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(54) **Mooring system for a floating structure**

(57) A mooring system for a floating structure, such as vessel, is described, comprising a mooring structure, such as a buoy, a further floating structure or a fixed tower. The mooring structure has a turntable rotatable around a vertical axis, and a connection structure adapted to provide a connection between the floating structure and the mooring structure. The connection structure comprises a rigid arm assembly and pendulum members, wherein the rigid arm assembly and pendulum members at one end are hingedly interconnected and at their other ends are adapted to be connected to the floating structure and the mooring structure respectively. Ballast weights are provided at the interconnected ends. A damping system for damping the swinging motion of the pendulum members is provided. The damping system comprises at least one liquid tank containing a liquid and being located in the mooring system at a distance from the vertical axis. The liquid tank has such dimensions that at a swinging motion of the pendulum members the liquid is adapted to move in the liquid tank to provide damping forces counteracting the swinging motion of the pendulum members.

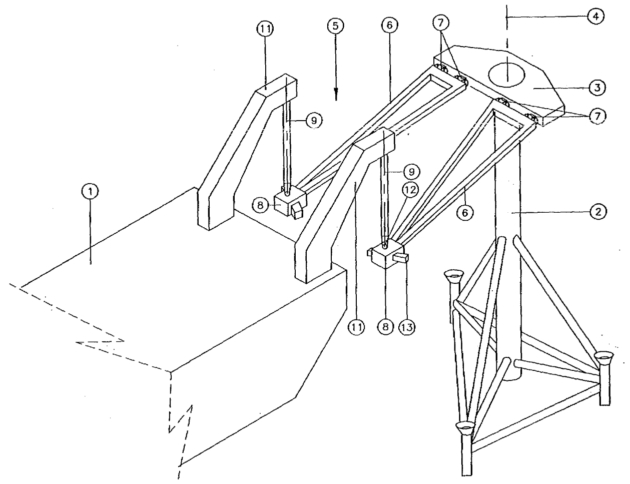

FIG. 1

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Description

[0001] The invention relates to a mooring system for a floating structure, such as vessel, comprising a mooring structure, such as a buoy, a further floating structure or a fixed tower, having a turntable rotatable around a vertical axis, and a connection structure adapted to provide a connection between the floating structure and the mooring structure, the connection structure comprising a rigid arm assembly and pendulum members, wherein the rigid arm assembly and pendulum members at one end are hingedly interconnected and at their other ends are adapted to be connected to the floating structure and the mooring structure respectively, wherein ballast weights are provided at the interconnected ends.

[0002] Mooring systems of this type are disclosed for example in EP-A-0 096 119, EP-A-0 105 976 and EP-A-0 152 975. In such a mooring system, the ballast weights provide restoring forces to enable the floating structure to maintain a position window relative to the mooring structure. The rigid arm assembly and pendulum members do not restrict the first order motions of the floating structure caused by the environmental conditions. In embodiments where the pendulum members are attached to the floating structure, the interconnected ends of the rigid arm assembly and pendulum members with the ballast weights are free to swing perpendicular to the restoring force due to for example the roll motions of the floating structure. In the known mooring system, the swinging motion of the pendulum members can become undesirably large when the pendulum is exited in or close to its natural frequency. It is noted that motion of the pendulum members involves motion of the other movable parts of the mooring system, i.e. the turntable and the rigid arm assembly. The natural frequency of this moving system depends on the geometry and weight of all parts. When reference is made to natural or swinging frequency or motion of the pendulum members this should be understood as the natural or swinging frequency or motion of the complete moving system, comprising the pendulum members, rigid arms and turntable.

[0003] The object of the invention is to provide an improved mooring system of the above-mentioned type, wherein damping of the motion of the pendulum members is obtained in an efficient manner.

[0004] According to the invention the mooring system is characterized by a damping system for damping the swinging motion of the pendulum members, the damping system comprising at least one liquid tank containing a liquid and being located in the mooring system at a distance from the vertical axis, wherein the liquid tank has such dimensions that at a swinging motion of the pendulum members the liquid is adapted to move in the liquid tank to provide damping forces counteracting the swinging motion of the pendulum members.

