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**Vessel Stabilisation Apparatus and Method**Field of the Invention

The present invention relates to a method and apparatus  
5 for stabilising a vessel such as a marine vessel.

Background of the Invention

Gyroscopic stabilisers (gyro stabilisers) have been used  
for many years for the purposes of stabilising marine  
10 craft, and in particular minimising the effects of roll  
created by wave action.

In 1904 Schlick suggested using a large gyroscope as a  
passive device in order to supply an internal torque to  
15 oppose roll motion of a vessel induced by wave action.  
The basic principle of the device was to lengthen the roll  
period of the vessel so that it would not interact with  
periodic wave motion thereby avoiding resonance. Most  
large vessels have a roll period of approximately 10  
20 seconds, with the longest wave period being approximately  
16 seconds. By extending the roll period of a vessel to  
greater than 16 seconds, the vessel will not resonate with  
a wave action.

25 One problem with the passive gyroscope is that in small  
craft it is often difficult to lengthen the period of roll  
outside the wave spectrum. In addition, the wave spectrum  
changes relative to the vessel's speed and heading. This  
can effectively alter the wavelength of the wave to be  
30 even longer.

Later, Sperry designed an active controlled gyroscope  
which forced the gyroscope into precession and proved to

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be more efficient than the passive gyroscope. The basic principle of the Sperry gyroscope was to apply roll torque to a vessel in opposition to that induced by the wave action to thereby reduce roll. This is known as a brute  
5 gyroscope.

Early models of brute gyroscopes were large and heavy, at times approaching 1.0% to 2.0% of the mass of the vessel, and had low spin rates.

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#### Summary of the Invention

The present invention was developed to provide an alternate method of operating a gyroscope to reduce the adverse effects of wave motion on a vessel.

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According to the present invention there is provided a method for controlling the motion of a vessel comprising the steps of:

installing a gyroscope having a flywheel in a vessel,  
20 said gyroscope mounted in a gimbal having a trunnion axis aligned in a plane containing motion of a vessel created by wave motion that is desired to be controlled;

spinning said flywheel about a spin axis;

sensing said motion of said vessel caused by a wave  
25 having a wave slope; and,

on the basis of said sensed motion, applying a force about the trunnion axis to the gyroscope in a direction so that said gyroscope produces a reactive torque which is applied to said vessel in a manner to urge said vessel to  
30 follow said wave slope.

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According to the present invention there is further provided a method for controlling roll motion of a vessel comprising the steps of:

installing a gyroscope in said vessel, said gyroscope  
5 having a spin axis in a vertical plane and mounted in a gimbal having a trunnion axis aligned athwart said vessel;

sensing roll motion of said vessel caused by a wave having a wave slope; and,

on the basis of said sensed motion, applying a force  
10 to said gyroscope about the trunnion axis in a direction so that said gyroscope produces a reactive torque which is applied to said vessel in a manner to roll said vessel to follow said wave slope.

15 According to the present invention there is further provided a method for controlling pitch motion of a vessel comprising the steps of:

installing a gyroscope in said vessel, said gyroscope  
having a spin axis in a vertical plane and mounted in a  
20 gimbal having a trunnion axis aligned fore and aft of said vessel;

sensing pitch motion of said vessel caused by a wave having a wave slope; and,

on the basis of said sensed motion, applying a force  
25 to said gyroscope about the trunnion axis in a direction so that said gyroscope produces a gyroscopic pitch torque which is applied to said vessel in a manner to pitch said vessel to follow said wave slope.

30 According to the present invention, there is provided a method for controlling the motion of a vessel having an athwart axis and a fore and aft axis comprising the steps of:

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installing a gyroscope having a flywheel in a vessel,  
said gyroscope mounted in a gimbal having a trunnion axis  
parallel to one of said athwart axis and fore and aft axis  
to control roll motion of said vessel about the other of  
5 said athwart axis and fore and aft axis generated by wave  
motion;

spinning said flywheel about a spin axis;

sensing said motion of said vessel caused by a wave  
having a wave slope; and,

10 on the basis of said sensed motion, applying a force  
to said gyroscope in a direction so that said gyroscope  
produces a reactive torque which is applied to said vessel  
in a manner to urge said vessel to follow said wave slope.

