My invention relates to stabilizing equipments for vehicles, particularly ships, and more particularly to stabilizing equipments adapted to damping the rolling of the ship. The stabilizing equipments of this kind known in the art comprise a device for supplying a stabilizing couple, said device being designed for instance as a gyroscope, a movable weight or the like, and a device for controlling the value of the stabilizing couple, the controlling device operating automatically or non-automatically.

The rolling of a ship is ruled by the following differential equation:

\[ I \ddot{\theta} + X = M(t) \]

in which \( \theta \) is the angle of rolling, \( I \) the moment of inertia of the ship about the longitudinal axis passing through its centre of gravity, \( M(t) \) the couple of rolling acting upon the ship and \( X \) the stabilizing couple. The problem to be solved by any stabilizing equipment resides in determining the law of the variation of \( X \) so as to damp as much as possible the rolling of the ship.

Some stabilizing equipments known in the art are based on the change of the sense of the angle of rolling \( \theta \), for instance by assuming \( Y = K \theta \). Now \( M(t) \) contains a term of the form \( mg(a-r) \theta \). \( m \) being the mass of the ship, \( g \) the acceleration of gravity, \( r \) the radius of curvature of the metacentric arc and \( a \) is the distance from the center of gravity, and \( r - a \) the metacentric distance. The term referred to represents a return couple. Thus it follows from Equation (1) that under these conditions only the natural period of the ship can be changed by the control \( X = K \dot{\theta} \).

In other stabilizing equipments known in the art the control is based on the velocity of rolling

\[ \frac{d\theta}{dt} \]

For instance the control is carried out in such manner that the velocity of the precession of a stabilizing gyroscope is held constant while its sense is instantaneously changed when

\[ \frac{d\theta}{dt} \]

vanishes. Putting

\[ X = K \frac{d\theta}{dt} \]

it will be seen from Equation (1) that at certain laws of change of \( M(t) \), for instance at the occurrence of beats of two systems of swell, the introduction of a term being a function of

\[ \frac{d\theta}{dt} \]

will cause anomalous amplitudes \( \theta \) which may cause accidents. Besides this any stabilizing equipment controlled in response to the angle of rolling \( \theta \) or the angular velocity \( \frac{d\theta}{dt} \) requires for its operation that a rolling is already existent in order that the stabilizing action can exert a damping effect.

From the foregoing it will be seen that control systems based on the angle of rolling or its time derivatives do not afford a perfect solution of the problem.

In another stabilizing equipment known in the art comprising a stabilizing gyroscope the control is carried out by putting \( X = M(t) \). By doing so the influence of the rolling couple is eliminated but the differential Equation (1) will be transformed into

\[ I \ddot{\theta} = 0 \]

In the movement defined by this equation there is no return force at all toward a position of equilibrium which would act upon the gyroscope. Whenever during a plurality of periods of swell the ship remains in an inclined position, a changing of condition will occur when the movement of precession reaches its extreme point so that the device intended for compensating the rolling tends to destroy its own effect.

It is an object of my invention to provide an improved stabilizing equipment not subjected to the drawbacks of the equipments known in the art which are discussed hereabove. In order to accomplish this I provide an automatically operating control means for the device supplying the stabilizing couple, said control means being designed in such manner that at any time the stabilizing couple is composed of two terms or components, the first of which is substantially equal and opposite to the couple of rolling, while the second term is a function of the angle of rolling or its time derivatives or integrals. The first component may depend on a time derivative of the couple of rolling or of the alternating component thereof.

In a stabilizing equipment according to my invention the automatically operating control means exert on the device supplying the stabiliz-
ing couple an action comprising a component being a function of the couple of rolling and its time derivatives and integrals and a second component being a function of the angle of rolling and its time derivatives and integrals.

Other important features and objects of my invention will be apparent from the following description and the drawing.

In the drawing affixed to this specification and forming part thereof some embodiments of my invention are illustrated diagrammatically by way of example.