[0005] In this manner an efficient damping system is obtained, wherein the counteracting forces of the liquid moving in the tank, more specifically the slamming impact forces and inertia forces, are used as damping forces to provide damping of the swinging motion of the pendulum members. The damping system cannot be directly exited by environmental forces. A further advantage is that the damping system is not subject to marine fouling.

[0006] The invention will now be explained in more detail with reference to the drawings schematically showing an embodiment of the mooring system according to the invention.

[0007] Fig. 1 schematically shows an embodiment of the mooring system according to the invention.

[0008] Fig. 2 schematically shows a top view of the mooring system of Fig. 1.

[0009] Fig. 3 is a cross section of the lower end of one pendulum member with a ballast weight and liquid tank of the mooring system of Fig. 1.

[0010] Figs. 1 and 2 show an embodiment of a mooring system for a floating structure 1, such as a vessel, which comprises a mooring structure 2, which in this embodiment is made as a fixed tower anchored to the sea bed. However, the mooring structure can also be made as a buoy or a further floating structure. This further floating structure can be for example a vessel keeping position by means of a further mooring system or for example a dynamic positioning system.

[0011] The tower 2 is provided with a turntable 3 rotatably supported on the tower 2 around a vertical axis 4. The mooring structure further comprises a connection structure 5 adapted to provide a connection between the floating structure 1 and the tower 2. In this embodiment the connection structure 5 comprises two rigid arms made as triangular yokes 6. At one end the yokes 6 each are connected to the turntable 3 by hinges 7. At the opposite end each yoke 6 is connected to a ballast weight 8.

[0012] The connection structure 5 further comprise two pendulum members 9 each connected by a hinge assembly (not shown) to support arms 11 mounted on the floating structure 1. At their lower ends the pendulum members 9 are connected by hinge assemblies 12 to the ballast weight 8, thereby providing an interconnection between the ends of the pendulum members 9 and the yokes 6. The hinge assemblies at the upper and lower ends of the pendulum members 9 provide two perpendicular hinge axes allowing movement of these pendulum members in all directions.

[0013] In the embodiment shown in Figs. 1 and 2, each ballast weight 8 includes a tank 13 containing a liquid, for example seawater, as schematically shown in Fig. 3. The dimensions of the tank 13 and the amount of liquid are chosen such that the liquid is adapted to move in the tank 13 due to the swinging motion of the pendulum members 9. This results in a liquid wave 14 or travelling water bullet providing slamming impact and inertia forces creating a tank reaction force that is counteracting the swinging motion of the pendulum members 9 thereby causing damping of the swinging motion of the pendulum members 9. In Fig. 3 the lower end of one of the pendulum members 9 is shown in an outer position, the swinging motion just reversing to the other outer position, wherein the reaction forces are represented by an arrow 15 counteracting the swinging motion. The direction of the swinging motion is represented in Fig. 2 by a dashed circle line having the axis 4 as its centre.

[0014] According to an embodiment of the invention, the damping characteristics of the tank 13 can be adjusted by adjusting the amount of liquid, i.e. the height of the liquid in the tank. As an alternative or added feature, the inner dimensions of the tank can be made adjustable, for example by varying the effective length of the tank.

[0015] As shown in the top view of Fig. 2, the length dimension of the tanks 13 is tangential to the radius to the rotation axis 4 of the turntable 3. This results in an efficient damping operation.

[0016] By selection of the tank dimensions, the number of tanks and the properties of the liquid in the tank, the amount of damping can be adjusted. In particular, when the tanks 13 are designed and installed, the dynamic behaviour of the tanks can be adjusted by the amount of liquid in the tank. Although the tanks 13 are located at the interconnected ends of the yokes 6 and the pendulum members 9 in the embodiment shown, the location of the tanks can be freely chosen on the yoke, pendulum members or turntable. Generally, the tanks 13 can be located at any location in the mooring system at a distance from the vertical axis 4. However, the tank reaction forces are most effective in damping the mooring system when the restoring forces generate the largest restoring moment around the rotation axis 4 of the turntable 3. Further, it is preferred for effective damping to have the length dimension of the tanks oriented perpendicular to the radius towards the rotation axis 4. It is possible to use different tanks with different lengths and liquid heights.

