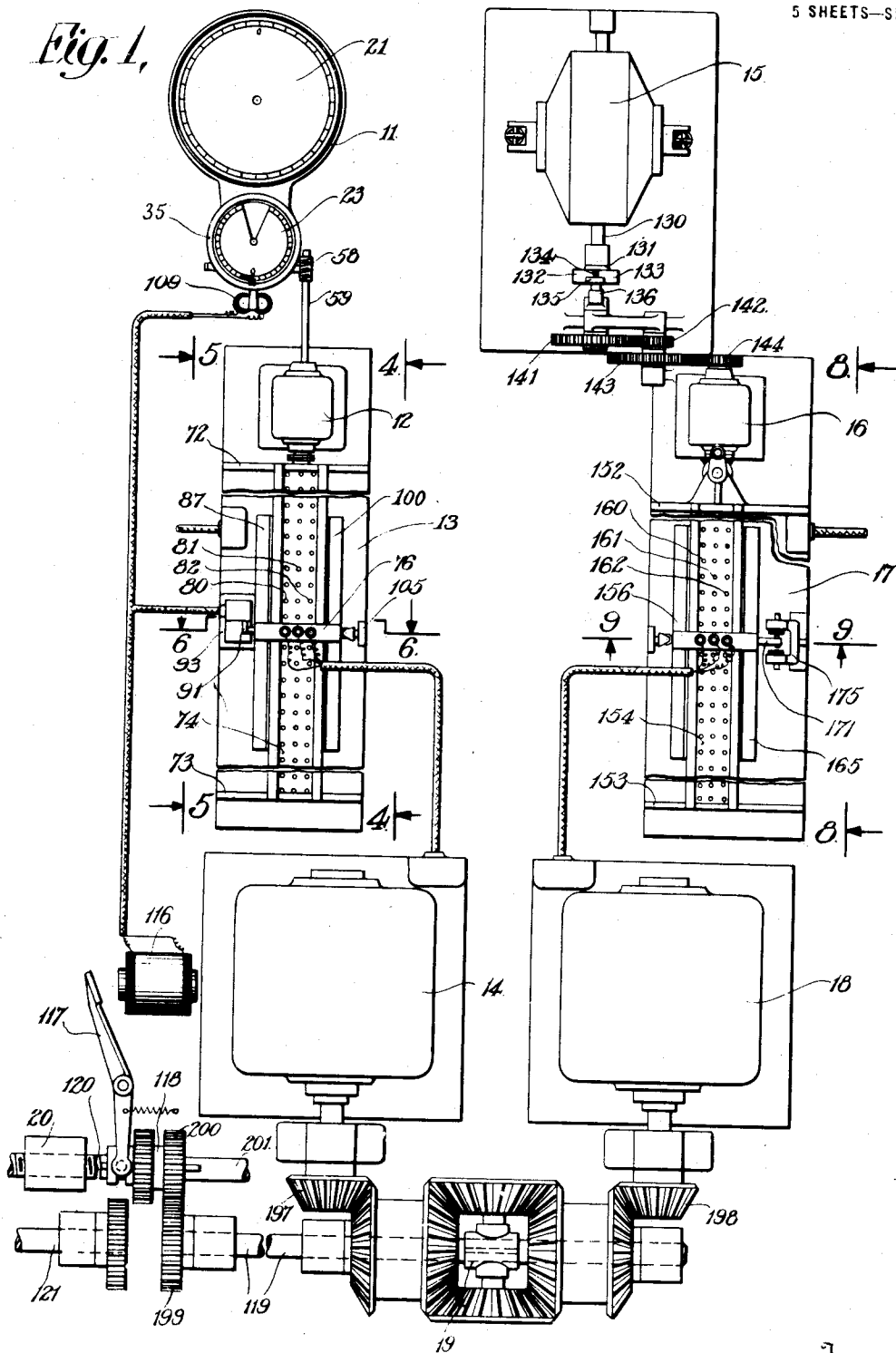


1,436,280.

Patented Nov. 21, 1922.

5 SHEETS—SHEET 1.

Fig. 1.



Inventor
 Nicolai Minorsky
 By his Attorney
 H. W. Plucker

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AUTOMATIC STEERING DEVICE.
APPLICATION FILED NOV. 2, 1918.

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Patented Nov. 21, 1922.

5 SHEETS--SHEET 2.

Fig. 2.

