the floating production vessel should optimise ballast and cargo loading performance and motion performance in site-specific metocean conditions to minimise production downtime. A novel asymmetric monohull, as described herein, is proven advantageous.

Summary

According to various embodiments, an asymmetric monohull vessel design for floating production is provided. The asymmetric monohull vessel has a bulge or sponson on one side of the hull, such that the bulge or the sponson is configured to provide additional buoyancy to the floating vessel to counterbalance transversely imbalanced loads on the one side. The bulge or the sponson is configured also to act as an effective roll motion reduction appendage to optimise the roll motion performance of the floating vessel.

According to various embodiments, the asymmetric monohull vessel may further include ballast compartments within the hull, such that the bulge or the sponson is in fluid communication with the ballast compartments.

According to various embodiments, the floating vessel may further include a riser balcony extending from the one side of the hull, wherein the transversely imbalanced loads include riser loads, wherein the riser balcony is used for attaching risers and supporting the riser loads.

Brief Description of Drawings

Fig. 1A shows a diagram of a conventional floating vessel during a floating production storage and offloading (FPSO) operation.

Fig. 1B shows a schematic cross-sectional view of the conventional monohull floating vessel in Fig. 1A for FPSO operation.

Fig. 2 shows a schematic cross-sectional view of an exemplary embodiment of an asymmetrical monohull vessel for floating production.

Fig. 3 shows examples of the asymmetric monohull floating vessel in various loading conditions.

Fig. 4 compares the resonant and optimised roll response amplitude operators (RAOs) of a conventional floating vessel and the asymmetric vessel as shown in Fig. 2 versus wave energy distribution over wave period.

Fig. 5 presents a table of exemplary roll natural period values of the conventional floating vessel and the optimised asymmetric floating vessel in Fig. 2 in the various load conditions as shown in Fig. 3.

Detailed Description

Fig. 1A shows a diagram of a conventional floating vessel 10 (commonly known as a FPSO) during a floating production, storage and offloading (FPSO) operation. Floating vessel 10 has mooring system 20 which positions the floating vessel 10 and the attached riser systems 30 for transporting fluid between the floating vessel 10 and nearby platform 40.

Fig. 1B shows a schematic cross-sectional view of the hull 12 of the conventional floating vessel 10 in Fig. 1A for FPSO operation. The hull of floating vessel 10 is a monohull. It includes a hull 12 with ballast compartments 14 to provide hydrostatic stability to the floating vessel 10 and storage compartments 16 for storing cargo. This exemplary hull 12 of floating vessel 10, as shown in Fig. 1B, is symmetrical about the vertical axis 10P like all conventional monohull floating vessels or FPSOs.

Fig. 2 shows a schematic cross-sectional view of an exemplary embodiment of an asymmetric monohull vessel 100 for floating production. The asymmetric hull form is non-symmetrical about the vertical plane 100V dividing the port side 110D and

starboard side 110E of the floating vessel 100. Specifically, the floating vessel 100 is an asymmetric monohull vessel that includes a hull 110 that has a bulge 120 on one side, e.g. port side 110D or starboard side 110E, of the hull 110, as shown in Fig. 2. The bulge may be a sponson integrated through oil tanker conversion. Bulge or sponson 120 provides additional buoyancy to the floating vessel and is configured to counter-balance any transversely imbalanced loads including riser loads as well as structural and facility loads offsetting to the one side. This is one of the most obvious advantages of the novel asymmetric monohull design.

The additional displacement from the bulge or sponson 120 may be 1.5 times of the static riser loads which also provides a greater FPSO weight and storage growth margin. Very significantly, due to a more balanced transverse buoyancy and load distribution, the floating vessel 100 has an improved ballast capacity (e.g., more than 14.5m draft for improved fire pump suction and reduced slamming); ballast efficiency; cargo operation flexibility; offloading availability; and damage stability margin.