#### 15 Brief Description of the Drawings

An embodiment of the present invention will now be  
described by way of example only with reference to the  
accompanying drawings in which:

Figure 1 is a schematic representation of a method of  
20 controlling roll motion of a vessel in accordance with the  
present invention;

Figure 2 is a schematic representation of the  
interaction between forces applied to a vessel by wave  
motion and an embodiment of the present invention;

25 Figures 3a - 3m depicts motion of a vessel and  
associate gyroscope in which the present method is applied  
to reduce roll of the vessel; and,

Figure 4 is a schematic representation of a control  
mechanism used in an embodiment of the present invention.

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#### Detailed Description of Preferred Embodiments

Figure 1 represents the vessel 10 to which embodiments of  
the present method for motion control are applied.

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Installed in the vessel 10 is a gyroscope 12 having a flywheel 14 mounted for rotation about a vertical spin axis 16. The gyroscope 12 is mounted in a gimbal (not shown) having a trunnion axis 18 which in this particular embodiment is mounted athwart the vessel 10. The gimbal also supports a motor (not shown) for driving the flywheel 14 so that it together with the flywheel can rotate with the gimbal. The entire system is securely mounted to the vessel 10.

Sensors 20 are mounted at various locations on the vessel 10 as well as on the gyroscope 12 to measure the motion of the vessel 10. The sensors 20 may consist of a variety of instruments including accelerometers and pressure transducers. The sensed motion includes motion and/or pressure generated by waves (which will have a corresponding wave slope) and may also include motion caused by a propulsion system of the vessel. When the vessel 10 interacts with a wave, the sensors 20 provide signals commensurate with the resultant vessel motion to a computer. A processor such as a computer in turn controls the gyro precession either by braking or by forced advancement about the trunnion axis 18 of the gyroscope 12 in a direction that causes the gyroscope 12 to provide a reactive that follows the slope of the wave inducing the roll and thus reduces the motion and/or force applied by the wave. This is in contrast with previous known methods where a gyroscope would be used to roll the vessel against the force induced by the wave slope.

The interaction of forces applied to a vessel by an embodiment of this method and the wave action is further shown in Figure 2. The reference number 10 depicts the

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position of the vessel at a current wave position 19 and number 10' depicts the position of the vessel at a future wave position 19'. The gyroscope 12 is spinning about vertical axis 16 and mounted in a gimbal having an athwart trunnion axis 18. The sensors 20 detect the motion of and forces on the vessel as the wave position changes from 19 to 19' and a computer using information or signals from the sensors controls a device to apply a force about the trunnion axis to cause the gyroscope to generate a torque T that acts in a manner to cause the vessel to follow the slope of the wave and move to position 10'. It should be noted that there are substantially no hydrodynamic or hydrostatic forces on the vessel at positions 10 and 10', and therefore the vessel cannot resonate with the wave. That is, since embodiments of the present invention have the effect of causing the gyroscope to apply torque to cause the vessel to follow the wave slope, the vessel can never resonate with the wave no matter what frequency the vessel 10 or wave operates at.

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It will be appreciated that the application of the force about the trunnion axis 18 in response to the sensed roll of the vessel 10 will cause the gyroscope 12 to process in an arc 22 about the trunnion axis 18. The gyroscope 12 will move through its precession arc twice for each roll of the vessel 10. This is also to be contrasted with prior art gyroscopic stabilisers where the gyroscope would typically precess only once. Accordingly, the gyroscope 12 will produce twice the gyrocoupling torque as a prior art gyroscope and therefore need be only half the weight of a prior art gyroscope to produce the same overall torque.

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Figures 3a - 3m depict the effect of the method on a vessel 10. Each of the figures depicts the movement of the vessel 10 and the gyroscope 12 with wave motion. Underneath each figure the "roll" indicates the roll angle of the vessel 10 from the vertical. In Figures 3a - 3m the roll of the vessel 10 reaches a maximum of  $3^\circ$ . The letter "P" indicates the position of the gyroscope 12 and moreover the arc angle of precession which varies between  $\pm 15^\circ$  from the vertical. It should be noted, as previously mentioned that the gyroscope 12 moves through its precession arc twice for each roll of the vessel 10. "Wave" is the wave slope and is depicted for a wave slope from  $0^\circ$  to  $6^\circ$ .