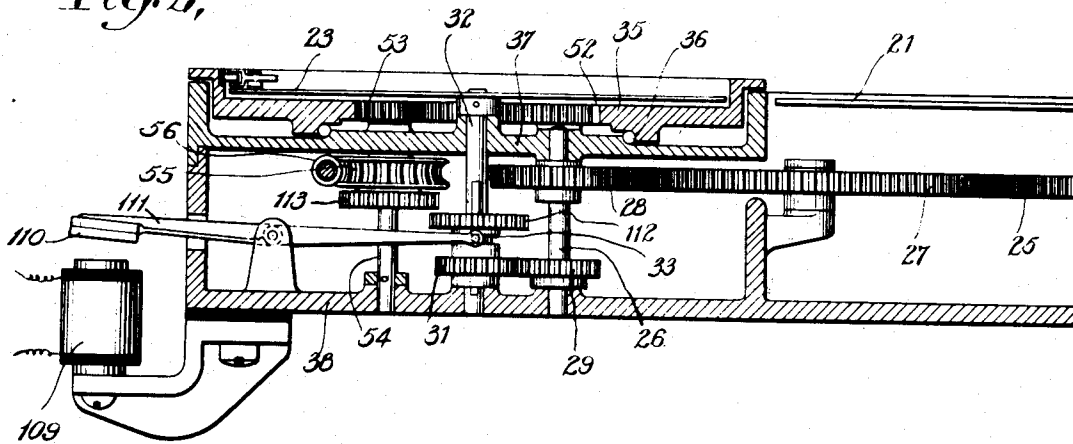
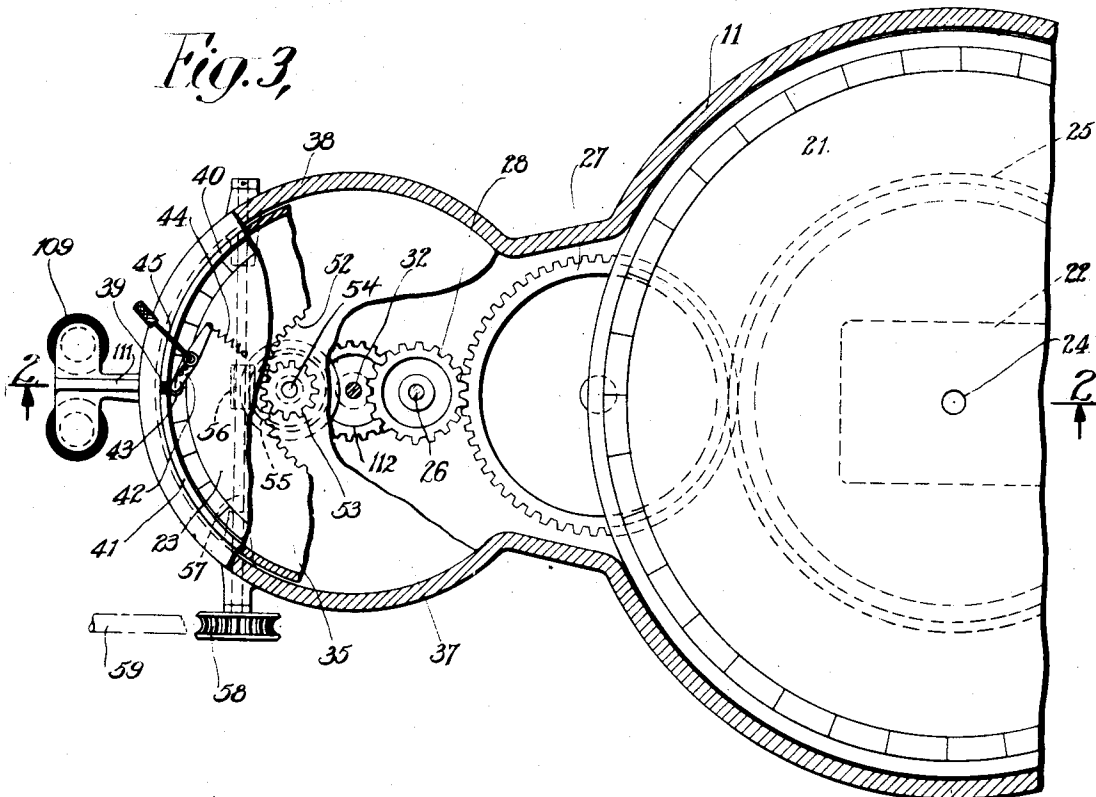


Fig. 3.



Inventor
Nicolai Minorsky

By his Attorney

H. W. Plucker

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5 SHEETS-SHEET 3.

Fig. 4.

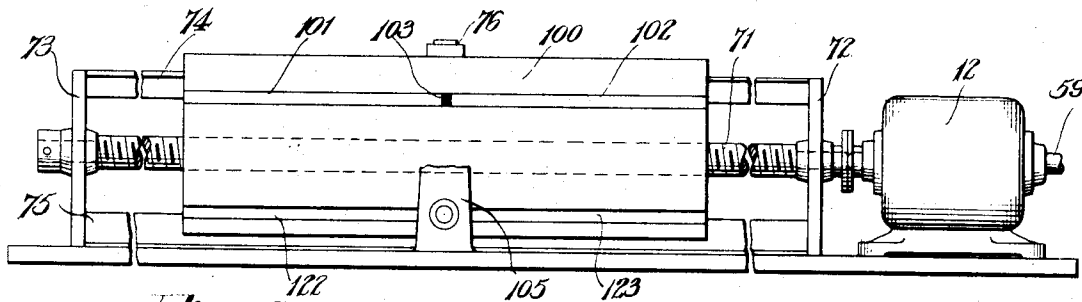


Fig. 5.

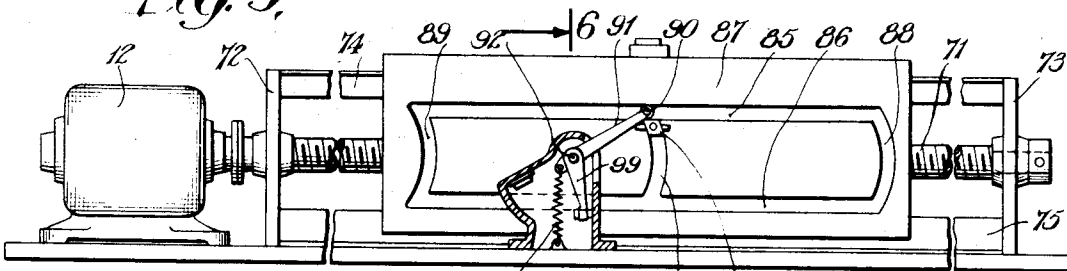


Fig. 6.

