The present invention relates to systems for reducing the pitching (alternate falling and rising of the bow and stern) of a vessel and, more particularly, to passive motion stabilizing systems employing the alternate transfer of a liquid ballast toward and away from the bow and stern sections of a vessel to create a damping or stabilizing moment in opposition to the pitching moments of the waves of a rough sea.

In the interest of economical ship operation, that is, to minimize power requirements and fuel consumption, it is desirable to keep the ship on as even a keel as possible at all times, or, in other words, to reduce rolling (transverse motion) and pitching (end-to-end motion) as much as possible. Accordingly, to the specific end of reducing unnecessary power expenditure, it is especially desirable to minimize power losses attributable to the motion of the vessel caused by rough seas. Additionally, the reduction of rough motion of a ship increases the comfort of the passengers and crew and substantially reduces various deleterious stresses induced in the vessel structure, itself.

Many passive devices (that is, non-power consuming devices as contrasted with active or power consuming devices) for reducing rolling have been heretofore successfully employed, however, passive systems for reducing pitching have not been available. Accordingly, it is an object of the present invention to provide new and improved systems of pitch stabilization, and, more specifically, it is an object of the invention to provide passive stabilization systems which require no expenditure of generated power, as would otherwise be required in the operation of an active stabilizing device, a gyroscope, for example.

In accordance with the specific principles of the invention, a pitch damping or stabilizing moment may be generated by a controlled, longitudinal or end-to-end shifting of a liquid cargo or ballast, in opposition to an unstabilizing, significant pitching moment of a wave. Specifically, this is advantageously accomplished by providing a "timing structure" which may include a longitudinal duct extending between forwardmost and rearmost liquid cargo holds and having baffles or orifices therein. The "timing structure" is of predetermined physical dimensions sufficient to generate a "stabilizing" wave, creating an advantageous free surface effect, and a weight moment within the vessel, itself, when the liquid ballast is shifted end-to-end, which "stabilizing wave" and weight moment will each have a period substantially equal to that of the significant pitching wave, but will be laggingly out of phase with the pitching wave by half its period, so as to be substantially vectorially opposed thereto. The new system is extremely effective in damping a wide range of encountered pitching frequencies due to the energy damping characteristics of the generated wave, which are, in effect, super-imposed upon the out of phase weight moment produced by the liquid transfer. This novel system of pitch stabilization may be characterized as a closed system in which the liquid stabilization medium is typically a cargo or a ballast contained entirely within the vessel, itself.

An alternate system for effectively stabilizing the pitching motion of a rough sea, in accordance with the invention, is characterized as an open system. This system is similar to the closed system in that it involves the employment of a "timing structure" for the generation of a stabilizing moment in vectorial opposition to the pitching waves. However, the stabilizing medium employed in the open system is sea water rather than a liquid cargo. Specifically, in the open system, a stabilizing weight moment and a stabilizing buoyant moment are created by the transfer of sea water to and from stabilizing tanks located at the waterline in the bow of the ship (or in both the bow and stern) through orifices of predetermined area sufficient to create the necessary, optimum phase lag between the generated weight and buoyant moments and the pitching wave of the sea. More specifically, as sea water rushes into the stabilizing tank on a downward pitch, air is entrapped in the tank and a buoyant moment is created tending to damp the downward pitch. Conversely, on an upward pitch, the gravitational flow of water from the tank creates a weight moment tending to damp the upward pitch.

For a more complete understanding of the invention, reference should be made to the following detailed description taken in conjunction with the accompanying drawing in which:

FIG. 1 is a schematic representation of a liquid cargo carrying ship embodying a closed stabilizing system in accordance with the principles of the present invention.

FIG. 2 is a cross-sectional view of the closed stabilizing system, taken along line 2–2 of FIG. 1, showing the "timing structure".

FIG. 3a is a schematic representation of an open stabilizing system with the ship in calm water; and

FIGS. 3b and 3c are schematic representations of the shifting of sea water to and from stabilizing tanks in the bow or stern of a ship embodying the open system to generate stabilizing buoyant moments and to generate stabilizing weight moments.