In addition to roll reduction, the method may also be applied for the purposes of pitch reduction and anti-broaching and emergency steering. In relation to pitch reduction, the trunnion axis 18 is aligned fore and aft of the vessel 10 with the axis 16 remaining in the vertical plane. The resultant torque is applied by the gyroscope 12 which will assist in reducing pitch. The process is to provide gyroscopic pitch torque to the vessel 10 which then reduces large fore and aft accelerations known as the "hobby horse" effect. Again, wave following techniques would be employed to optimise the action of the gyroscope 12.

The gyroscope 12 can also be used to induce yaw motion to the vessel 10 to provide anti-broaching and emergency steering. This may be achieved by turning the gyroscope 12 so that the spin axis 16 lies in a horizontal plane. The computer receives motion information from the sensors 20 and applies, via a motor or prime mover, a force

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through the trunnion axis 18 to cause the gyroscope to provide appropriate horizontal motion to the vessel 10. Steering and compass settings may also be used as information inputs to the computer in order to maximise the anti-broaching effect.

From the above description, it will be appreciated that embodiments to the present invention reduce rolling motion of a vessel 10 to the limit of the wave slope, which typically is between 3° to 5°, and can do so by using gyroscopes, and in particular flywheels, of lower mass than typically required in the prior art where gyroscopes apply forces counter to the roll motion. Further, there are no external fins, thus reducing the potential for damage. Installation of a system incorporating embodiments of the present invention is relatively simple, and the system can be positioned in any convenient location within the mechanical structure of the vessel 10. The method provides roll stability at any speed including at anchorage.

It is envisaged that relatively small gyroscopes of less than 0.5 kg of the vessel's weight could be placed in pairs in one or more regions of the vessel under the control of a centralised computer.

A method for controlling the motion of marine vessel 10 comprises mounting a gyroscope 12 in a gimbal and fixing the gimbal inside the vessel. In one arrangement, a trunnion axis 18 of the gimbal is mounted athwart the vessel 10. Sensors 20 are mounted at various locations on the vessel 10, as well as on the gyroscope 12 to measure the motion of the vessel 10 including motion caused by

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5 wave action. Signals from the sensors 20 are processed by a computer that in turn controls the procession of the gyroscope by applying either braking or advancement force on the gyroscope about the trunnion axis in a direction that causes the gyroscope 12 to provide a reactive torque urging the vessel 10 to follow the slope of the wave and reduce the motion in the vessel 10. Thus, the method causes the gyroscope to apply reactive force that causes the vessel 10 to follow the slope of the waves acting on the vessel. This reduces hydrodynamic and hydrostatic forces on the vessel and therefore acts to prevent resonance of the vessel 10 with the waves. The precession of the gyroscope 12 about the trunnion axis 18 can be controlled by braking or by being driven by a motor or hydraulic pump. Moreover, non-linear control over the precession is preferred for the reasons stated below. In one embodiment where a braking mechanism is used to provide the non-linear control, the braking mechanism may be in the form of a variable damper controlled by a computer, for example by way of controlling a valve in between the damper and an air motor, to provide wave following. The advantages of non-linear precession over linear precession are:

- A larger force applied early in the roll cycle.
- 25 • A greater usage of gyroscopic coupling in non-regular wave patterns.
- A larger reduction in maximum roll velocity of the vessel due to larger forces applied early in the roll cycle.

30 Figure 4 depicts a schematic representation of one embodiment of applying the non-linear control of the

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precession of the gyroscope 12. The gyroscope 12 is shown with its flywheel 14 housed within an outer casing or box 24 and mounted on the trunnion axis 18. A motor 26 for spinning the flywheel 14 is also depicted. Circle 28  
5 traces the precession path of the gyroscope 12 within its casing 24. A damper 30 shown in three positions A, B and C is coupled to the gyroscope casing 24 to provide the non-linear control of the precession of the gyroscope 12. The damper 30 is coupled with an air pump via a valve  
10 (both of which are not shown) which is under the control of a computer or other processor receiving the information from the sensors 20. The computer is operated to operate the valve to vary air pressure within the damper 30 to provide the non-linear control. In this particular  
15 instance, the control is exerted by applying a braking force to the gyroscope 12. However, in alternative embodiments the control can be provided by applying a non-linear force about the trunnion axis 18.