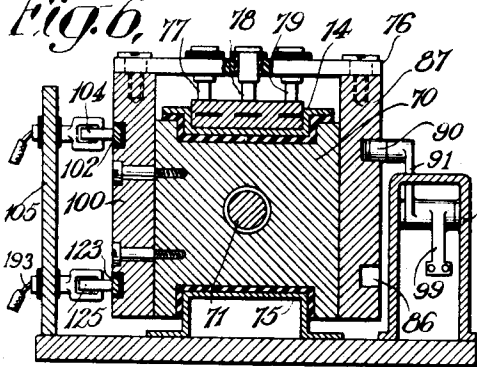


Fig. 9.

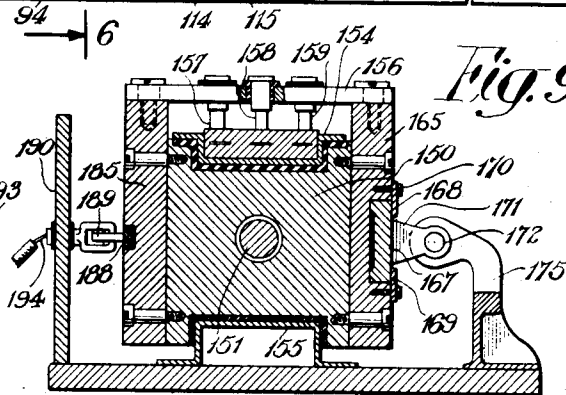
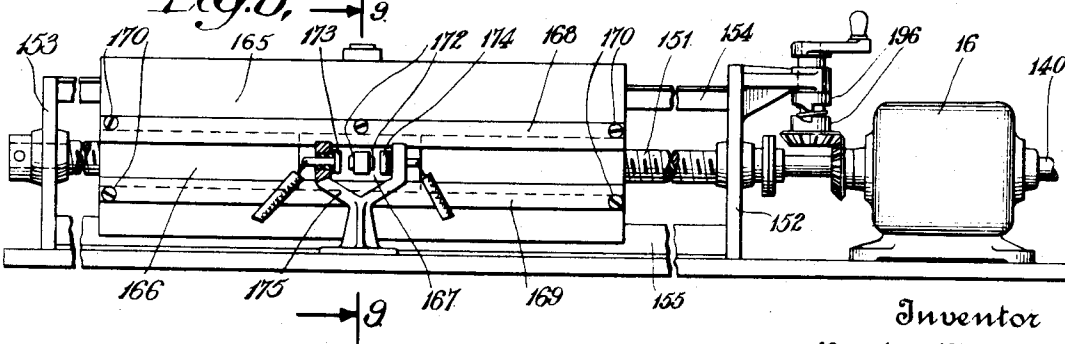


Fig. 8.



Inventor

Nicolai Minorsky

By his Attorney

H. W. Plucker

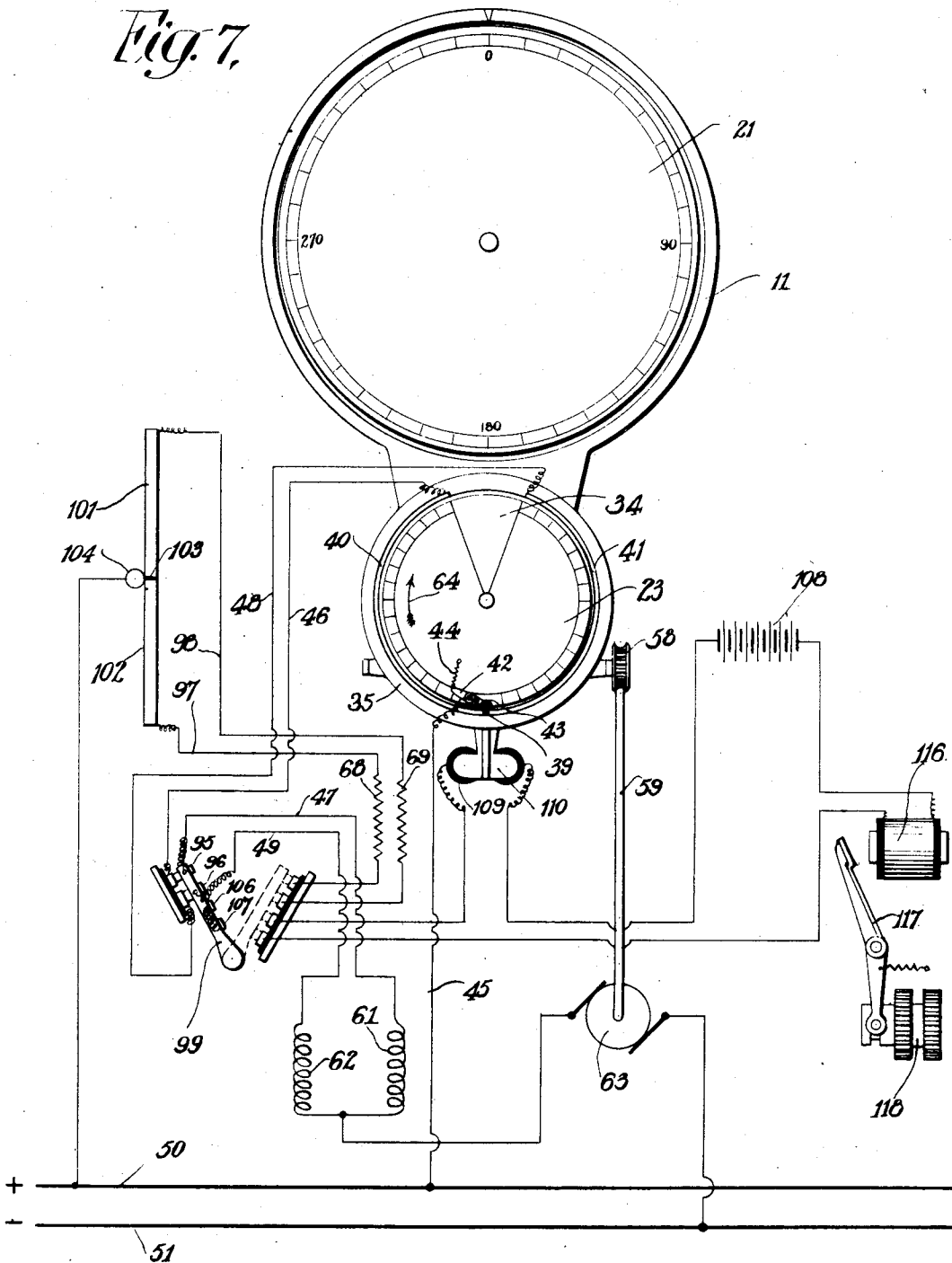
N. MINORSKY.
AUTOMATIC STEERING DEVICE.
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1,436,280.

