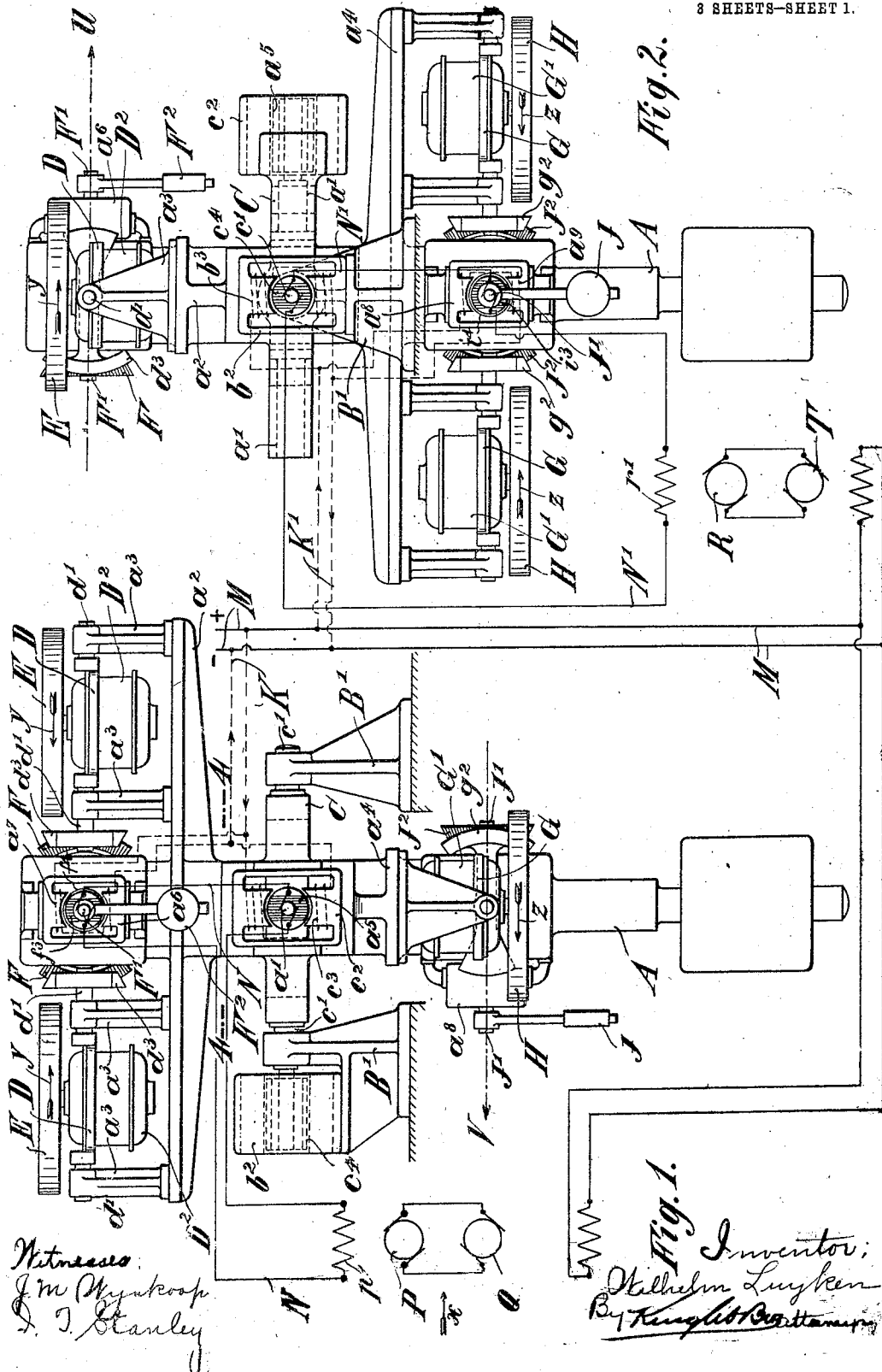


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 DEVICE FOR MAINTAINING THE EQUILIBRIUM OF A PENDULUM.
 APPLICATION FILED FEB. 29, 1912.

1,083,370.

Patented Jan. 6, 1914.

3 SHEETS-SHEET 1.

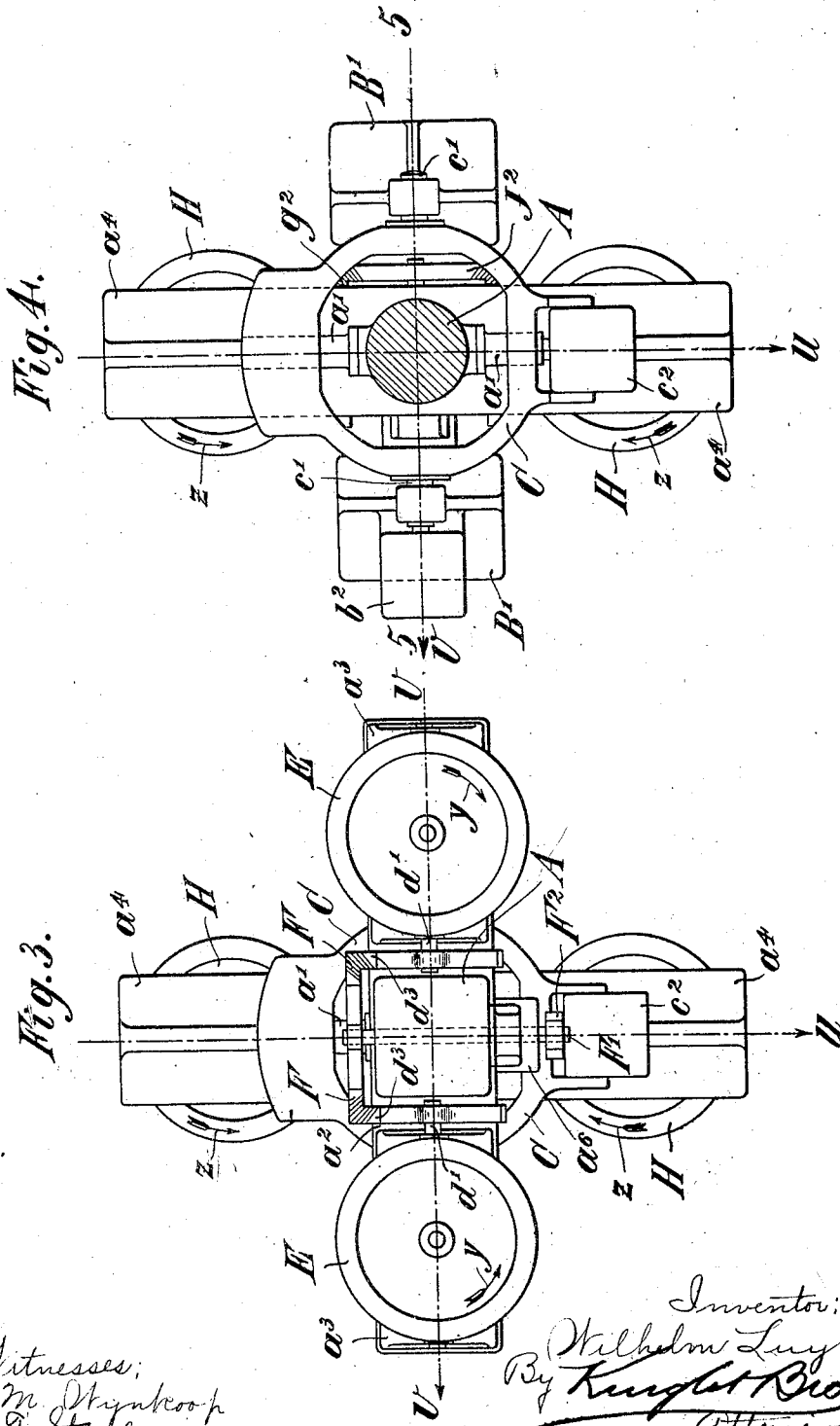


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3 SHEETS—SHEET 2.