In the drawing:

- Figs. 1 and 2 are diagrammatic side and front views, respectively, of a ship provided with devices for measuring the couple of rolling.
- Fig. 3 is a wiring diagram illustrating the operation and connection of the measuring devices shown in Figs. 1 and 2.
- Fig. 4 is a perspective view of a device for measuring the angle of rolling.
- Figs. 5 and 6 are wiring diagrams of devices for forming time derivatives and integrals of the couple or angle of rolling measured by the devices shown in Figs. 1 to 4.
- Fig. 7 is a diagram of a complete stabilizing equipment and control means according to my invention, in which the stabilizing couple is supplied by the reaction of the output of two pumps.
- Fig. 8 is a modified embodiment of a manometrical device for measuring the rolling forces.
- Fig. 9 is a wiring of an embodiment of my invention provided with manometrical devices as shown in Fig. 8.
- Fig. 10 is a diagrammatic perspective view of the front portion of a ship provided with a device for directly measuring:

\[ \frac{d\theta}{dt} \]

Before more fully describing the invention in connection with the drawing it will be useful to explain shortly the mathematical theory of the devices producing the stabilizing couple, since by understanding of my invention will be considerably facilitated.

In a gyroscope the counteracting couple is given by the following term:

\[ J\frac{d^2\theta}{dt^2} \]

By eliminating \( B \) from the Equations (2) and (3) and by putting

\[ Y=Y_1+Y_2 \]
\[ Y_1=\left(1-\frac{I}{JW}\right)K\frac{d\theta}{dt} - \frac{JW}{d\theta} \sin(t) \]
\[ Y_2=-a\frac{d\theta}{dt} + b\theta + c \frac{d^2\theta}{dt^2} \]

the following equation will be obtained:

\[ (4) \quad \frac{d^2\theta}{dt^2} + \frac{JW}{d\theta} \frac{d\theta}{dt} + [K+J(W)\frac{d\theta}{dt}]^2 = \frac{JW}{d\theta} \frac{d\theta}{dt} + J\omega^2 = 0 \]

If the coefficients \( a \) and \( c \) are sufficiently large this equation represents a combination of two damped-sinoidal movements. If under these conditions the equipment counteracting the rolling is set into operation the ship will very rapidly be brought into its vertical position of equilibrium even if the surface of the sea is in a very irregular condition. By further carrying out the calculation it will be found that the anti-rolling couple is composed of a term equal to \( M(t) \) and another term containing the angle \( \theta \) and its derivatives.

If a device different from a gyroscope is used for producing the stabilizing couple the same result will be obtained, viz, an angle of rolling \( \theta \) defined by a linear differential equation which is independent of the time and represents a damped movement. In this case also the anti-rolling equipment is controlled in response to a value depending upon the couple and angle of rolling and their derivatives and integrals. In a particularly interesting embodiment of my invention the stabilizing couple is produced by a practically inertialess device, for instance by the reaction to the output or the suction of pumps preferably arranged on the ship such as those of British Patent to Baze, 465,211, Dec. 21, 1933, so that the stabilizing couple will depend on the output of the pumps which in their turn may be controlled in an inertialess manner. Thus in the equation

\[ \frac{d^2\theta}{dt^2} + X = M(t) \]

it may be put

\[ X = X_1 + X_2 \]

and

\[ X_1 = M(t) \]
\[ X_2 = a\frac{d\theta}{dt} + b\theta \]

the coefficients \( a \) and \( b \) may be determined in the following manner: One regulates \( a \) to the desired value in order that the couple \( d\theta \) is equal to the maximum couple which may be produced by the anti-rolling device when \( \theta \) is of a convenient value, say, for example, 30°.

One regulates \( b \) to the desired value in order that the couple

\[ \frac{d\theta}{dt} \]

is equal to the maximum couple which may be produced by the anti-rolling device when

\[ \frac{d\theta}{dt} = \frac{d\theta}{dt} \]

if of a convenient value, say, 5° of rotation per second.
Hence it will be sufficient to measure the quantity
\[ M(t) + a \frac{dt}{dt} + b t \]
and to control the output of the pumps proportionally to this expression.

Referring now to the drawing and particularly to Figs. 1 and 2, 1, 2, 3 and 1, 2, 3 are two sets of manometers arranged below the water line at opposite sides of a ship, respectively. Preferably the manometers are arranged at points in which the radius of curvature of the cross section of the ship passes at one side of the centre of gravity G of the ship.

The manometers are connected with each other in such manner that the effects of manometers arranged at the same side of the ship are added to each other, while the effects of manometers belonging to different sets counteract each other, so that the resultant effect is proportional to the couple of rolling.