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5 SHEETS—SHEET 4.

Fig. 7.



By his Attorney

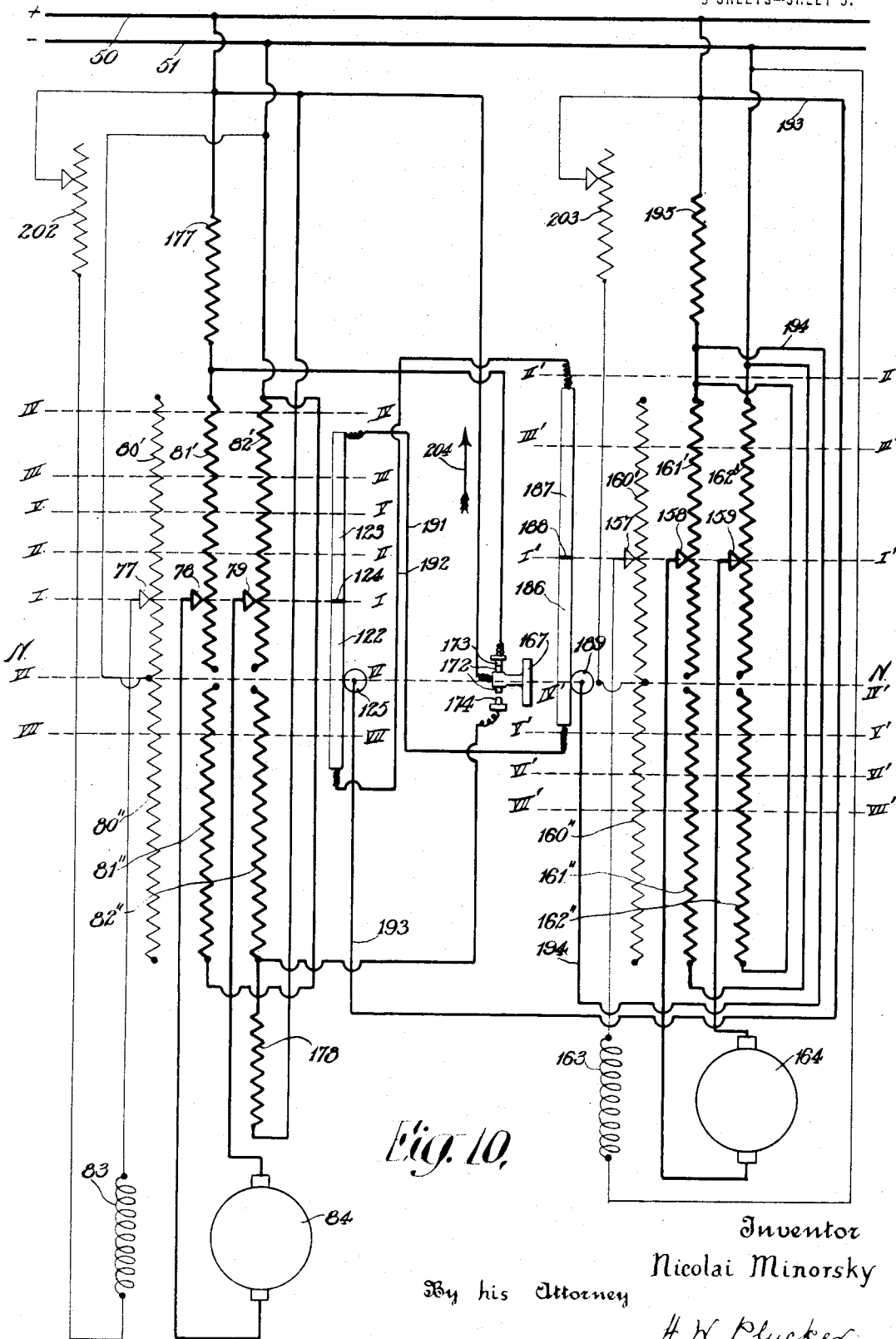
Inventor
Nicolai Minorsky

H. W. Plucker

1,436,280.

Patented Nov. 21, 1922.

5 SHEETS—SHEET 5.



Inventor
 Nicolai Minorsky
 By his Attorney
 H. W. Plucker

UNITED STATES PATENT OFFICE.