20 In the present illustrated embodiment, the braking effect is arranged to be at a minimum in the centre of the precession cycle corresponding to the damper 30 having minimum extension shown at position A with a braking effect at a maximum at the precession limits shown by the  
25 dampers at positions B and C.

Modifications and variations of the invention that would be obvious to a person of ordinary skill in the art are deemed to be within the scope of the present invention the  
30 nature of which is to be determined from the above description.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A method for controlling the motion of a vessel  
5 comprising the steps of:  
installing a gyroscope having a flywheel in a vessel,  
said gyroscope mounted in a gimbal having a trunnion axis  
aligned in a plane containing motion of a vessel created  
by wave motion that is desired to be controlled;  
10 spinning said flywheel about a spin axis;  
sensing said motion of said vessel caused by a wave  
having a wave slope; and,  
on the basis of said sensed motion, applying a force  
to said trunnion axis in a direction so that said  
15 gyroscope produces a reactive torque which is applied to  
said vessel in a manner to urge said vessel to follow said  
wave slope.
2. The method according to claim 1, wherein said  
20 installing comprises mounting said gyroscope with said  
trunnion axis orientated athwart said vessel.
3. The method according to claim 1, wherein said  
installing comprises mounting said gyroscope with said  
25 trunnion axis aligned fore and aft of said vessel.
4. The method according to any one of claims 1 to 3,  
wherein said spin axis is substantially vertical.
- 30 5. The method according to any one of claims 1 to 3,  
wherein said spin axis is substantially horizontal.

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6. A method for controlling roll motion of a vessel comprising the steps of:

installing a gyroscope in said vessel, said gyroscope having a spin axis in a vertical plane and mounted in a gimbal having a trunnion axis aligned athwart said vessel;

sensing roll of said vessel caused by a wave having a wave slope; and,

on the basis of said sensed motion and/or forces, applying a force to said trunnion axis in a direction so that said gyroscope produces a reactive torque which is applied to said vessel in a manner to roll said vessel to follow said wave slope.

7. A method for controlling pitch motion of a vessel comprising the steps of:

installing a gyroscope in said vessel, said gyroscope having a spin axis in a vertical plane and mounted in a gimbal having a trunnion axis aligned fore and aft of said vessel;

sensing pitch motion of and/or forces applied to said vessel caused by a wave having a wave slope; and,

on the basis of said sensed motion and/or forces, applying a force to said trunnion axis in a direction so that said gyroscope produces a gyroscopic pitch torque which is applied to said vessel in a manner to pitch said vessel to follow said wave slope.

8. A method for controlling the motion of a vessel having an athwart axis and a fore and aft axis comprising the steps of:

installing a gyroscope having a flywheel in a vessel, said gyroscope mounted in a gimbal having a trunnion axis parallel to one of said athwart axis and fore and aft axis

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to control roll motion of said vessel about the other of said athwart axis and fore and aft axis generated by wave motion;

spinning said flywheel about a spin axis;

5       sensing said motion of said vessel caused by a wave having a wave slope; and,

on the basis of said sensed motion, applying a force about said trunnion axis in a direction so that said gyroscope produces a reactive torque which is applied to  
10       said vessel in a manner to urge said vessel to follow said wave slope.

9. A method according to any one of claims 1 to 8 comprising installing a pair of gyroscopes in said vessel.  
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10. A method according to any one of claims 1 to 8 comprising installing a plurality of pairs of gyroscopes in said vessel.

20       11. A method according to claim 9 or claim 10, wherein the trunnion axes of the gyroscopes are parallel to each other.

12. A method according to any one of claims 1 to 11,  
25       wherein said control is applied in a non-linear manner.