An embodiment of such a connection is shown in Fig. 3, in which each manometer actuates the sliding contact of a potentiometer 4, 5, 6 and 4', 5', 6' each of which is connected to a current supply 7, 8, 9 and 7', 8', 9', respectively. The potentiometers 4, 5, 6 and 4', 5', 6' are connected in series, respectively, the two sets of potentiometers being connected in opposition to each other so that the voltage arising at the terminals 10, 11 will be proportional to the couple (M) to the current.

Referring now to Fig. 4, a small gyroscope is shown for measuring the angle of rolling \( \theta \). The gyroscope comprises an outer frame 66 provided at opposite sides thereof with tapered studs 65 engaging suitable holes provided in fixed members 62 forming part of the ship. 63 is an inner frame arranged substantially normally to the outer frame and provided with tapered studs 64 engaging suitable holes in the inner side of the frame 60 with their connecting line coinciding with the connecting line of the studs 61 at a right angle. In the inner frame 63 the flying body 12 of the gyroscope is rotatably mounted by means of a shaft 65 to the lower extension of which the sliding contact 66 of a potentiometer 13 connected to a current supply 14 is secured. The potentiometer 13 is rigidly secured to the body of the ship so that the position of the sliding contact 66 will depend on the angle of rolling \( \theta \). In consequence thereof the voltage arising at the terminals 15, 16 will be proportional to the angle of rolling.

In order to form from the voltages obtained by means of the devices illustrated in Figs. 3 and 4 time derivatives and integrals, voltages proportional to the couple and angle of rolling, which are obtained for instance by means of the devices shown in Figs. 3 and 4, are fed to an amplifier, for instance a grid valve in the output circuits of which suitable impedances such as ohmic resistances, inductances and capacities are arranged, from which a voltage may be withdrawn representing a time derivative or integral of the voltages applied to the input or a linear function thereof.

Referring now particularly to Fig. 5, a connection is shown supplying a voltage determined from the formulas
\[ a \theta + \frac{b \theta \theta}{dt} \]
or
\[ aM(t) + b \frac{dt}{dt} + M(t) \]
In order to accomplish this the terminals 10, 11 of Fig. 3 or 15, 16 of Fig. 4 are connected to the input terminals 17, 18 of a grid valve 19 shown as a screen grid valve, in the plate circuit of which a resistance 20 proportional to the coefficient \( a \) and an inductance 21 proportional to the coefficient \( b \) is provided, so that the voltage arising at the terminals 22, 23 will be that indicated above as determined by the constants.

In order to obtain a voltage proportional to the time integral of the voltage applied to the input of the valve a condenser may be arranged in the output circuit of the valve the capacity of which corresponds to the numerical coefficient of the integral. Since the anode circuit is proportional to the value A or M(t) applied to the grid of the valve the voltage arising at the terminals of the condenser will amount to
\[ u = \frac{1}{C} \int dt \]
Repeating now particularly to Fig. 6 in the output circuit of the valve 19 a condenser 24 is provided besides the ohmic resistance 20 and the inductance 21 so that the voltage arising at the terminals 22, 23 will be determined by the formula
\[ a \theta + \frac{b \theta \theta}{dt} + c \frac{dt}{dt} \]
The anode voltage of the valve 19 is fed in Fig. 6 by the current of a saturated valve 25 instead of which, if desired, another device may be provided having a practically infinite resistance at varying currents.

In order to obtain a term proportional to the second derivative of the input voltage of valve 19 the voltage arising at the terminals of the inductance 21 may be applied to the input of a second valve, the anode circuit of which contains a suitably chosen inductance. It has heretofore been pointed out that an anode current flows in the anode circuit of the tube 19 which is proportional to the initial potential pressed upon the grid. Furthermore, as also pointed out, a potential appears at the inductance 21 which is proportional to the first differential quotient of the anode current, and thus also proportional to the first differential quotient of the initial potential.

When this potential is transferred as initial potential to a second tube, the anode circuit of which is in turn provided with an inductivity, then a potential must appear at this inductivity which is proportional to the first differential of the initial potential of the second tube and thus also proportional to the second differential quotient of the initial potential of the first tube.