[0017] Generally, the swinging motion period can vary from 6-16 seconds, depending on the pendulum member lengths and the instantaneous pendulum member inclination relative to the vertical. It is noted that the inertia of the rotating turntable 3 has a natural period increasing effect on the swinging period of the pendulum members 9. The natural period will become shorter as the floating structure moves away from or towards the mooring structure due to the inclination of the pendulum members in the plane perpendicular to the swinging motion. Highest efficiency is therefore obtained when damping optimum of the anti-yaw tanks is around 85% - 95% of the natural period as found with vertical pendulums.

[0018] In case of a natural frequency of a shallow liquid wave in the tank, the dimensions of the tank can be determined by means of the following equations:

$$M = \rho.N.B.h.L$$

$$T = 2.L/\nu_w$$

$$\nu_w = \sqrt{(g.h)}$$

[0019] with the density of the fluid in the tank ρ[T/m^3];
the number of tanks N;
the width of the tank B (perpendicular to flow direction) [m];
the liquid level in the tank h [m];
the length of the tank L (in line with flow direction) [m];
the tuned period of the tank T [s];
the wave propagation speed in the tank v_w[m/s];
the constant of gravity g [m/s^2].

[0020] In practice, also the tank motion amplitude is of importance which will require a longer tank length with increasing motion amplitude. At large amplitudes of the swinging motion the tank natural frequency ceases to exist since the flow regime is such that the water behaves more like a "liquid bullet" than as a standing wave or water bore for which a tank frequency can be theoretically determined. The following empirical relations have been established based upon test results. These relations however do not limit the dimensions of the tank.

$$L_{tank} \approx a \cdot L_{pend} \cdot \gamma \quad or$$

$$L_{tank} \approx a \cdot g / \omega_{pend}^2 \cdot \gamma$$

$$h_{tank} \approx b \cdot L_{tank}$$

$$H_{tank} \approx c \cdot h_{tank}$$

$$B_{tank} \approx d \cdot F_{pend} / (g \cdot \rho_{liquid} \cdot h_{tank} \cdot L_{tank} \cdot N) \cdot \gamma^{0.5}$$

$$\gamma = R_{tank} / R_{pend}$$

With:

$0.57 < a < 0.73$ or longer for unlimited length tanks
$0.035 < b < 0.05$
$2 < c < 4$
$0.10 < d < 0.13$ or wider for unlimited width tanks

where L_{tank} is the length of the tank, ω_{pend} the natural frequency of the moving system , h_{tank} the liquid level in the tank, H_{tank} the structural height of the tank or tank level, B_{tank} the width of the tank and N the number of levels, F_{pend} is the force in the lower pendulum hinge, and ρ_{liquid} the liquid density. All units are SI units (m, kg, N, sec). The ratio y denotes the ratio between the effective radius from the turntable bearing to the tank centreline, R_{tank}, over the radius from the turntable bearing to the lower pendulum hinge point, R_{pend}.

[0021] The invention is not limited to the embodiment as described above, which can be varied in many ways within the scope of the invention as defined in the claims.

Claims

1. Mooring system for a floating structure, such as vessel, comprising a mooring structure, such as a buoy, a further floating structure or a fixed tower, having a turntable rotatable around a vertical axis, and a connection structure adapted to provide a connection between the floating structure and the mooring structure, the connection structure comprising a rigid arm assembly and pendulum members, wherein the rigid arm assembly and pendulum members at one end are hingedly interconnected and at their other ends are adapted to be connected to the floating structure and the mooring structure respectively, wherein ballast weights are provided at the interconnected ends, **characterized by** a damping system for damping the swinging motion of the pendulum members, the damping system comprising at least one liquid tank containing a liquid and being located in the mooring system at a distance from the vertical axis, wherein the liquid tank has such dimensions that at a swinging motion of the pendulum members the liquid is adapted to move in the liquid tank to provide damping forces counteracting the swinging motion of the pendulum members.