NICOLAI MINORSKY, OF NEW YORK, N. Y.

AUTOMATIC STEERING DEVICE.

Application filed November 2, 1918. Serial No. 280,866.

To all whom it may concern:

Be it known that I, NICOLAI MINORSKY, a citizen of Russia, residing at New York, New York, U. S. A., have invented certain new and useful Improvements in Automatic Steering Devices, of which the following is a specification.

This invention relates to automatic steering devices and is more particularly adapted for use on large vessels.

It is well known that in steering large vessels the ship does not answer instantaneously to her rudder and that a certain interval of time usually elapses before the ship assumes the requisite angular motion. The reason why this is so can be readily understood if the enormous inertia of a large modern ship is considered as well as the change in the distribution of pressure on different parts of the ship before the torque which is thus created increases to a considerable extent the original action of the helm.

On the other hand, if, owing to some sudden unexpected reason such as the action of wind, waves, etc., the ship deviates from her original course—such deviation cannot instantly be stopped. Again, in trying to “meet her” care must be taken to time the action of the rudder to comply with prevailing circumstances, as otherwise the yawing or angular deviation may assume a permanent character and cause a decrease in speed and an increase in the consumption of fuel, while also in the case of a battleship interfering seriously with the accuracy of her gunfire.

The value of a good helmsman depends greatly on his ability “to ease and to meet her” properly, before the desired direction or angular velocity is reached, and the objections which have heretofore been raised against attempts to introduce into practice any automatic steering device for ships have chiefly arisen owing to the apparent inability to perceive how it would be possible to produce any mechanical or electrical device, sufficiently perfect to replace that species of intuition which enables an efficient helmsman to check the vessel with the helm at the right moment. An objection of this nature however, is only a parallel instance to that which arose in the early days of steam engines, when the necessity of employing a

boy to time the admission of steam to the engine seemed incapable of being avoided by any form of mechanical contrivance.

It will be clear, however, that the angular motion of a ship round the vertical axis (her yawing) can be determined if at any moment three fundamental elements are known, viz.—

1. Angle of deviation from the true course (γ);

2. Angular velocity of the ship ($\dot{\gamma}$);

3. Angular acceleration of the ship ($\ddot{\gamma}$).

The first element, which is of a purely geometrical nature is indicated to the helmsman by the compass and, though very important, has directly very little to do with the yawing.

The second and third are both dynamical characteristics of the motion and are therefore of very considerable importance. The second, i. e., her angular velocity, can be appreciated to a certain extent by the helmsman under special conditions, viz.:—absence of mist and smoke, by observing the rate of change of a bearing. The third, i. e., the angular acceleration, though a very important dynamical quantity and showing clearly the play of the different torques on the ship at any particular moment, entirely escapes the helmsman's notice. The rather vague expression (“tendency to yaw”) which is sometimes employed is simply the angular acceleration of the ship and as stated is an extremely important dynamical factor, hence the necessity of obviating the helmsman's entire lack of due appreciation of the angular acceleration and the species of intuitive guess-work which he exercises in timing the action of the helm.

It is the object of this invention to provide a device for controlling automatically the action of a rudder whereby a more refined and accurate mode of steering is obtained than can be effected by a helmsman. With this object in view the principal feature of the invention consists in providing a steering device responsive to both the positional and dynamical elements of the angular motion of the ship or body to be steered. This steering device, usually a rudder, is so controlled that its rates of movement through the water as well as its

positions of rest are determined in such a way as to keep the body to be steered, on her course under all conditions, or to return her to the course after yawing, without oscillations about the course.

Another object is to make it possible to control with facility the conditions of relative movement of elements in a system, whereby any tendency for the conditions to oscillate about the predetermined desired condition of equilibrium is quickly overcome. In the present instance the system is exemplified by the movement of a ship relatively to the surface of the earth, and the desired condition of movement is that the ship stay on a course which has been laid out for her upon the earth's surface.

To this end the device comprises two main factors, viz: an instrument responsive to changes in the direction of motion of the ship, such as a compass, and an instrument responsive to variations in the angular velocity with which such changes take place, such as a gyrometer, (i. e. an instrument of the kind referred to in Letters Patent No. 1,306,552, dated June 10, 1919, and in my co-pending patent application Ser. No. 268,283, filed December 26, 1918), the respective actions of both instruments being combined by suitable means which are utilized to control the action of the rudder, the resultant effect of the device on the rudder being determined by the extent to which the influence of the compass or that of the gyrometer enters into the action.

The two controlling instruments may be arranged to act on the supply of current to a single electric motor having a very slightly saturated magnetic circuit so as to permit the combination of the controlling actions without any appreciable error. It is found preferable, however, to adapt the compass and gyrometer to control separate electric motors, which may be of any suitable type, and to combine the movements of such motors by means of a differential gear which in turn drives a member the movements of which may be transmitted to the rudder through any suitable mechanical or electrical connections.

In order to develop sufficient power for the purpose in view the compass should be one in which the directive force is created artificially, e. g. by means of a small repeater or follow up motor. This motor or a similar one connected with a second compass adapted to magnify the deviations indicated by the first compass, is utilized to operate a mechanism for controlling the operation of the motor that will influence the differential gear in accordance with the deviations of the ship, which motor will be referred to hereinafter as the compass motor. The structure of the controlling mechanism will of course depend upon the type of motor

employed: thus, for example, if the compass motor is of the repulsion type, the controlling mechanism will be adapted to vary its speed in magnitude and direction by displacing the brushes on the commutator in either direction; if a D. C. motor is employed the controlling mechanism will be adapted to insert resistances in series with the armature and, if desired, the field coils thereof.