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3 SHEETS—SHEET 3.

Fig. 5.

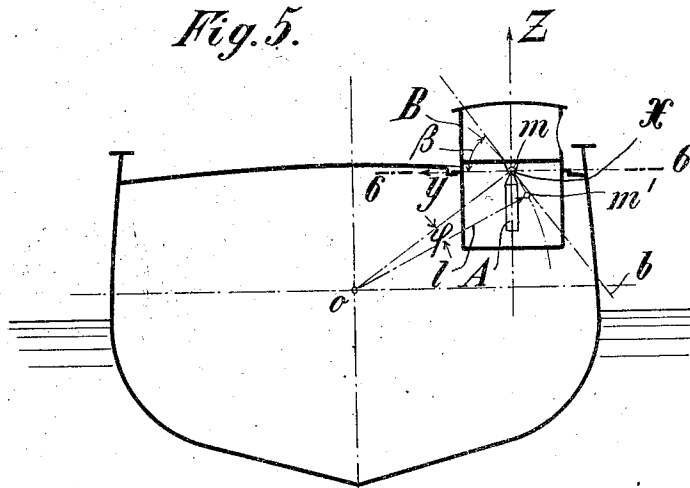


Fig. 6. V

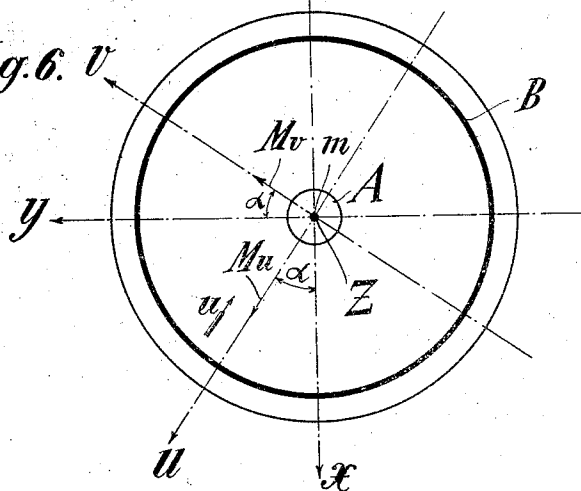
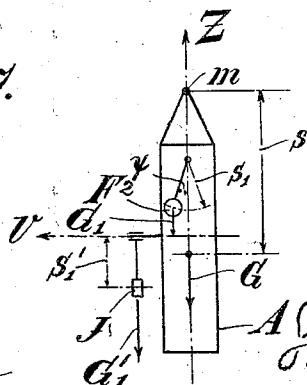


Fig. 7.



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DEVICE FOR MAINTAINING THE EQUILIBRIUM OF A PENDULUM.

1,083,370.

Specification of Letters Patent.

Patented Jan. 6, 1914.

Application filed February 29, 1912. Serial No. 680,761.

To all whom it may concern:

Be it known that I, WILHELM LUYKEN, residing at Essen-on-the-Ruhr, Germany, a subject of the Emperor of Germany, have invented a certain new and useful Improvement in Devices for Maintaining the Equilibrium of a Pendulum, of which the following is a specification.

This invention relates to a device for preserving the equilibrium of a pendulum suspended from a swinging body, and consists in the employment of a revolving disk carried in a swinging frame for producing the moment for influencing the pendulum so as to preserve the equilibrium; and that the axis of rotation of the revolving disk swings in resonance with the body from which the pendulum is depending.

In the accompanying drawings is represented one embodiment of the invention under the supposition that such a pendulum is hung in a gun turret of an armored battle ship and in consequence can turn, together with the gun turret, around an axis that is perpendicular when the ship is in equilibrium.

The drawings illustrate in Figure 1 an elevation of the device; Fig. 2 a side elevation of Fig. 1 seen in the direction of the arrow in Fig. 1; Fig. 3 a top plan view of Fig. 1; Fig. 4 a section on line 4—4 of Fig. 1, seen from above; Fig. 5 a diagrammatic cross section of the ship and the gun turret along line 5—5 of Fig. 4; the following figures are in larger scale namely Fig. 6 a diagrammatic section on line 6—6 of Fig. 5, seen from above; and Fig. 7 a diagrammatic elevation of the pendulum seen in the direction of the arrow *u* in Fig. 6.

The pendulum A is hung on a universal bearing in the turret B, Figs. 5 and 6. For this purpose, a frame C, Figs. 1, 2 and 4, is carried to swing on two trunnions c^1 in two bearing stands B^1 which are rigidly secured in the gun turret, and in this frame the pendulum A is hung on two trunnions a^1 , the axis of which intersects at right angles the axis of the trunnions c^1 . The pendulum A is provided with a crosshead a^2 situated above the frame C on which two disk carriers D, each with a pair of trunnions d^1 are supported to swing in bearings c^2 . The oscillation axes of the disk carriers D coincide with each other and are perpendicular

to a plane drawn through the axes of the trunnions a^1 and the center of gravity of the pendulum A. In each of the two carriers D is situated a revolving disk E, driven by an electric motor D^2 and arranged so that its axis of revolution may swing in a plane perpendicular to the axis of the trunnions d^1 . Each of the two trunnions d^1 , located nearest together, on the disk carriers D, is provided with a bevel wheel sector d^3 . Each of the two bevel wheel sectors d^3 is in mesh with one of two other bevel wheel sectors F, situated diametrically opposite each other but connected to form one piece and rigidly secured on one end of a shaft F^1 , which is parallel to the trunnions a^1 . On the other end of the shaft F^1 is suspended an auxiliary pendulum F^2 with considerable damping. The gearing ratio is equal to one between the bevel wheel sectors F and d^3 , so that the two disk carriers D must swing with the same angular velocity as the auxiliary pendulum, but in a direction opposite to each other. The pendulum A, in the following designated as the main pendulum, is furthermore provided with a second cross-head a^3 situated below the frame C and at right angles with the first cross-head a^2 and on which is likewise arranged a system of revolving disks. This revolving disk system consists of two disk carriers G which are mounted to oscillate around a common axis which is parallel with the axis of the trunnions a^1 ; as well as of two revolving disks H, which are driven by electric motors G^1 and arranged on the carriers G in the same manner as the revolving disks E on the carriers D. Another auxiliary pendulum J with considerable damping is also provided on the main pendulum A, the axis of oscillation of which is perpendicular to a plane drawn through the center of gravity of the main pendulum and the axis of the trunnions a^1 . This auxiliary pendulum J, which is fastened on a shaft J^1 has gearing connection with the disk carriers G through the bevel wheel sectors J^2 , g^2 , arranged in such a manner that disk carriers G must oscillate with the same angular velocity as the auxiliary pendulum J, but in a direction opposite to each other; similarly to what is the case with the auxiliary pendulum F^2 and the disk carriers D. It is furthermore arranged both for the revolving disk system G H and

for the revolving disk system D E, so that the axes of rotation of the revolving disks each form right angles with their axes of oscillation, when the auxiliary pendulums stand in their middle position; and that the center of gravity of the revolving disk carriers, together with all parts situated thereon fall within the axis of oscillation of the revolving disk carriers.