As will be seen from the foregoing by the means described in connection with Figs. 3 to 6 any voltages may be obtained which are linear functions of the couple and angle of rolling and of their time derivatives and integrals of any order.

The voltages obtained in this manner are to be applied to a relay influencing the control of the device supplying the stabilizing couple. An embodiment of this arrangement is shown in Fig. 7 in which the stabilizing couple is supplied by means of two pumps 24 and 24'. The measuring devices correspond exactly to those shown in Figs. 3 and 4. The voltage delivered by the gyroscope 12 which is proportional to the angle of rolling \( \theta \) is applied to a valve 25 connected in similar manner to the valve 19 shown in Fig. 5, the output circuit of the valve 25 containing an inductance 28 proportional to the coefficient \( a \) and a subdivided resistance 27, 28 proportional.
to the coefficient, $b$, so that, a voltage of the form,

$$\frac{d}{dt}a + b$$

will be obtained. The voltage supplied by the manometers 1, 2, 3, and 1', 2', 3', which is proportional to the couple of rolling $M(t)$, is applied to the input of valve 25 in the output of which the section 26 of the ohmic resistance is connected, the ratio of the sections 27, 28 being so chosen that the voltage arising at the terminals, 28, 30 is equal to the quantity

$$M(t) + a\frac{d}{dt} + b$$

This voltage is applied to an amplifier or relay 31 controlling the slides 33, 33' of the pumps 24, 24', respectively.

It is clear that the coefficients of these manometers which are proportional to the angle of rolling and its derivatives, can be influenced by varying the sensitivity of the amplifier 31. That the ship's own period, on the other hand, is dependent on these coefficients, is a result of the fact that these coefficients enter the differential equation which governs the rolling of the ship. Consequently the period of the ship may be controlled by regulating the sensitivity of the amplifier. At 32 I have shown diagrammatically a device by means of which the sensitivity of the amplifier may be regulated.

Referring now to Fig. 8, a modified embodiment of a manometer is shown which may be used for each of the manometers 1, 2, 3, 1', 2', 3'.

36 is an electrically conductive sleeve secured to the wall 35 of the ship. 37 is a diaphragm mounted in the front portion of the sleeve 36. Preferably the diaphragm consists of a resistive material such as stainless steel. The diaphragm forms the movable armature of a condenser, the fixed armature 38 of which is connected by means of a connection 40 to an intake terminal of a device 41, for instance an amplifier or the like transforming the variations of capacity of the condenser 31-38 into a corresponding varying voltage which may be withdrawn from the output terminals 42. The electrical connection of the armature or diaphragm 37 to the other terminal of the device 41 is made by means of the sleeve 36. The manometer shown in Fig. 8 is entirely inertialess even at very rapidly varying pressures. The sleeve 36 and the diaphragm 37 are arranged in such manner that they do not trouble the lines of flow of the water flowing along the sides of the ship.

Fig. 9 is a diagram of a connection in which manometers according to Fig. 8 are used. The manometers designated by 1, 2, 3 and 1', 2', 3', are arranged at opposite sides of the ship S in similar manner as shown in Fig. 1 and are connected in pairs to amplifying devices 43, 44, 45, each corresponding to the device 41 shown in Fig. 8, in such manner that they counteract each other, so that each device 43, 44, 45 supplies a voltage proportional to the difference of the actions of the manometers 1, 1', 2, 2', 3, 3' or to the couples of forces exerted in the lines 1, 1', 2, 2', 3, 3', respectively. The voltages delivered by the devices 43, 44, 45 are superposed by means of a suitable device 46 thus supplying a voltage proportional to the couple of rolling $M(t)$ exerted on the ship by the sea. 47 indicates a device of the kind shown in Figs. 5 or 6 and forming a linear function of $M(t)$ and its time derivatives and integrals. If, the method for damping the rolling operates practically in an inertialess manner the device 47 may be dispensed with. If desired, the coupling of the manometers may be carried out in a different manner and particularly the manometers and their associated parts may be designed in such manner that the pressure measured by the manometers is multiplied by an adjustable coefficient.

48 is a device for measuring the angle of rolling similar to that shown in Fig. 4 and 49 is a device for forming time derivatives or integrals of the angle of rolling or linear functions thereof as more fully described hereinafore and as illustrated in Fig. 17. 50 is a relay combining the voltages supplied by the devices 41 and 48 and feeding the combined voltage to the control device 51 corresponding for instance to the device 31 of Fig. 7.