The gyrometer is also provided with a repeater or follow up motor. The movements of the latter are proportional to the angular velocity of yawing, and it may be connected with means similar to those used in controlling the compass motor, in order to control the motor which is to influence the differential gear in accordance with variations in the angular velocity, which motor henceforth will be termed the gyrometer motor. The gyrometer also controls means responsive to changes in the sign of the angular acceleration with a view to effecting a further regulation of the speed of the motors whenever the acceleration varies from a positive to a negative value and vice versa.

The action of the compass is to define the course of the ship, the compass motor tending to operate the rudder so as to maintain the ship on the right course; the compass control thus exerts an action similar to that of the Obry gyroscope control in the Whitehead torpedo. Owing to the considerable inertia of the ship this compass control, however, would not be sufficient to check the yawing of the ship, as the action of the rudder would always be felt too late and the ship would consequently follow a zigzag course intersecting the true course before each deviation was checked. The function of the gyrometer, therefore, will be to correct the action of the compass by introducing the dynamical factors of velocity and acceleration, thereby properly timing the action of the helm and permitting a dead course being steered between very fine limits.

Under these conditions any permanent deviation of the ship from her true course would indicate that the ship has ceased to respond to her helm. To meet this contingency means are preferably provided for stopping the normal operation of the automatic steering device when the deviation to either side exceeds a predetermined angle.

In the accompanying drawings, which illustrate, by way of example, an embodiment of this invention:

Figure 1 is a plan view of the entire steering device;

Figure 2 is a partial sectional elevation of the compass taken on line 2-2 of Figure 3;

Figure 3 is a plan view, partly in section, of the compass at a larger scale;

Figures 4 and 5 are elevations viewed

from opposite sides of the mechanism controlling the operation of the compass motor, and Figure 6 is a cross-sectional view thereof taken on line 6—6 of Figures 1 and 5;

5 Figure 7 is a wiring diagram showing the electrical connections between the parts of the device illustrated in Figures 2 to 6, the compass being shown in plan view;

10 Figure 8 is a side elevation of the mechanism controlling the operation of the gyrometer motor, and Figure 9 is a cross-sectional view taken on line 9—9 of Figure 8; and

15 Figure 10 is a wiring diagram illustrating the connections between the compass and gyrometer motors and their respective controlling mechanisms.

Referring to Figure 1, the embodiment of the invention illustrated herein comprises 20 three main parts, one including the compass 11, its follow up motor 12, the controlling mechanism 13 and the compass motor 14, the second including the gyrometer 15, its follow up motor 16, the controlling mechanism 25 17 and the gyrometer motor 18, and the third part including the differential gear 19 which combines the movements of the motors 14 and 18 and transmits them to a member 20 which may be connected to the helm in any 30 preferred or well known manner, such connections not forming part of the present invention.

Both the compass and the gyrometer may be of any suitable construction or type. 35 They are shown conventionally in the accompanying drawings with only such details as will be necessary to the proper understanding of their mode of co-operation, which forms the subject-matter of this invention. The motors 14 and 18 are shown 40 to be D. C. motors but it will be apparent from the following detailed description of the automatic steering device that the controlling mechanisms could be adapted, with 45 comparatively simple constructional changes, to regulate the speed of A. C. motors of any desired type.

The first part of the device is more particularly illustrated in Figures 2 to 7. The 50 compass 11 may be a master compass or, as shown in the drawings, a repeater compass the card 21 of which is operated in synchronism with that of the master compass (not shown) by means of a small electric motor 22 in the usual manner. For convenience 55 the motor 12 is not arranged to follow directly the movements of the compass card 21, but it follows the movements of an auxiliary or operating card 23 which magnifies the deviations registered by the card 21. To 60 this end the shaft 24 of the motor 22 carries a gear 25 adapted to drive a small shaft 26 (Figs. 2 and 3) through the intermediary of gears 27 and 28. On the shaft 26 is mounted 65 a gear 29 normally in mesh with a similar

gear 31, which is keyed on the shaft 32 supporting the operating card 23, and is adapted to slide axially thereon upon operation of a clutch 33 of which the gear 31 is a part. By suitably proportioning the gears above 70 referred to the deviations of the compass card 21 will be magnified to the desired extent by the operating card 23. The latter may be provided with graduations symmetrically arranged on both sides of its zero 75 (0) mark and it has an idle sector 34, the extent of the graduated portions comprised between the zero mark and the sides of said sector corresponding to the maximum deviation permissible on either side of the line 80 defining the course to be followed by the ship.

To control the movements of the follow up motor 12 I may use any of the arrangements usually employed for similar purposes. I have illustrated by way of example 85 a system of connections in which the motor is provided with two oppositely wound field coils, and a member such as a trolley wheel mounted on the operating card, is adapted 90 to close an electric circuit when said card is rotated to either side of its normal or neutral position, thereby allowing current to pass through the armature and one of the field coils of the follow up motor. Surrounding the operating card 23 and coaxial 95 therewith is a follow up ring 35 mounted on a ball race 36 carried by a partition 37 in the compass box 38 (Fig. 2). Opposite the zero mark of the card the ring 35 carries 100 on its inner face a narrow piece of insulating material 39 on both sides of which are arranged arc-shaped conducting strips 40 and 41, which are insulated from the body of the ring and extend up to points substantially in alignment with the sides of the idle sector 34 (Fig. 7). On the card 23 is pivoted a small lever 42 provided at one end 105 with a trolley wheel 43 which is kept in engagement with the inner face of the ring 35 by a spring 44. A wire 45 attached to the pivot of lever 42 connects the trolley wheel 43 to one 50, of a pair of bus bars 50 and 51 fed by a suitable source of current, and 115 wires 46, 47 and 48, 49 connect the extremities of the strips 40 and 41 respectively to the oppositely wound field coils 61 and 62 of the follow up motor 12, both of which are in series with the armature 63 of said motor and connected therethrough to the bus 120 bar 51. The ring 35 is also provided with an internal gear 52 in mesh with a small gear 53 (Figs. 2 and 3) mounted on a vertical shaft 54 which carries a helical wheel 55 engaged by a worm 56 on a shaft 57 extending across the box 38. Upon the shaft 125 57 is mounted a helical wheel 58 engaged by a worm on the shaft 59 of the motor 12.