At the free end of one of the trunnions a^1 is located an inductor which consists of an armature rigidly connected with this trunnion, having a winding a^5 , with a magnet stand c^2 rigidly connected with the frame C and in the field of which the armature is situated. From the oscillations of the ship, electromotoric force will then be generated in the inductor $c^2 a^5$ which is proportional to the angular velocity of the relative oscillation between the main pendulum A and the frame C. On the shaft F^1 of the auxiliary pendulum F^2 is furthermore located an armature having a winding f^3 which can swing in a magnet stand a^6 rigidly secured to the main pendulum A, in consonance with the auxiliary pendulum F^2 ; so that an electromotoric force will be generated in the inductor, comprising the armature and the magnet stand a^6 , which is proportionate with the angular velocity of the auxiliary pendulum F^2 . This armature carries beside the winding f^3 , also a hollow copper cylinder f^4 , which in well known manner produces the above mentioned damping of the auxiliary pendulum F^2 . The exciting windings $c^3 a^7$ of the magnet stands $c^2 a^6$ is connected to a net-work M of constant tension by means of the conducting wires K, Fig. 1. The two armature windings $a^5 f^3$ are by means of the conducting wires N, coupled with the exciting winding p^1 of a generator P, built as a series wound continuous current dynamo; which generator operates a separately excited motor Q by means of Leonard connections. On one of the two trunnions c^1 is furthermore fastened an armature with winding c^4 , which can oscillate in a magnet-stand b^2 , that is rigidly attached to the bearing block B^1 belonging thereto, actuated by the oscillation of the ship and in consonance with the frame C; whereby an electromotoric force will be generated in the inductor $c^4 b^2$ comprising the magnet-stand b^2 and the armature; which electromotoric force is proportionate with the angular speed of the frame C. An armature having a winding j^3 is fastened to a shaft J^1 of the auxiliary pendulum J which armature is adapted to oscillate in consonance with the auxiliary pendulum J in a magnet stand a^8 which is rigidly connected with the main pendulum A; whereby an electromotoric force is generated in the inductor $j^3 a^8$ proportionate with the angular speed of the auxiliary pendulum J. Beside the winding j^3 , the armature of

this inductor is provided with a hollow copper cylinder j^4 which constitutes the damping device for the auxiliary pendulum J. The exciting windings b^3 and a^9 of the magnet-stands b^2 and a^8 are, in the same manner as the exciting winding c^4 and a^7 , connected with the net-work M by means of the wiring K¹, Fig. 2. The armature windings c^4 and j^3 are, by means of the wiring N¹, series connected with the exciting winding r^1 of the generator R built on the principle of a continuous current dynamo, which operates a separately excited motor T through Leonard connection.

The motors Q and T may for instance be used to guide a platform for an observation telescope, which is, in the same manner as the main pendulum A, carried in universal bearings in the gun turret, whereby the angular position thereof will not be influenced by the oscillation of the ship. For this purpose it is only necessary, on the one hand, to move in consonance with the frame C and by means of the motor T, the part of the universal bearing of the platform which corresponds to the frame C, which part may be considered as seen through the cross-head a^2 of the main pendulum; and on the other hand to move the platform itself, relatively to this part of its universal bearings by means of the motor Q; so that the relative angular position of both parts always agrees with the relative angular position of the main pendulum A and the frame C. That this problem can be solved by means of the motors Q and T will be shown in the following.

By utilizing the described device the two revolving disks E, which possess the same moments of inertia, are driven by the electric motors D² with the same angular speed but with a direction opposite to each other; and the two revolving disks H which likewise possess the same moments of inertia are similarly driven by the electric motors G¹. The direction of rotation of the revolving disks E is indicated on the drawings by the arrows y , while the direction of rotation of the revolving disks H is indicated by the arrows z . Looking at the two disk revolving systems from the side, from which the bevel wheel sectors F and J² appear to lie behind the axis of rotation of the carriers D and G, the righthand revolving disk E or H in each case, always revolves with the clock, seen from above, and the lefthand revolving disks in the opposite direction; as indicated by the direction of the arrows. In consequence of the rocking movement of the ship in sea-way, the auxiliary pendulums F^2 and J will be set swinging, and the same amount of swinging will be transferred by the beveled gears F a^2 or J² g^2 respectively, to the revolving disk carriers D and G. Each revolving disk E will natu-

rally then exercise on the main pendulum A a moment which acts in a plane determined by the axis of revolution and the axis of oscillation of the carrier D belonging thereto, the vector of which will be perpendicular to this plane and will swing in consonance with the disk carrier D. The vectors of the moments which are generated by means of the two revolving disks E, will, in their middle position, always have the same direction and be parallel to the axis of oscillation of the auxiliary pendulum F². As the two disk carriers D always move in opposite directions with the same angular speed, the two vectors will always deflect the same angle, but in opposition to the direction of the axis of oscillation of the auxiliary pendulum F²; the two moments generated by the revolving disks E will consequently give a resultant moment, the vector of which falls in the direction of the axis of oscillation of the auxiliary pendulum F². This means that the resultant moment operates as seen in Fig. 1, always in the plane of the drawing or in a plane parallel thereto. The moment caused by each single revolving disk will be equal to the product of its moment of inertia, its angular speed and the angular speed of the disk carrier. Or if in the ordinary way the product of the moment of inertia of the revolving disk and its angular velocity is designated as "kinetic moment," this revolving disk moment will be equal to the product of the kinetic moment of the revolving disk and the angular velocity of the disk frame. If the kinetic moment of the revolving disks E is designated by Δ and the angular velocity of the auxiliary pendulum F² that belongs thereto is designated with w (which is equal to the angular velocity of the revolving disk frame D) each revolving disk will then exercise a moment of the magnitude Δw . As the deflection of the auxiliary pendulum F² can only be very small on account of its considerable damping, the angle by which the vectors of the two revolving disk moments are deflected from the direction of the axis of oscillation of the auxiliary pendulum F², will similarly always be very small. The components of the two vectors falling in the direction of the axis of oscillation of the auxiliary pendulum may therefore be almost exactly designated as Δw , and in consequence the resulting moment of the revolving disk system D E be approximately equal to $2\Delta w$, the vectors of this system being equal to the sum of the above mentioned components. In a similar way it can be shown that the revolving disk system G H will give a resultant moment which, looking at Fig. 1, always acts in the plane perpendicular to the plane of the drawing, and the vector of which consequently will fall in the direction of the axis of oscillation of

the auxiliary pendulum J, and that the magnitude of this moment is equal to $2\Delta'w'$ when the kinetic moment of the revolving disk H is called Δ' and the angular velocity of the auxiliary pendulum J is called w' .

In each of the two revolving disk systems the two revolving disks could naturally be substituted by a single one the kinetic moment of which would have to be twice as large as the kinetic moment of each single revolving disk, this substitute revolving disk would set up a moment, the vector of which as regards the main pendulum, would not fall in a constant direction, but would swing in a plane perpendicular to the axis of rotation of the revolving disk frame just as the vectors of the single revolving disks. The vertical component of this vector would correspond to a moment which attempts to turn the main pendulum around the vertical axis through its center of gravity. This moment which, by the way, will be comparatively small, is however without influence on the perpendicular equilibrium of the main pendulum. The moment corresponding to the horizontal components of the vector can in that case only be considered. This moment agrees, however, with the resultant moment from the two single revolving disks.

The axis of oscillation of the auxiliary pendulum F² will now be called U and the axis of oscillation of the auxiliary pendulum J will be called V. As indicated by the arrows in the drawing, (Fig. 3) respectively for the U-axis and the V-axis, that direction will be called positive from which the respective bevel-wheel-sectors F and J² appear to be situated behind the axis of rotation of the corresponding disk carriers D and G. The moment set up by the revolving disk system D E will be called M_u and the moment of the revolving disk system G H will be called M_v . Both these moments will be considered positive when their vectors fall in the positive direction of the U-axis or V-axis respectively. Should the auxiliary pendulum F², looking from the positive side of the U-axis, or, which means the same, when looking at it in Fig. 1, turn in the same direction as the hands of a clock, then M_u will be negative when the disk E revolves in a direction denoted by the arrow y . If the angular speed w of the auxiliary pendulum F² is considered as positive, when the same turns in the above mentioned direction, it follows that

$$M_u = -2\Delta w \quad (1)$$

It will also be evident that

$$M_v = -2\Delta'w' \quad (2)$$

if it is supposed that w' is considered as positive, when the auxiliary pendulum J, seen from the positive side of the V axis,

deflects in the direction of the hands of a clock.