A very important embodiment of my invention in which the control is considerably simplified is the following:

Be it assumed that the device for damping the rolling operates practically without inertia which may be obtained in the manner described above by using centrifugal pumps or the like, then it will be sufficient to carry out the control according to the following equation:

$$X = M(t) + a\frac{d}{dt} + b$$

Now the only constant term of $M(t)$ is derived from $mg(\omega - \theta)$ and corresponds to a perpetual inclination of the ship which is compensated by introducing the return couple $a\theta$ into the anti-rolling couple $X$. The devices such as 43 to 46 in Fig. 9 are slightly modified in the manner described hereinafore so as to be unable to supply the constant term of $M(t)$. The remaining term $M(t)$ constitutes a couple which owing to its alternating character tends to bring the ship back into its vertical position of equilibrium. Thus it will be seen that the couple for damping the rolling may be controlled according to the simplified equation

$$X = M(t) + b\frac{d}{dt}$$

In order to suppress in the output circuits of the devices 43 to 46 the constant term of $M(t)$, a capacity having an infinite impedance for the constant term of the current may be inserted in each circuit carrying a current proportional to $M(t)$, the capacity being chosen so that the condenser is permeable for an alternating term of $M(t)$ even of the lowest frequency. In calculating the capacity of the condenser obviously the impedances of the input and output circuits of the devices 43 to 46 should be taken into consideration. Further in this case the angle of rolling $\theta$ need not be measured since it is sufficient to measure its derivative

$$\frac{d\theta}{dt}$$

which may be done in a simple manner, for instance by means of the device shown in Fig. 10 in which 52 is a small gyroscope connected to the ship's such a manner that it can carry out only small displacements occurring in spite of the fact that the counteraction of the spring are transmitted to the sliding contact of a potentiometer 54 connected to a current supply 56 so that at the termi-
In the embodiment operating according to this principle and employing a practically inertialess device for damping the rolling of ship, shown in Fig. 9 may be simplified by omitting the device 47 and replacing the devices 48, 49 by a single device without providing any devices for forming derivatives or integrals.

The preceding explanations relate to the minimum number of manometers required for a sufficient measurement of $M(t)$. Obviously the measurement need not afford the highest possible exactness, a measurement being sufficient which practically coincides with the couple $M(t)$ and which has the same sense of variation. Two manometers (one at each side of the ship) are entirely insufficient but four manometers (two at each side of the ship) will afford a practically sufficient measurement. If six manometers (three at each side of the ship) are used the exactness of the measurement will amount at least 1%, provided that the pressure exerted on the wall of the ship is uniform. In any case in different cross sections of the ship sufficient measuring devices must be provided for measuring the couple exerted by the sea.

I wish to be understood that I do not desire to be limited to the exact details of construction shown and described for obvious modifications will occur to a person skilled in the art.

In the case affixed to this specification no selection of any particular modification of the invention is intended to the exclusion of other modifications thereof and the right to subsequently make claim to any modification not covered by these claims is expressly reserved.

I claim:

1. A stabilizing equipment for ships comprising a device for impressing a stabilizing couple upon the ship, means for measuring the couple of rolling and the angle of rolling, means for forming time derivatives and integrals of the couple and of the angle of rolling, means for forming a linear function of the couple and angle of rolling and of their time derivatives and integrals and means for controlling said device to be arranged at opposite sides of the ship, respectively, and the potentiometers belonging to the same set being connected in series, the potentiometers belonging to different sets being connected in opposition to each other, means for forming time derivatives and integrals of the couple and the angle of rolling, means for forming a linear function of the couple and angle of rolling and of their time derivatives and integrals and means for controlling said device in response to this linear function.

2. A stabilizing equipment for ships comprising a device for impressing a stabilizing couple upon the ship, means for measuring the couple of rolling and the angle of rolling, said means for measuring the couple of rolling comprising two sets of manometers arranged at opposite sides of the ship, respectively, and means for counteracting the effect of manometers belonging to the same set and of counteracting the effect of manometers belonging to different sets, means for forming time derivatives and integrals of the couple and the angle of rolling, means for forming a linear function of the couple and angle of rolling and of their time derivatives and integrals and means for controlling said device in response to this linear function.