Figs. 3 and 7 show the various parts of the follow up system at rest, the trolley 130

wheel 43 bearing against the insulating strip 39, which is the position corresponding to the ship being exactly on her course. When, in the normal operation of the apparatus, the card 23 is rotated, say, in the direction of the arrow 64 (Fig. 7) as the result of a deviation of the ship from the predetermined course, the trolley wheel 43 engages the strip 40 and closes a circuit passing from bar 50 through wire 45, lever 42, wheel 43, strip 40, wires 46 and 47, field coil 61 and armature 63 to bar 51, thereby driving the motor shaft 59 and rotating the ring 35 through the gears 58, 56, 55 and 53, until the insulating piece 39 is again engaged by the trolley wheel. Should the card 23 be rotated in the opposite direction, the trolley wheel would close a circuit including strip 41, wires 48 and 49 and field coil 62, and the shaft 59 and ring 35 would again be rotated in the same direction as the card. The action of the motor 12 is practically instantaneous and, for all practical purposes, the shaft 59 and ring 35 move in synchronism with the card 23.

The controlling mechanism 13 (Figs. 1 and 4 to 6) comprises a movable block 70 in threaded engagement with a screw 71 mounted in standards 72 and 73 and driven by the shaft 59 of the follow up motor 12. The block 70 is mounted for sliding movement between a pair of longitudinal guides 74, 75, extending between the standards 72 and 73. Centrally of the block 70 and suitably secured thereto is a transverse bridge piece 76 provided with a series of brushes, three such brushes being herein shown and designated by 77, 78 and 79 respectively. The screw 71 being operatively connected with the shaft 59, to every deviation of the ship from her course will correspond a certain linear displacement of the block 70 from its central or neutral position, which corresponds to the position of card 23 illustrated in Figs. 3 and 7. As the block 70 is moved to either side of its neutral position these brushes are adapted to co-operate with series of stationary contacts 80, 81 and 82 (Fig. 1) respectively connected to three sets of resistances 80'-80'', 81'-81'' and 82'-82'' (Fig. 10) carried by the upper guide 74. These resistances are inserted in electric circuits including the field and armature windings 83 and 84 respectively, of the compass motor 14, the arrangement being such that said motor will be rotated with a gradually increasing speed as the block 70 moves away from its neutral position and vice versa, as will be more fully understood from the description of the operation of the entire device given below with reference to Fig. 10 of the drawings.

As stated above the operating card 23 is intended to register only deviations within predetermined limits corresponding to the

maximum deviation permissible on either side of the true course. When for any reason the ship ceases to respond to her helm and the deviation to one side exceeds the predetermined maximum, it is desirable to disconnect the automatic device from the helm controlling member 20 and return the various parts to their neutral positions. This may be effected automatically by means of the following arrangement. On one side of the block 70 (Figs. 5 and 6) are provided parallel grooves 85 and 86, which may be formed in a plate 87 secured to the block 70. At distances from the middle of these grooves 85 and 86 corresponding to the maximum admissible deviation they are connected with one another by parallel arc-shaped grooves 88 and 89. A roller 90 mounted on an arm 91 carried by a rock shaft 92 supported in fixed standards 93, normally engages the upper groove 85 and rolls to and fro in said groove as the block 70 reciprocates. A spring 94 shown to be normally under compression tends to push the arm 91 downwardly, so that when the roller 90 reaches either end of the groove 85 it will ride down the groove 88 or 89 and rest in the groove 86. At the same time the arm 91 operates a switch controlling the supply of current to the motor 12 in such a manner as to reverse its direction of rotation and cause the motor to return the block 70 and operating card 23 to their neutral positions.

To this end the arm 91 is operatively connected with an arm 99 (Figs. 5 and 7) carrying two contacts 95 and 96 which are insulated from one another and connect the wires 47 and 49 with the wires 46 and 48 respectively as long as the roller 90 engages the groove 85 and the arm 99 remains in the normal position shown in full lines in Fig. 7. When the roller 90 drops in the groove 88 or 89 the arm 99 is moved to the dotted line position and, by means of the contacts 95 and 96, connects the wires 47 and 49 with wires 97 and 98 respectively, which are connected to one of the bus bars 50, 51, in the following manner. On the side of the block 70 opposite the plate 87, I have provided another plate 100 (Figs. 4 and 6) which carries a pair of conducting strips 101 and 102 in alignment with one another and separated by a narrow piece of insulating material 103. A roller 104 carried by a fixed standard 105 engages the insulating piece 103 and rides over the strips 101 and 102 as the block 70 moves to and fro. The roller 104 is connected to bar 50 (Fig. 7) while the strips 101 and 102 are respectively connected to the wires 98 and 97. Assuming a deviation of the ship has carried the trolley wheel 39 beyond the end of the strip 40, the roller 104 being then near the outer end of the strip 101, the roller 90 will ride down

the groove 88 and the arm 99 be thrown to its dotted line position (Fig. 7) thereby allowing current to pass through roller 104, strip 101, wires 98 and 49, coil 62 and armature 63, and the motor 12 will return the block 70 to its normal position. The speed of the motor 12 during this movement may be regulated by means of resistances 68, 69 inserted in the wires 97 and 98 respectively.