In the following will now be shown that the moments M_u and M_v in each instance will have such a value as will be required for preserving the perpendicular equilibrium of the main pendulum A.

The oscillating movements of the ship in a sea-way, as is well known, consist—(1) in rolling, that is, the swinging around the main longitudinal axis through the center of gravity of the ship which, in Fig. 5 is projected into a point o , (2) in the stamping movement, that means the swinging around the transverse axis through the center of gravity of the ship, and (3) in the diving movement, that means the swinging of the whole ship's body in a vertical direction. In very large and heavy ships, such as armored battle ships (for which the described device is intended) the diving movement is, as a rule very small in comparison with the oscillations of the rolling and stamping movements; this diving movement may therefore be entirely left out in the discourse, as it is of very little consequence as compared to the magnitude of the oscillations of the rolling and stamping movements. The stamping movement may also be left out of the reckoning as it is, in the ships in question, comparatively insignificant and also causes very small turning of the ship, which in the aiming of the guns scarcely has any disturbing influence. As it furthermore would not be difficult to compensate for the influence of this stamping movement, in describing this device it will be practically sufficient to consider the adjustment for the influence of the rolling movement only. In the following, it will therefore be supposed that the ship only rolls.

Ships having very large moments of inertia and comparatively small moments of stability, such for instance as armored battle ships, will roll in a sea-way almost according to the same law as in calm water; that is they oscillate with the closest approximation like an ordinary pendulum. If therefore the angle in which the ship deflects from its middle position during the time t is called, φ , and φ_0 is the largest value of φ and T the constant duration of the complete oscillation: the following equation may be written according to the law of the pendulum—

$$\varphi = \varphi_0 \sin. \frac{2\pi t}{T}$$

or if we put $\frac{2\pi}{T} = \lambda$;

$$\varphi = \varphi_0 \sin. \lambda t \quad (3)$$

In Fig. 5 the position of the suspension point of the main pendulum A is denoted by

m , that means the position of the intersections of the axes of the trunnions a^1 and a^2 with the ship in its middle position; and m^1 the position of the same point, when the ship is swung around the oscillation axis drawn through the point o an angle equal to φ during the rolling. It will now be supposed that the turning angle of the ship in its rolling movement is very small (less than 10°). In this case it can be supposed that the point m moves approximately in a straight line $m-b$, which stands perpendicular to the straight line $o-m$, and that its total acceleration p is approximately equal to the tangential acceleration

$$l \frac{d^2 \varphi}{dt^2}$$

when l denotes the distance $m-o$ of the point m from the oscillating axis. Considering then the equation (3) we obtain—

$$p = -l \varphi_0 \lambda^2 \sin. \lambda t \quad (4)$$

or if we put $l \varphi_0 \lambda^2 = p_0$

$$p = -p_0 \sin. \lambda t \quad (5)$$

The gun turret B may be swung into any angular position. That position should be considered as the main position of the gun turret, in which the axis of the trunnions a^1 is parallel to the oscillating axis of the ship drawn through the point o , Fig. 5, with the ship and the pendulum A at rest. The angular position of the gun turret may then be denoted by the same angle α , as the one formed between the axis of the trunnions a^1 and the oscillating axis, when the ship and the pendulum A are at rest.

If the main pendulum A always hangs perpendicular during the oscillation of the ship, the frame C of the universal bearing must generally oscillate both in relation to the main pendulum A around the axis of the trunnions a^1 , as well as in relation to the bearing stands B^1 around the axis of the trunnions a^2 , with any angular position of the gun turret. Calling the angle φ_1 in which the frame C is turned from its middle position during its oscillation around the axis of the trunnions a^1 during the time t ; and calling the angle φ_2 in which the frame C turns from its middle position during its oscillation around the axis of the trunnions a^2 ; during the same length of time, the following equations may be written with the greatest approximation as obtaining between the angles φ_1 or φ_2 and φ respectively, which will easily be evident for so small a value of φ

$$\varphi_1 = \varphi \cos. \alpha \quad (6)$$

and

$$\varphi_2 = \varphi \sin. \alpha \quad (7)$$

A perceptible turning of the pendulum A around the axis going through its center of gravity, and through the suspension point

would take place with larger values of φ during the oscillation of the ship. For smaller values of φ this turning would, however, be so trifling that it could be completely neglected. It may therefore be supposed, without any noticeable mistake, that the movement of the pendulum A in its continuously perpendicular position during the oscillation of the ship consists simply of a translation, that is that all the points of the pendulum have the same acceleration, namely the acceleration p of the suspension point m .

A three-axial coördinate system X Y Z, Figs. 5 and 6 may be considered to be arranged with the suspension point m as starting point, in which the Z-axis is always vertical and the X-axis and Y-axis always parallel to the direction respectively which the longitudinal and transverse axes, drawn through the center of gravity of the ship, will take when the latter is in its equilibrium. The Z-axis coincides in the above mentioned movement of the pendulum A with the axis going through the center of gravity and through the point m ; while the X-axis and the Y-axis always make an angle α , Fig. 6, with the axis of the auxiliary pendulums F^2 or J , that means with the U-axis or the V-axis respectively, during the angular position α of the turret B.

The main pendulum A is influenced besides by the gravity and by the two moments M_u and M_v from the two revolving disk systems, also by a moment which is generated by the inductors $c^2 a^5$ and $b^2 c^4$. The moments generated by the inductors $a^5 f^3$ and $a^5 i^3$ are not here taken into account as they depend on forces, which may be considered as inner forces relative to the main pendulum. The inductor $c^2 a^5$ exercises a moment on the main pendulum, the vector of which falls in the direction of the U-axis. This moment will be called m_u and considered positive, when its vector points in the direction of the positive side of the U-axis. The inductor $c^4 b^2$ exercises the moment m_v , the vector of which falls in the axis of trunnions c^1 . This axis moves during the swinging of the ship, when the main pendulum hangs perpendicular, in a vertical plane through the V-axis, and forms with the V-axis a very small, almost constant angle φ_1 [compare equation (6)]. With regard to the vertical equilibrium of the main pendulum that horizontal component of the moment-vector will only be considered that falls in the direction of the V-axis and possesses the magnitude of $m_v \cos. \varphi_1$. As the angle φ_1 is just as small as the angle φ ; $\cos. \varphi_1$ may be put down as approximately equal to 1. It may therefore be supposed with great approximation that the inductor $c^4 b^2$ will produce a moment-vector, which falls in the direction of the V-axis, and has a magnitude that will

be m_v , and considered as positive, when it points toward the positive side of the V-axis.