2. Mooring system according to claim 1, wherein at least one liquid tank is provided at the interconnected ends of the rigid arm assembly and pendulum members.

3. Mooring system according to claim 1 or 2, wherein the inner dimensions of the tank and/or the amount of liquid are/is adjustable to adjust the damping characteristics of the tank.

4. Mooring system according to claim 1, 2 or 3, wherein the length dimension of the tank is tangential to the turntable

rotation axis.

5. Mooring system according to any one of the preceding claims, wherein the dimensions of the tank substantially meet the equations of page 5, line 36 - page 6, line 14.

6. Damping system for a mooring system according to any one of the preceding claims, comprising at least one liquid tank having such dimensions that the liquid is adapted to move in the liquid tank to provide damping forces counteracting the swinging motion of the pendulum members.

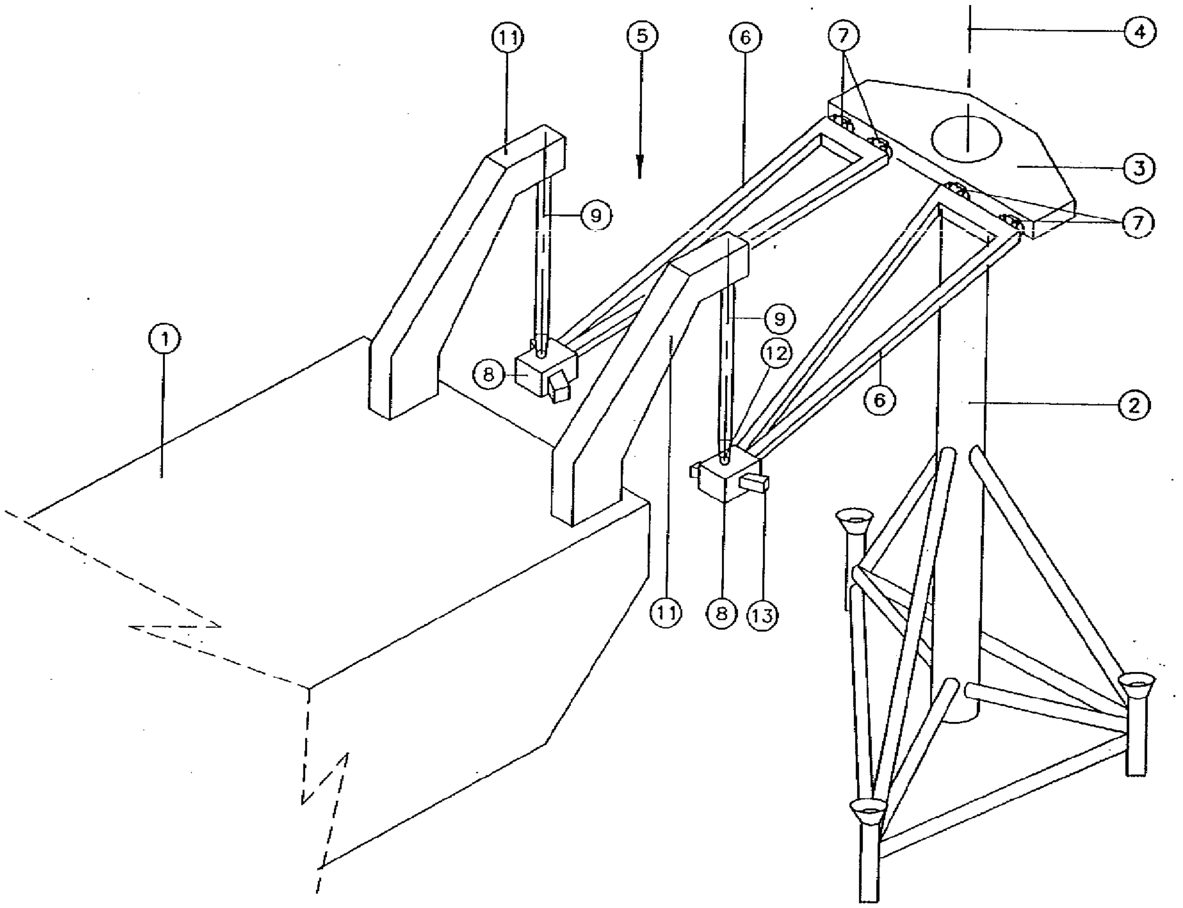

FIG. 1

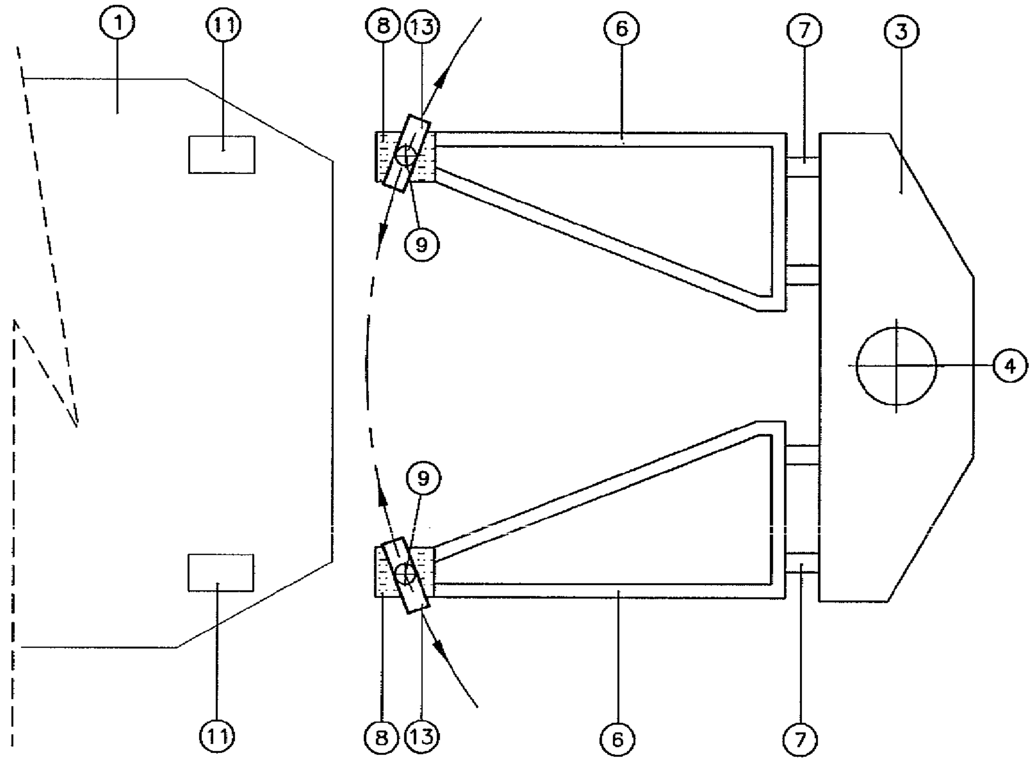

FIG. 2

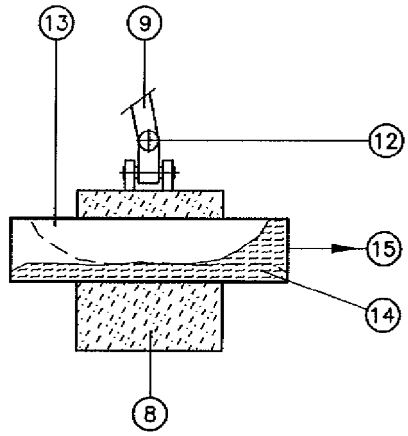

FIG. 3

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EUROPEAN SEARCH REPORT

Application Number
EP 06 12 2163

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
Munich	25 June 2007	Moya, Eduardo

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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