3. A stabilizing equipment for ships comprising a device for impressing a stabilizing couple upon the ship, means for measuring the couple of rolling and the angle of rolling, said means for measuring the couple of rolling comprising two sets of units each comprising a manometer, a potentiometer and a movable contact operated by said manometer, the manometers of said sets being arranged at opposite sides of the ship, respectively, and the potentiometers belonging to the same set being connected in series, the potentiometers belonging to different sets being connected in opposition to each other, means for forming time derivatives and integrals of the couple and the angle of rolling, means for forming a linear function of the couple and angle of rolling and of their time derivatives and integrals and means for controlling said device in response to this linear function.

4. A stabilizing equipment for ships comprising a device for impressing a stabilizing couple upon the ship, means for measuring the couple of rolling and the angle of rolling, said means for measuring the couple of rolling comprising two sets of manometers arranged at opposite sides of the ship, a movable diaphragm in each manometer, two sets of condensers associated with said manometers, respectively, each condenser comprising a movable armature formed by the diaphragm of the associated manometer, and means for combining the effects of condensers belonging to the same set and of counteracting the effect of condensers belonging to different sets, means for forming time derivatives and integrals of the couple and the angle of rolling, means for forming a linear function of the couple and angle of rolling and of their time derivatives and integrals and means for controlling said device in response to this linear function.

5. A stabilizing equipment for ships comprising a device for impressing a stabilizing couple upon the ship, means for measuring the couple of rolling and the angle of rolling, said means for measuring the couple of rolling comprising two sets of manometers, arranged at opposite sides of the ship, and means for combining the effects of manometers belonging to the same set and of counteracting the effect of manometers belonging to different sets, means for forming time derivatives and integrals of the couple and the angle of rolling, means for forming a linear function of the couple and angle of rolling and of their time derivatives and integrals and means for controlling said device in response to this linear function.

6. A stabilizing equipment for ships comprising a device for impressing a stabilizing couple upon the ship, means for measuring the couple of rolling and the angle of rolling, said means for measuring the angle of rolling comprising a gyroscope, a potentiometer and a movable potentiometer contact operated by said gyroscope, means for forming time derivatives and integrals of the couple and the angle of rolling, means for forming a linear function of the couple and angle of rolling and of their time derivatives and integrals and means for controlling said device in response to this linear function.

7. A stabilizing equipment for ships comprising a device for impressing a stabilizing couple upon the ship, means for supplying electric voltages proportional to the couple of rolling and to the angle of rolling, means for amplifying said electric voltages, said amplifying means comprising in their output circuits an impedance supplying a voltage proportional to a linear function of said voltages proportional to the couple and angle of rolling and of their derivatives and integrals and means for controlling said device in response to this linear function.

8. A stabilizing equipment for ships comprising a device for impressing a stabilizing couple upon the ship, means for supplying electric cur-
for controlling said force-producing means consisting of a plurality of manometers stationed on each of the opposite sides of a ship so as to be exposed to sea-water pressure, means by which the manometers on the respective sides are serially connected in order to produce a cumulative effect in the respective series, and means coupling the manometer-series in opposing relationship to each other and also embracing said force-producing means.

10. A stabilizing equipment for ships comprising anti-roll force-producing means, and means for controlling said device in response to this linear function.

9. A stabilizing equipment for vehicles comprising a device for impressing a stabilizing couple upon the vehicle, said device consisting of means for measuring the couple and angle of rolling and for forming time derivatives and integrals of said couple and angle of rolling and comprising a gyroscope, and automatically operated means associated with said gyroscope for controlling said device in such manner as to provide two components, the first of which depends on the derivative and the integral of the couple of rolling, while the second component is a function of the angle of rolling, its integral and its second derivative.

10. A stabilizing equipment for ships comprising anti-roll force-producing means, and means for controlling said force-producing means consisting of a plurality of manometers stationed on each of the opposite sides of a ship so as to be exposed to sea-water pressure, means by which the manometers on the respective sides are serially connected in order to produce a cumulative effect in the respective series, and means coupling the manometer-series in opposing relationship to each other and also embracing said force-producing means.

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