If we now examine what conditions have to be fulfilled whereby the main pendulum A, during the oscillation of the ship, will always retain its perpendicular equilibrium, it will be found, by using for instance the principle of d'Alembert, that—

$$M_u = \frac{p_0}{g} \cos. \beta G s \cos. \alpha \sin. \lambda - m_u \quad (8)$$

and

$$M_v = -\frac{p_0}{g} \cos. \beta G s \sin. \alpha \sin. \lambda - m_v \quad (9)$$

In these equations the signs denote: g the acceleration of gravity, G the weight of the main pendulum (comprising all the different parts thereon), s the distance of its center of gravity from the suspension point m (compare Fig. 7) and β the angle, which the straight line $m-b$ Fig. 5 forms with the Y-axis. It will furthermore be supposed that the angle α from the part of the X-axis which is absolutely considered as positive, and which in Fig. 6 has been indicated by an arrow, will be counted as positive in the direction in which the clock runs; and that the positive part of the U-axis must be turned 90° as the clock runs, in order to make it coincide with the positive part of the V-axis as is the case in the arrangement selected for the drawing, Fig. 6. It is furthermore supposed that the angle φ from the line $o-m$, Fig. 5, looked at from the positive side of the X-axis, will be read as positive in the same direction as the clock runs. It will now only be necessary to further develop two principal equations (8 and 9). It will then be supposed that the angular deflection of the auxiliary pendulums F^2 and J , which will be denoted as ψ and ψ^1 respectively, as seen from the positive side of the U-axis or the V-axis, will be read as positive, from the middle position of the auxiliary pendulums, in the same direction as the clock runs. It will furthermore be supposed that, at the instant under consideration, which would be determined by the time t , both the ship and the two auxiliary pendulums turn in the positive direction and that the angles φ , ψ and ψ^1 have simultaneously positive values. The angular position of the gun turret will be selected, as shown in Fig. 6, so that α will be a positive acute angle.

For the circuit $a^5 f^3 N p^1$, that direction of the current will be established as positive, in which the current runs in the positive direction as regards the U-axis, in the part of the armature winding a^5 , which lies below the upper pole-piece of the magnet stand c^2 , that means in looking at Fig. 1, that the current runs toward the spectator. It will also be supposed that the current has a positive

direction as regards the electromotoric forces generated in the inductors $a^5 c^2$ and $f^3 a^5$.

When the ship has turned out of its middle position, in the same direction as the clock runs, the angle of φ , the frame C has simultaneously turned, relative to the main pendulum A (which has to be considered as hanging continuously perpendicular) around the axis of the trunnions a^1 in the same direction, an angle $\varphi_1 = \varphi \cos. \alpha$ (compare equation 6). An electromotoric force E will thereby be generated in the inductor $c^2 a^5$, which force is proportionate with the field power of the inductor, the number of turns of the armature winding a^5 and the angular velocity

$$\frac{d\varphi_1}{dt}$$

If the product of the field force, the number of turns of the armature winding a^5 and the proportionate factor were summed up as the (constant) quantity N, one would obtain as a result for the electromotoric force the expression

$$E = N \frac{d\varphi_1}{dt}$$

or

$$E = N \varphi_0 \lambda \cos. \alpha \cos. \mu t \quad (10)$$

The quantity N would be considered positive, when the uppermost pole of the magnet frame c^2 is a north pole, as is indicated in Fig. 1 by the direction of the arrow of the exciting current in the conductor K; and it will be considered negative when said pole is a south pole. As is shown in Fig. 1, E is positive when N is positive and changes its sign simultaneously with N. The equation (10) will therefore give the direction as well as the magnitude of E.

The following expression will be obtained for the electromotoric force e in the inductor $a^5 f^3$, when n designates the value corresponding to the quantity N, neglecting the signs

$$e = n \frac{d\phi}{dt}$$

The quantity n should be considered as positive, according to the sign rule for N, when the upper pole of the magnet frame a^5 is a north pole, as is indicated in Fig. 1 by the direction of the arrow of the exciting current; and should be considered as negative, when the upper pole is a south pole. With a positive value of N, as indicated in Fig. 1, and the accepted moving condition of the auxiliary pendulum F^2 , e will have negative direction, under the supposition that the armature windings $a^5 f^3$ are connected in such a manner, that a current runs in the positive direction of the U-axis if such current is going in the positive direction

both in the part of the armature winding f^3 which is situated below the upper pole piece of the magnet stand a^5 , and in the part of the armature winding a^5 which is situated below the upper pole piece of the magnet stand c^2 . Should on the other hand the armature windings a^5 and f^3 be connected so that a current going in the positive direction in the part of the armature winding f^3 that lies beneath the upper pole piece of the magnet stand a^5 , run in the negative direction of the U-axis, then e will have positive direction with a positive value of n . We have therefore to write, taking the signs into consideration,

$$e = \mp n \frac{d\phi}{dt}$$

wherein the upper sign has to be taken for the first named connection and the latter sign for the last named connection of the armature windings a^5 and f^3 . For the sake of brevity, it will, in the following, be said as regards the first named connection, that the armature windings are similarly connected, and as regards the latter connection that they are oppositely connected. If the resistance of the circuit $a^5 f^3 N p^1$ is called ζ , we will, for the current force i have the expression

$$i = \frac{E + e}{\zeta} = \frac{N \varphi_0 \lambda}{\zeta} \cos. \alpha \cos. \mu t \mp \frac{n}{\zeta} \frac{d\phi}{dt} \quad (11)$$

The moment m_a , exercised by the inductor $c^2 a^5$ on the principal pendulum is proportionate with the expression $N i$, and the factor of proportion which in the following will be called c , is indeed dependent on the selected unity of measure. When the moment acts in the same direction as the clock runs and consequently has to be considered as positive, when N and i have positive values, and also changes its sign simultaneously with N and i , then the following equation is obtained

$$m_a = + c N i \quad (12)$$

from which the following equation will be evolved when the value of i , given in equation (11) is inserted

$$m_a = \frac{c N^2 \varphi_0 \lambda}{\zeta} \cos. \alpha \cos. \mu t \mp \frac{c N n}{\zeta} \frac{d\phi}{dt} \quad (13)$$

In order to further develop the above equation the movement of the auxiliary pendulum F^2 , described by the angle ϕ has first to be decided. The acceleration p (compare equation 4) will influence this movement besides the moment created by inductor $a^5 f^3$. The moment caused by the inductor has its absolute value depending on the quantity $c n i$. The sign results from the following discussion: When n is positive and the armature windings a^5 and f^3 are continuously connected, the induced electromotive

force will, at the instant under consideration, have negative direction, under the supposition on which the calculation is based. Should i at the same time be positive, the current and the electromotive force will consequently have opposite signs (as in an electromotor). The moment caused by the inductor acts therefore in the direction of the movement of the auxiliary pendulum and has consequently to be taken as positive during the supposed condition of movement of the auxiliary pendulum. Should the sign-change of one or the other of the quantities i and n , the sign of the moment will then change simultaneously. With the armature windings a^b and f^3 continuously connected, the term $+cni$ then expresses the magnitude and sign of the moment. Are, on the other hand, the armature windings a^b and f^3 oppositely connected, the moment exercised on the auxiliary pendulum, will reversely be expressed as to magnitude and sign by $-cni$, which will be readily understood. With regard to the manner of connection of the armature winding, the moment, exercised by the inductor $a^b f^3$ on the auxiliary pendulum,

will therefore be expressed by $\pm cni$. The components of the acceleration p falling in the direction of the axis of oscillation, that is in the direction of the U-axis, do evidently not at all come under consideration for the movement of the auxiliary pendulum F^2 . Even the component falling in the direction of the Z-axis may be neglected, as the deflections ψ Fig. 7 of the auxiliary pendulum on account of the supposed considerable damping, may be considered as small and consequently the factor φ_0 of the Z component of p comprising the factor will generate a moment as regards the axis of the auxiliary pendulum which moment contains the small quantity $\varphi_0 \sin. \psi$ of the second order. The component falling in the direction of the V-axis need therefore only be taken into the reckoning, namely

$$p_v = -p \cos. \beta \cos. \alpha = +p_0 \cos. \beta \cos. \alpha \sin. \lambda t$$

For the movements of the auxiliary pendulum F^2 is consequently obtained by using for instance the principle of d'Alembert, the differential equation

$$\textcircled{H} \frac{d^2 \psi}{dt^2} + k \frac{d\psi}{dt} + G_1 s_1 \psi \mp cni = -\frac{p_0}{g} \cos. \beta G_1 s_1 \cos. \alpha \sin. \lambda t$$

in which $\textcircled{H}$ is the moment of inertia, reduced to the axis of the auxiliary pendulum, of all the oscillating parts of the revolving disk system D E, that means of the parts E D² D³ D⁴ F F¹ F²; k the factor of damping, G_1 the weight of the parts F F¹ F² and s_1 the distance of the center of gravity of

the parts F F¹ F² from the axis of the auxiliary pendulum.