Referring to Fig. 2, for the asymmetric monohull vessel 100, bulge or sponson 120 only extends from the one side, e.g. port side 110D, and does not protrude from the opposite side, e.g. starboard side 110E, of the hull 110. Bulge or sponson 120 is designed to be submerged in the water, i.e., below the waterline 100W of the floating vessel 100, when the floating vessel 100 is operational in the water. Hence, the bulge or sponson 120 is disposed adjacent a bottom portion 110B of the hull 110. As shown in Fig. 2, the height of the bulge or sponson 120 is a portion of the height of the hull 110. In other words, the bulge or sponson 120 does not extend along the whole height of the hull 110. Bulge or sponson 120 may extend parallelly to the longitudinal axis 110L throughout the length of the hull 110 or only over a portion of the hull length, e.g., 80% of the length of the hull 110, primarily depending on the additional displacement required to counterbalance the transversely imbalanced riser and structural loads. The additional buoyancy provided by the bulge or sponson 120 can be translated to greater storage or topside weight carrying capacity of the floating vessel 100. Bulge or sponson 120 may extend downwardly from an underside 110U of the hull 110 and outwardly from the hull 110. It would be clear to a person skilled in the

art that the bulge or sponson 120 may extend both from the one side and the underside 110U.

One important design consideration of the shape of the bulge or sponson 120 is its impact on roll motion. Bulge or sponson 120 may be configured to act as an effective roll motion reduction appendix to optimise motion performance of the floating vessel 100. As will be explained later, the bulge or sponson 120 changes the resonant roll period of the floating vessel 100 and avoids vessel resonance with ambient waves of high energy concentration.

Floating vessel 100 includes a ballast system with ballast compartments 130 within the hull 110. A ballast system is configured to control the distribution of water in the ballast compartments 130. Bulge or sponson 120 is hollow. Bulge or sponson 120 may be void or be in fluid communication with the ballast compartments 130 so that water from the ballast compartments 130 may flow into the bulge or sponson 120 to increase ballast capacity. Bulge or sponson 120 may even be constructed as part of the ballast compartments 130. Floating vessel 100 may include storage compartments 140 within the hull 110.

Referring to Fig. 2, the floating vessel 100 may include a riser hang-off balcony or riser balcony 150 extending from one side of the hull 110 and from about the topside 110P of the hull 110. The riser loads are applied on the vessel through the riser balcony 150. Topside facilities for the floating vessel 100 are installed above the deck of the floating vessel 100. As shown in Fig. 2, the riser balcony 150 extends from the same side as where the bulge or sponson 120 extends from.

Floating vessel 100 may be built from scratch or converted from a ship. Bulge or sponson 120 may be designed and fabricated in an integrated fashion with the hull 110, in which case it becomes an integral part of the main hull 110. If the floating vessel 100 is converted from an existing ship, the sponson 120 may be fabricated separately and attached to the main hull 110 of the ship to form the bulge 120.

Fig. 3 illustrates one of the design alternatives of the asymmetric monohull floating vessel 100 in various loading conditions. In the example, the loading conditions are checked against a 48,000 ton of topside weight. In the first loading condition in row 302 of the table 300, i.e., ballast condition, the floating vessel 100 has no cargo but the ballast compartments 130 are filled with water at a weight of 88,260 ton. As shown, the bulge or sponson 120 is also filled with water. In the second loading condition in row 304, i.e., intermediate condition, the floating vessel 100 has a cargo volume of 780,000 barrels (bbls) of oil and the water is pumped out of the ballast compartments 130 to reduce the ballast weight to 32,600 ton. In the third loading condition in row 306, i.e., full load condition, the floating vessel 100 is fully loaded with a cargo volume of 1,400,000 bbls and the ballast compartments 130 and the bulge or sponson 120 are emptied.

Fig. 4 presents a comparison 400 demonstrating the resonant and optimised roll response amplitude operators (RAOs) of a conventional hull 12 of floating vessel 10 as shown in Fig. 1B, and the asymmetric floating vessel 100 as shown in Fig. 2 versus wave energy distribution over wave period. Curve 452 represents the wave spectrum of a design condition. In this example, a typical bi-model wave spectrum of seas and swells is demonstrated. Curve 454 represents the roll RAO of the conventional hull 12 of floating vessel 10, as shown in Fig. 1B, against wave period and Curve 456 represents the roll RAO of the floating vessel 100 of Fig. 2. As shown in Fig. 4, the most energetic wave periods of the swells are in the range of 12-18 seconds with the wave energy density peaking at about 15 seconds and the peak period of the roll RAO of the conventional hull 12 of floating vessel 10, as shown in Fig. 1B, is also about 15 seconds. This results in high amplitude roll motion on the conventional floating vessel, which consequently results in increased structural fatigue, off-specification production and frequent process shut-downs, which ultimately results in significant downtime of the conventional floating vessel. Asymmetric floating vessel 100 as shown in Fig. 2 has a natural roll period at the roll RAO peak of about 19 to 21 seconds, which is higher than the swell wave period range. Floating vessel 100 effectively avoids resonant vessel roll motion caused by the swells. In general, the natural roll period should be 2-3 seconds higher than the peak period of the most unfavourable wave environment for

turret-moored system and 3-5 seconds for spread-moored system. Floating vessel 100 is designed to be suitable for both systems.