Referring to FIG. 1, the stabilizing systems of the present invention may be embodied to advantage in a liquid cargo carrier or tanker. Such a vessel is of substantial size; exemplary hull dimensions between the forward and aft perpendiculars, designated FP, AP, respectively, being about 500–1000 feet; the molded beam being about 75–200 feet; and the molded depth being about 40–90 feet. Located at the stern of the ship are the engine room 11, boiler room 12, steering gear 13, and superstructure 14, while forepeak tank 15 and forward compartments 16 are located at the bow. Independent cargo carrying tanks 17–26 are centrally located and are typically laden with a liquid cargo 27, such as oil.

In accordance with the principles of the invention, a longitudinal duct or conduit 28 is installed in the central cargo carrying section and extends for a major portion of the ship's length between the forwardmost cargo tank 17 and the rearmost cargo tank 26. In the illustrated preferred embodiment, the duct is disposed symmetricaly with respect to the centerline of the ship and is located substantially above the waterline and in intersection with the cargo level CL, advantageously located immediately below the deck 29, as shown in FIG. 2. Maintenance of the cargo level in tanks 26 and 17 beneath the upper wall 28a of the duct 28 provides a free surface. As will be understood, this arrangement accommodates stabilizing wave generation and utilization of a free surface effects of generated waves to damp pitching motion.

As a very important aspect of the invention, a plurality of baffles or orifice plates 30 are included in the duct and constitute what has been characterized as a "timing structure." The number of plates and the effective areas of the orifices are empirically determined by the specific geometry and size of the ship, as well as the ranges of characteristics of the waves (amplitude, frequency, period) which are expected to be encountered at sea. More specifically, the significant pitch creating forces of a
3,286,677

rough sea, those causing the alternate rise and fall of the bow and stern, will cause the liquid cargo to be transferred from end-to-end through the duct 28. The weight forces of the transfer of this cargo and the free surface effects of the moving cargo create a weight moment and energy damping moment, respectively, which may be utilized for pitching stabilization. Through predetermined proportioning of the “pitching structure,” in accordance with the invention, the moments generated by the cargo shift are made to lag substantially the unstabilizing moment of the wave forces which normally cause the ship to rise and fall. When the lag of the moments generated by the weight transfer and the free surface effect is carefully controlled and maintained substantially 180° out of phase with the unstabilizing pitching moments, the generated moments have a damping effect and tend to minimize significantly the pitching movement of the vessel over wide ranges of frequency of encountered waves. The effectiveness of this closed system over wide frequency ranges is believed to be due, in a large measure, to the combinative effect of the superimposition of the moment caused by the free surface effect upon the moment caused by the weight transfer of the cargo.

In accordance with the principles of the invention, an alternative open system may be used in lieu of the closed system or in addition to the closed system, which, as should be understood, will be inactive when the cargo holds are empty. As shown schematically in FIGS. 3e–3e', an orifice 40 (the bow, or in some instances the bow and stern) of the ship 43 is fitted with a stabilizing tank 41, the major portion of which is located above the waterline. Orifices 42 are provided in the tank at locations above the waterline, and, as will be understood, they accommodate admission and expulsion of surrounding sea water, through gravitational flow, to and from the tank 41. The function of the restrictive openings 43 corresponds generally to that of the “pitching structure” of the above-described closed system.

Operation of the open system is broadly analogous to the closed system, in that stabilizing moments are created by the shifting of a liquid medium in neutralizing, vectorial opposition to the unstabilizing moment caused by the sea. Specifically, in calm water, as shown in FIG. 3a, the ship 43 is on an even keel and the tank 41 is substantially empty. However, upon encountering a rough sea and being subjected thereby to a downward pitch by wave forces, the sea water will tend to rush into and fill the stabilizing tank 41 at a rate controlled by the “pitching structure.” In accordance with the inventive principles, the controllably admitted inrushing water will entrap and compress substantial quantities of air 44 in the tank 41, in a manner whereby the stabilizing buoyant moment of the ship and tank 41 will tend to damp the downwardly directed, unstabilizing moment of the rough sea. Thereafter, as the ship is subjected to an upwardly directed pitch, due to the rough sea and as shown in FIG. 3c, the filled tank 41 will tend to exhaust at a rate controlled by the orifices 42. As its acquired sea water due to gravity and due to the expansive forces in the overlying layer of compressed air 44, in a manner that the anti-pitch or stabilizing weight moment of the previously admitted water is 180° out of phase with the falling pitch.