If the value of i given in the equation (11) is inserted in the above differential equation, the equation will take the following appearance after several deductions

$$\textcircled{H} \frac{d^2 \psi}{dt^2} + \left(k + \frac{cn^2}{s}\right) \frac{d\psi}{dt} + G_1 s_1 \psi = -\frac{p_0}{g} \cos. \beta G_1 s_1 \frac{\cos. \alpha}{\cos. \gamma} \sin. (\lambda t \mp \gamma)$$

The phase displacing-angle γ found in the above equation is here given as

$$\text{tg. } \gamma = \frac{cNn\varphi_0\lambda}{\frac{p_0}{g} \cos. \beta G_1 s_1} \quad (14)$$

The solution of the differential equation as regards the state of permanence, which here only will be considered, is as follows

$$\psi = -\frac{p_0}{g} \cos. \beta \frac{G_1 s_1}{\left(k + \frac{cn^2}{s}\right)\lambda} \frac{\cos. \alpha}{\cos. \gamma} \sin. \delta \sin. (\lambda t \mp \gamma - \delta) \quad (15)$$

The phase-displacing angle δ will be decided through the equation

$$\text{tg. } \delta = \frac{\left(k + \frac{cn^2}{s}\right)\lambda}{G_1 s_1 - \textcircled{H}\lambda^2} \quad (16)$$

If now the condition is selected so that

$$G_1 s_1 = \textcircled{H}\lambda^2 \quad (17)$$

so follows that

$$\delta = \frac{\pi}{2}$$

which is evident from equation (16). In this case of synchronism, equation (15) will be transformed into

$$\psi = \frac{p_0}{g} \cos. \beta \frac{G_1 s_1}{\left(k + \frac{cn^2}{s}\right)\lambda} \frac{\cos. \alpha}{\cos. \gamma} \cos. (\lambda t \mp \gamma) \quad (18)$$

Through the differentiation of the above equation the following value of the angular velocity w of the auxiliary pendulum R^2 will be obtained

$$w = \frac{d\phi}{dt} = -\frac{p_0}{g} \cos. \beta \frac{G_1 s_1}{k + \frac{cn^2}{s}} \cos. \alpha \sin. (\lambda \mp \gamma) \quad (19)$$

If the above value of $\frac{d\phi}{dt}$ is inserted in equation (13) we obtain.

$$m_u = \frac{cN^2 \varphi_0 \lambda}{s} \cos. \alpha \cos. \lambda \pm \frac{cNn p_0}{s g} \cos. \beta \frac{G_1 s_1}{k + \frac{cn^2}{s}} \cos. \alpha \sin. (\lambda \mp \gamma) \quad (20)$$

Lastly we get from equation (1) with regard to equation (19).

$$M_u = 2A \frac{p_0}{g} \cos. \beta \frac{G_1 s_1}{k + \frac{cn^2}{s}} \cos. \alpha \sin. (\lambda \mp \gamma) \quad (21)$$

We will now be able to completely evolve the first conditions set down by equation (8), namely that the main pendulum retains its equilibrium. If namely the values given of M_u in equation (21) and the value of m_u obtained from equation (20), are inserted in equation (8) and the latter equation is divided by $\cos. \alpha$ the following will be obtained.

$$\begin{aligned} 2A \frac{p_0}{g} \cos. \beta \frac{G_1 s_1}{k + \frac{cn^2}{s}} \frac{\sin. (\lambda \mp \gamma)}{\cos. \gamma} &= \frac{p_0}{g} \cos. \beta G s \sin. \lambda - \\ - \frac{cN^2 \varphi_0 \lambda}{s} \cos. \lambda \mp \frac{p_0}{g} \cos. \beta \frac{cNn}{s} \frac{G_1 s_1}{k + \frac{cn^2}{s}} \frac{\sin. (\lambda \mp \gamma)}{\cos. \gamma} \end{aligned} \quad (22)$$

It must now be evident that the foregoing equations will be identically satisfied by selecting:

$$N = \pm n \frac{Gs}{G_1 s_1} \quad (23)$$

and

$$A = \frac{1}{2} k \frac{Gs}{G_1 s_1} \quad (24)$$

The first main condition for the equilibrium given in equation (8) will therefore be fulfilled, when A and N have the values determined by the above equations (23) and (24), irrespective of what value λ and γ have.

In an equally simple manner it can be proved that the second main condition set forth by equation (9) for maintaining the equilibrium of the main pendulum has been fulfilled. The quantities corresponding to the quantities N , n , E , e , i and ς for the inductors b^2 , c^4 and a^3 , i^3 will be designated as N^1 , n^1 , E^1 , e^1 , i^1 and ς^1 . With regard to the signs for N^1 , n^1 , E^1 , e^1 and i^1 the same rules will hold good as before as to the direction of the same. The armature windings c^4 and i^3 will furthermore be designated as heretofore, as similarly or oppositely connected, according to how the currents flow in the same or the opposite direction to each

other in the part of the armature winding lying underneath the upper pole piece of the magnet stands b^2 and a^3 . Likewise, as everywhere heretofore, when in the following equations simultaneously a plus + or minus - sign is given, the upper sign will refer to the first kind and the lower sign to the second kind of connection of the armature winding. While the ship has turned during the time t from its equilibrium an angle φ in the same direction as the clock runs, the frame C has also turned in the same direction around the axis of the trunnion c^1 an angle

$$\varphi_2 = \varphi \sin. \alpha$$

from its middle position [compare equation (7)]. An electromotoric force will then be generated in the inductor b^2 , c^4 of

$$E' = -N' \frac{d\varphi_2}{dt}$$

or

$$E' = -N' \varphi_0 \lambda \sin. \alpha \cos. \lambda$$

Simultaneously will be generated in the inductor a^3 , i^3 an electromotoric force

$$e' = \mp n' \frac{d\varphi'}{dt}$$

We therefore get

$$\dot{\psi} = \frac{E' + e'}{\zeta'} = -\frac{N' \varphi_0 \lambda}{\zeta'} \sin. \alpha \cos. \lambda \mp \frac{n'}{\zeta'} \frac{d\psi'}{dt} \quad (25)$$

Furthermore will be found

$$m_v = +cN' \dot{\psi}$$

Comparing equation (25) with equation (11) we shall find that equation (11) also will do equally well for $\dot{\psi}$ as regards the signs, when α is substituted by $(\alpha + 90^\circ)$, compare Fig. 6, in accordance with the angular position of the turning axis of the auxiliary pendulum J, that is the angular position of the V-axis. As the arrangement of the auxiliary pendulum J in which the quantities G_1, s_1 (H) and k have been substituted by the corresponding quantities G_1', s_1' (H) and k' , only differs from the arrangement

of the auxiliary pendulum F² therein that the angular position of its axis of revolution is described by the angle $(\alpha + 90^\circ)$ instead of α ; it will be evident, that equations (18) and (19), which determine the deflection and the angular velocity of the auxiliary pendulum F², will also do for the deflection ψ' and the angular velocity

$$w' = \frac{d\psi'}{dt} \quad 30$$

of the auxiliary pendulum J, when $(\alpha + 90^\circ)$ is substituted for α , regard being taken to the direction. We consequently have

$$\psi' = -\frac{p_0}{g} \cos. \beta \frac{G_1' s_1'}{k' + \frac{cn'^2}{\zeta'}} \frac{\sin. \alpha}{\cos. \gamma'} \cos. (\lambda \mp \gamma') \quad (26)$$

and

$$w' = \frac{d\psi'}{dt} = \frac{p_0}{g} \cos. \beta \frac{G_1' s_1'}{k' + \frac{cn'^2}{\zeta'}} \frac{\sin. \alpha}{\cos. \gamma'} \sin. (\lambda \mp \gamma') \quad (27)$$