The dynamic design principle of the floating vessel 100 may be shown by the
5 mathematical formula below to calculate the natural roll period of the vessel:

$$T_{n4} = 2\pi \sqrt{\frac{I_{44} + a_{44}}{\rho g \nabla GM}}$$

where

10 T is the natural period of roll motion of the floating vessel,
 I is the roll moment of inertia of the floating vessel,
 a is the added moment of inertia due to roll motion,
 ρ is the density of sea water,
 g is the gravitational acceleration,
 ∇ is the displaced volume of vessel, and
15 GM is the metacentric height.

Referring to the formula above, by having an asymmetrical hull 110 due to the bulge or sponson 120, the natural period of the roll motion of the floating vessel 100 effectively increases due to increased added moment of inertia. The design of the hull
20 110 of floating vessel 100 is configured to avoid resonant vessel roll motion with the site-specific wave conditions. It needs to include the identification of vessel natural periods and to achieve the targeted natural periods through sizing and optimizing the principal dimensions of the hull 110, and the dimensions of the bulge and sponson 120.

25 Fig. 5 presents a table 500 of exemplary roll natural period values of the conventional floating vessel and the optimised asymmetric floating vessel 100 in Fig. 2 in the various load conditions as shown in Fig. 3. The readings in the table are obtained from motion analysis of the conventional floating vessel and the floating vessel 100 with an asymmetric hull 110. In the various load conditions, i.e., ballast,
30 intermediate, full load, the natural period of the conventional hull 12 of floating vessel 10, as shown in Fig. 1B, is about 15 seconds. However, the natural period of the floating vessel 100 is about 19 seconds. As mentioned earlier, the natural period of the

conventional floating vessel coincides with swell wave period range and suffers the problems of resonant vessel roll motion caused by the swells. On the other hand, the natural period of the floating vessel 100 effectively avoids the swell wave period range and avoids resonant vessel roll motion caused by the swells.

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The asymmetrical floating vessel 100 with optimised motion performance has many advantageous effects. It minimizes the probability of vessel motion exceedance for greater windows of operability and availability, e.g., process plant operation, offloading operation, crew habitability and helicopter operation. It also minimizes the cumulative motion-induced fatigue for reduced process, structural, riser and mooring system maintenance and repair. It reduces off-specification production and frequency of process shut-downs. Overall, the problems and issues which cause significant loss in productivity and net present value (NPV) of the floating vessel over its lifetime are mitigated.

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A skilled person would appreciate that the features described in one example may not be restricted to that example and may be combined with any one of the other examples.

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The present invention relates to an asymmetrical, monohull vessel for floating operation generally as herein described, with reference to and/or illustrated in the accompanying drawings.

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CLAIMS

1. An asymmetric monohull vessel (100) for floating production of hydrocarbon and minerals in deep water, wherein the monohull vessel (100) is asymmetrical about
5 a vertical plane (100V) dividing the monohull vessel (100) into a port side (110D) and a starboard side (110E), the monohull vessel (100) comprising:
a hull (110) comprising a bulge or sponson (120) on one side of the hull (110) and comprising a height, wherein the bulge or sponson (120) comprises a height which is a portion of the height of the hull (110), and extends from a
10 bottom portion (110B) of the hull (110), wherein the bulge or sponson (120) is fully submerged in water when the monohull vessel (100) is operational in water, wherein the bulge or the sponson (120) is configured to provide additional buoyancy to the monohull vessel (100) in addition to counterbalancing transversely imbalanced loads offsetting to the one side of the
15 hull (110), and wherein the bulge or the sponson (120) is configured also to act as an effective roll motion reduction appendage to optimise roll motion performance of the monohull vessel (100).
2. The monohull vessel (100) according to Claim 1, further comprising ballast
20 compartments within the hull (110), wherein the bulge or sponson (120) is in fluid communication with the ballast compartments.
3. The monohull vessel (100) according to Claim 1, wherein the monohull vessel (100) further comprises a riser balcony (150) extending from the one side of the hull
25 (110), wherein the transversely imbalanced loads comprise riser loads, wherein the riser balcony (150) is used for attaching risers and supporting the riser loads.