In accordance with the principles of the invention, the size and number of these orifices are predetermined to ensure that the buoyant moment and weight moment generated by the exchange of ballast to and from the surrounding sea are substantially 180° out of phase (lhogging) with the rising and falling pitching moments, respectively, of the waves. More specifically, in the open system, a rising pitch (FIG. 3c) is effectively stabilized by a weight moment timely controlled by the exhausting of sea water through the orifices, which stabilizing weight moment will be lagging the unstabilizing, upward pitching moment by 180° due to the restrictive effect of the orifices 42. A falling pitch (FIG. 3b) will be counteracted by the timely controlled buoyant moment, which stabilizing buoyant moment will be lagging the unstabilizing, downward pitching moment by 180° due to the restrictive effect of the orifices 42. In other words, the generated buoyant stabilizing moment is in phase with the downwardly directed pitch, while the generated weight stabilizing moment is in phase with upwardly directed pitch.

In some instances it might be found desirable or necessary to provide additional orifices 42' (shown in outline) below the waterlines to provide additional exhaust capacity to the stabilizing tank, as shown in FIGS. 3b and 3c. As will be understood, the orifices 42' accommodate the establishment of a water level within the tank, itself, coincident with the waterline of the ship.

In accordance with the principles of the invention, a ship may be provided with passive pitch stabilizing systems which tend to keep a ship on an even keel by naturally generated stabilizing moments. Accordingly, the stabilization realized with the inventive systems requires no power from the ship and enables the ship's power to be used more efficiently for propulsion purposes. Moreover, the new stabilization systems reduce stresses on the ship structure and substantially increase passenger comfort as can readily be appreciated.

It should be understood that the specific structures herein illustrated and described are intended to be representative only, as certain changes may be made therein without departing from the clear teachings of the disclosure. Accordingly, reference should be made to the following appended claims in determining the full scope of the invention.

What is claimed is:

1. A ship having a reduced tendency to pitch in rough sea comprising
   (a) an elongate hull having a predetermined waterline,
   (b) a series of fluid cargo holds adapted to hold a fluid cargo consecutively arrayed from stern to bow,
   (c) duct means interconnecting a forward one and a rearward one of said holds for communication therebetween and being disposed symmetrically about the center line of said hull and substantially above said waterline,
   (d) flow restricting means of predetermined areas arranged in said duct means to retard fluid cargo flow between said holds in a manner that transfer of said cargo from said holds will occur periodically when said ship is periodically elevated at alternate ends by periodically encountered wave forces.
   (e) said restricting means being of sufficient predetermined area and number to create substantially a one-half period phase lag between said applied wave forces and the period of said cargo transfer,
   (f) whereby said transfer of cargo will create damping moments in substantial opposition to the moment created by said wave forces.

2. A ship in accordance with claim 1, in which
   (a) the forward one and rearward one of said cargo holds have a predetermined cargo level located beneath the deck of said hull,
   (b) said duct means intersects said cargo level,
   (c) whereby a free surface of cargo will be present in said duct means when said holds are filled to said predetermined cargo level.

3. A ship having a reduced tendency to pitch in rough sea comprising
   (a) an elongate hull having a deck portion and a predetermined waterline,
   (b) a first pitch stabilizing tank at a forward portion of said hull,
   (c) a second pitch stabilizing tank at an aft portion of said hull,
   (d) liquid ballast means filling said tanks to a predetermined level adjacent the deck portion,
3,286,677

5. The combination of claim 4 wherein said plate means are of sufficient predetermined area and number to create substantially a one-half period phase lag between the applied wave forces and the period of the liquid transfer between said first and second tanks.

6. A ship in accordance with claim 2 in which said duct means includes vertical side wall portions intersecting the cargo fluid level in at least some of the fluid cargo holds between said forward one and rearward one whereby transverse free surface waves in said holds are limited.

7. A tanker in accordance with claim 4 including a plurality of amidship cargo tanks between said first cargo tank and said second cargo tank and wherein said duct means includes vertical side wall portions intersecting the free surface level of a fluid cargo in said amidship cargo tanks whereby transverse free surface waves in said amidship cargo tanks are limited.

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