The phase-displacing-angle γ' will then be expressed in accordance with equation (14) by

$$\text{tang. } \gamma' = \frac{cN'n'\varphi_0\lambda}{\frac{p_0}{g} \cos. \beta \zeta' G_1' s_1'} \quad 40$$

It is furthermore supposed in accordance

$$m_v = -\frac{cN'^2 \varphi_0 \lambda}{\zeta'} \sin. \alpha \cos. \lambda \mp \frac{cN'n'}{\zeta'} \frac{p_0}{g} \cos. \beta \frac{G_1' s_1'}{k' + \frac{cn'^2}{\zeta'}} \frac{\sin. \alpha}{\cos. \gamma'} \sin. (\lambda \mp \gamma') \quad (29)$$

Furthermore, in accordance with equation (2), as compared with equation (27) will be found

$$M_v = -2\Delta' \frac{p_0}{g} \cos. \beta \frac{G_1' s_1'}{k' + \frac{cn'^2}{\zeta'}} \frac{\sin. \alpha}{\cos. \gamma'} \sin. (\lambda \mp \gamma')$$

with equation (17) that the condition of synchronism has been fulfilled.

$$G_1' s_1' = (H)' \lambda^2 \quad 45$$

It must also be perceived that equation (20) with the same direction will do for m_v when α is substituted by $(\alpha + 90^\circ)$ so that the equation will be:

If the above value of M_v and the expression m_v given in equation (29) is inserted in equation (9), expressing the second and main condition for the maintaining of the equilibrium of the main pendulum; the following equation will be obtained if the whole equation is divided by $-\sin. \alpha$:

$$2\Delta' \frac{p_0}{g} \cos. \beta \frac{G_1' s_1'}{k' + \frac{cn'^2}{\zeta'}} \frac{\sin. (\lambda \mp \gamma')}{\cos. \gamma'} =$$

$$\frac{p_0 G_s}{g} \cos. \beta \sin. \lambda - \frac{cN'^2 \varphi_0 \lambda}{\zeta'} \cos. \lambda \mp \frac{p_0}{g} \cos. \beta \frac{cN'n'}{\zeta'} \frac{G_1' s_1'}{k' + \frac{cn'^2}{\zeta'}} \frac{\sin. (\lambda \mp \gamma')}{\cos. \gamma'}$$

This equation which corresponds in form to equation (22), will be identically satisfied when, in accordance with equations (23) and (24) is put down

$$N' = \pm n' \frac{G_s}{G_1' s_1'} \quad (30) \quad 65$$

and

$$\Delta' = \frac{1}{2} k' \frac{G_s}{G_1' s_1'} \quad (31)$$

When consequently Δ' and N' have the

values determined by equations (30) and (31), the second main condition for the maintenance of the vertical equilibrium of the main pendulum given by equation (9) has been fulfilled, and irrespective of what the values of l, β, φ_0 and ζ' have. The preservation of the equilibrium of the main pendulum depends consequently neither on the position of the suspension point m denoted by l and β Fig. 5, nor on the angular position of the gun turret de-

noted by the angle α ; nor, on the amount of the rolling motion denoted by φ_0 (if φ_0 only lies below the above given limits of about 10°). As it furthermore does not depend on the magnitude of ς and ς' , the equilibrium of the main pendulum will be maintained, when ς and ς' is permitted to be of infinite magnitude; that means, as regards the maintenance of the equilibrium of the main pendulum, that it is indifferent whether the circuits $a^5 f^3 N p^1$ and $c^4 i^3 r^1 N^1$ are open or closed. As equations (23) and (30) show, it is furthermore of no consequence whether the armature windings a^5 and f^3 as well as c^4 and i^3 are connected similarly or oppositely, as long as the signs of N and n , as well as N^1 and n^1 have been correctly selected. Of the greatest importance is, however, (1) that the two conditions of synchronism determined by equations (17) and (28) are fulfilled, (2) that for each revolving disk system the direction of rotation of the revolving disk has been so selected, looking at the system from that side from which the beveled wheel sector, arranged on the shaft of the auxiliary pendulum, appears to be situated behind the axis of oscillation of

the revolving disk frame; that the right-hand revolving disk will run in the same direction as the clock, if seen from above, (3) that the number of revolutions and the moment of inertia of the revolving disk is selected for each disk system, so that the kinetic moment of each separate revolving disk takes the value determined by equations (24) and (31) respectively; and (4) that the quantities N and n as well as N^1 and n^1 will satisfy equations (23) or (30) respectively. As the equilibrium of the main pendulum will also be maintained when the circuit $a^5 f^3 N p^1$ and $c^4 i^3 r^1 N^1$ are open, that means that the inductors $c^2 a^5$, $f^3 a^5$, $b^2 c^4$ and $a^2 i^3$ are idle, the arrangement of the inductors can naturally be entirely neglected, as long as regard has been taken thereto that the main pendulum in itself maintains its vertical equilibrium. In this case the conditions of 1, 2 and 3 alone will come in question.

If for i in equation (11) is inserted the value $\frac{d\phi}{dt}$ determined by equation (19), the following is obtained after several transformations of the equation:

$$i = \pm \frac{n}{\varsigma} \frac{G_1 s_1}{k + \frac{cn^2}{\varsigma}} \frac{p_0}{g} \cos. \beta \cos. \alpha (\sin. \lambda t \pm \frac{N \varphi_0 \lambda k}{n \frac{p_0}{g} \cos. \beta G_1 s_1} \cos. \lambda t)$$

If in accordance with the equation (5) regard is taken that

$$p_0 = l \varphi_0 \lambda^2$$

and in accordance with equation (23)

$$\frac{N}{n} = \pm \frac{G_s}{G_1 s_1}$$

and in accordance with equation (24)

$$k \frac{G_s}{G_1 s_1} = 2A$$

if we write

$$\text{tg. } \varepsilon = \frac{2A}{\lambda \frac{G_1 s_1}{g} \cos. \beta} \quad (32)$$

and

$$A = \frac{N}{\varsigma} \frac{G_1 s_1}{G_s} \frac{G_1 s_1}{k + \frac{cn^2}{\varsigma}} \frac{\lambda^2 \cos. \beta}{g \cos. \varepsilon} \quad (33)$$

the equation for i will be transformed into

$$i = A \varphi_0 \cos. \alpha \sin. (\lambda t + \varepsilon)$$

Similarly will be found that

$$i' = -A' \varphi_0 \sin. \alpha \sin. (\lambda t + \varepsilon') \quad (34)$$

wherein ε' will be determined, in accordance with equation (32), by the equation

$$\text{tg. } \varepsilon' = \frac{2A'}{\lambda \frac{G_1' s_1'}{g} \cos. \beta}$$

and A' in accordance with equation (33) will be determined by equation:

$$A' = \frac{N'}{\varsigma'} \frac{G_1' s_1'}{G_s} \frac{G_1' s_1'}{k' + \frac{cn'^2}{\varsigma'}} \frac{\lambda^2 \cos. \beta}{g \cos. \varepsilon'} \quad (35)$$

The currents i and i' serve to excite the generators $P p^1$ and $R r^1$. As has already been said the motor T fed by the generator $R r^1$ must always steer the part of the universal bearing of the platform corresponding to the frame C , so that said part always turns the same angle as the frame C (around the axis of the trunnions c^1) as regards the gun turret, actuated by the rolling movement of the ship. The angle in which each part has been turned as regards the gun turret, counted from the middle position, by means of the motor T during the time t will be called ξ . As the exciting current i' of the generator $R r^1$ in accordance with equa-

tion (34) is periodically changeable, it will now be evident, that also ξ will be periodically changeable. Furthermore it will be easily understood that ξ will have the same periods as i^1 , and that its maximum value is proportionate with the maximum value of i^1 . Furthermore ξ will generally have another phase-displacement than i^1 as regards the oscillation of the ship. In accordance with equation (34) we may consequently write

$$\xi = B \varphi_0 \sin. \alpha \sin. (\lambda t + \varepsilon' + \eta)$$

Herein B stands for a constant, which as regards its sign is dependent on the direction of the magnetic field of the generator and motor; and as regards its magnitude is dependent not only on A^1 but also on the field power and the numeral of the conductor acting on the armature of the generator and the motor, as well as the number of revolutions of the generator, and η expresses the angle around which ξ is deflected in the phase as regards i^1 . By means of a suitable arrangement (for instance by insertion of a phase regulator) it may now be attained

$$\eta = -\varepsilon'$$

The ratio may furthermore be so selected that $B=1$.

It follows then that

$$\xi = \varphi_0 \sin. \alpha \sin. \lambda t$$

or with regard to equations (3) and (7)

$$\xi = \varphi_2$$

that means, that the part of the universal bearing of the platform corresponding to the frame C, will be moved in regard to the gun turret by means of the motor T just the same amount as the frame C. It might also be shown in a similar manner, that the platform itself, as regards the part of the universal bearing that corresponds to the frame C, may be moved by the motor Q, the same amount as the main pendulum A, (around the axis of the trunnions α^1) in regard to the frame C. The platform as well as the main pendulum A, will therefore always remain in equilibrium during the oscillation of the ship.

With $\alpha=0$, the auxiliary pendulum J remains always at rest, as the discussion has disclosed, and also the equation shows, in regard to the main pendulum A; so that the revolving disk system G H remains out of action. For this reason, the revolving disk system G H might be left out entirely, when the main pendulum is not suspended in a gun turret but rather suspended in a body that does not turn as regards the ship's body. Similarly the main pendulum need not in this case be suspended in universal bearings, but it would be sufficient to have a suspension with two trunnions only, the axis of

which had to be parallel with the longitudinal axis of the ship. If, however, the main pendulum has been suspended in universal bearings and provided with a second revolving disk system beside the arrangement of the revolving disk system G H, this second revolving disk system may be utilized to counteract the influence of the stamping movement of the ship. This is not objectionable as the stamping movement follows the same laws as the rolling movement, which alone has hitherto been considered.

The above discussion has been executed with the supposition that the oscillation of the ship follows sufficiently close to the sine-law. The equilibrium of the pendulum A is, however, maintained with great correctness in the described device, when the oscillation of more complicated kind is concerned. This will however not be discussed in the present discussion.

I claim:—

1. A device for maintaining the equilibrium of a pendulum suspended from an oscillating body, said device comprising an oscillating frame mounted on said pendulum, a revolving disk, bearings in said frame for said revolving disk, and means for automatically imparting to said frame an oscillating movement in synchronism with the oscillation of said body from which the pendulum is suspended.

2. A device for maintaining the equilibrium of a main pendulum suspended from an oscillating body, said device comprising an oscillating frame mounted on said main pendulum, a revolving disk, bearings in said frame for said revolving disk, an auxiliary pendulum, damping arrangement for said auxiliary pendulum, and means establishing positive connection between said auxiliary pendulum and said frame, said auxiliary pendulum having a length so determined that the period of its free vibration is essentially the same as that of the oscillation of said body from which the main pendulum is suspended.

3. A device for maintaining the equilibrium of a main pendulum, said device having a universal bearing for said main pendulum, two revolving disk systems independent of each other and each comprising a pair of oscillating frames and a pair of revolving disks mounted to rotate in said frames; said revolving disk systems adapted to influence said main pendulum and to generate moments, the vectors of which fall approximately in the direction of the axes of said universal bearing.

4. A device for maintaining the equilibrium of a pendulum suspended from an oscillating body, said device having a universal bearing for said pendulum, two revolving disk systems independent of each other and each comprising an oscillating

frame mounted on said pendulum and a revolving disk mounted to rotate in said frame; said revolving disk systems being adapted to influence said pendulum and to generate moments, the vectors of which essentially fall in the directions of the axes of said universal bearing, and means for automatically imparting to said frames an oscillating movement in synchronism with the oscillation of said body from which the pendulum is suspended.

5. A device for maintaining the equilibrium of a main pendulum suspended from an oscillating body, said device having a universal bearing for said main pendulum, two revolving disk systems independent of each other and each comprising an oscillating frame mounted on said main pendulum and a revolving disk mounted to rotate in said frame; said revolving disk systems being adapted to influence said main pendulum and to generate moments, the vectors of which essentially fall in the directions of the axes of said universal bearing, two auxiliary pendulums mounted on the main pendulum, the axes of said auxiliary pendulums respectively being parallel with the axes of said universal bearing when said oscillating body is in its middle position, and damping arrangements for said auxiliary pendulums, the length of the auxiliary pendulums being so determined that the period of their free vibration is essentially the same as that of the oscillation of said body from which the main pendulum is suspended.

6. A device for maintaining the equilibrium of a main pendulum suspended from an oscillating body, said device comprising an oscillating frame mounted on said main pendulum, a revolving disk, bearings in said frame for said revolving disk, an auxiliary pendulum, damping arrangement for said auxiliary pendulum, means establishing positive connection between said auxiliary pendulum and said frame, said auxiliary pendulum having a length so determined that the period of its free vibration is essentially the same as that of the oscillation of said body from which the main pendulum is suspended, an inductor actuated by means of the movement of said auxiliary pendulum to generate an electromotoric force being proportionate to the angular velocity of the

auxiliary pendulum, another inductor actuated by means of the movement of the main pendulum relative to its bearing to generate an electromotoric force, proportionate to the angular velocity of said movement, and an electric circuit connecting said inductors.

7. A device for maintaining the equilibrium of a main pendulum suspended from an oscillating body, said device having a universal bearing for said main pendulum, two revolving disk systems independent of each other and each comprising an oscillating frame mounted on said pendulum and a revolving disk mounted to rotate in said frame; said revolving disk systems being adapted to influence said main pendulum and to generate moments, the vectors of which essentially fall in the directions of the axes of said universal bearing, two auxiliary pendulums mounted on the main pendulum, the axes of said auxiliary pendulums respectively being parallel with the axes of said universal bearing when said oscillating body is in its middle position, the length of the auxiliary pendulums being so determined that the period of their free vibrations is essentially the same as that of the oscillation of said body from which the main pendulum is suspended, two pairs of inductors, each pair comprising an inductor, actuated by means of the movement of one of said auxiliary pendulums to generate an electromotoric force proportionate to the angular velocity of the auxiliary pendulum appertaining thereto and a second inductor actuated by means of the relative turning of the main pendulum around that axis of said universal bearing which is parallel with the axis of the auxiliary pendulum actuating said first-named inductor to generate an electromotoric force, proportionate to the angular velocity of said relative turning, and electric circuits connecting the inductors of each pair of inductors.

The foregoing specification signed at Bremen, Germany, this 12th day of February, 1912.

WILHELM LUYKEN. [L. S.]

In presence of—

HELEN NUFER,

ALBERT F. NUFER.