The arm 99 also carries another pair of contacts 106 and 107 which are connected with one another and become operative, when the arm 99 is in the dotted line position, to close a local circuit fed by a suitable source of current 108 and containing an electro-magnet 109. The armature 110 of this electro-magnet is carried by a lever 111 (Fig. 2) adapted to operate the clutch 33 when the magnet is energized, thereby disconnecting the gears 29 and 31 and causing a gear 112 to engage a small gear 113 secured to the shaft 54. The operating card 23 is thereby disconnected from the compass card 21 and connected with the shaft 59 of the follow up motor 12, which returns it to its normal position together with the ring 35.

To restore the arm 91 and its attached parts to normal position there is provided in the plate 87 a third arc-shaped groove 114 (Fig. 5) which is normally closed at its upper end by a removable filling piece 115. The removal and subsequent insertion of piece 115 and the upward movement of the arm 91 are, of course, effected manually.

To disconnect the automatic device 19 from the controlling member 20 when the lever 99 is in the dotted line position, I have provided an electro-magnet 116 (Figs. 1 and 7) which may be inserted in the circuit controlled by the contacts 106, 107. The armature of this electro-magnet 116 is carried by a spring controlled lever 117 adapted to operate a clutch 118 which normally connects the differential shaft 119 with a screw 120 on which the block 20 is shown to be slidably mounted (Fig. 1). Upon energization of the magnet 116 the clutch 118 is operated to disconnect the screw 120 from the shaft 119 and couple it to a shaft 121 which may be connected in any suitable way with hand controlled device (not shown).

In addition to the strips 101 and 102 there is arranged on the plate 100 (Fig. 4) a pair of similar conducting strips 122, 123, separated by a small piece of insulating material 124 (Fig. 10) and engaged by a roller 125 carried by the standard 105 (Fig. 6). These strips 122 and 123 are electrically connected with similar elements in the gyrometer system and their function is to control the insertion of resistances in the circuit of the gyrometer motor 18, for a purpose which will be apparent from the further description of the device.

The second part of the device will now be

described with particular reference to Figs. 1, 8 and 9. It comprises a gyrometer such as 15, which controls the movements of the follow up motor 16 in a manner very similar to that in which the operating card 23 controls the movements of the motor 12. As shown in Fig. 1, the shaft 130, which is connected to the frame of the gyroscope forming part of the gyrometer, carries a disc 131 having on its periphery two conducting strips 132 and 133 separated by a narrow insulating piece 134. On the periphery of the disc 131 rides a small trolley wheel 135 carried by a crank 136 mounted on a shaft in alignment with the shaft 130. The shaft carrying the crank 136 is operatively connected with the armature shaft 140 of the motor 16 by means of suitable gears 141, 142, 143, 144. Electrical connections similar to those existing between the strips 40 and 41 and the field and armature windings of the motor 12 are provided between the strips 132 and 133 and the field and armature windings of the motor 16. The arrangement and operation of these connections being similar to those previously described in connection with the compass follow up system the same need not be described in detail and it will be understood that the wheel 135 and crank 136 will automatically follow the movements of the shaft 130 just as the ring 35 follows the movements of the card 23, and that the movements of the shaft 130 will be suitably amplified by the armature shaft 140.

The controlling mechanism 17 operated by the follow up motor 16 comprises a sliding block 150 which, in plan view, is practically identical with the block 70, the block 150 being actuated by a screw 151 driven by the shaft 140 and supported by standards 152 and 153. Longitudinal guides 154 and 155, similar to the guides 74 and 75 respectively, engage the block 150, and a bridge piece 156 arranged centrally of and secured to the block 150, has a set of brushes 157, 158 and 159 adapted to co-operate with sets of contacts 160, 161, and 162 connected with resistances 160'—160'', 161'—161'' and 162'—162'' (Fig. 10) carried by the guide 154. These resistances are inserted in circuits including the field and armature windings 163 and 164 of the gyrometer motor 18, and serve to regulate the speed of this motor in accordance with variations in the angular velocity of yawing, such variations being recorded by the shaft 130 of the gyrometer and instantaneously transmitted to the shaft 140 and the block 150.

In order to introduce the factor acceleration among those controlling the operation of the compass motor 14, which is desirable with a view to accentuating the "easing" action of the device, I provide on one side of the block 150 a plate 165 (Figs. 8 and 9) having formed therein a longitudinal groove

166 in which a small block 167 is slidably mounted. A pair of adjustable spring plates 168, 169 are adapted to press the block 167 against the bottom of the groove 166, screws 170 being provided for varying the pressure exerted on the block 167 by the plates 168, 169. The block 167 is formed with a lateral projection 171 carrying a contact 172 adapted alternately to engage two symmetrically arranged stationary contacts 173 and 174 adjustably mounted on a forked support 175 located opposite the middle line 9—9, (Fig. 8), of the block 150. The contacts 173 and 174 are very close to one another and they serve as abutments limiting the movements of the block 167 on both sides of its inoperative position shown in Fig. 8. Owing to its frictional engagement with the plates 165, 168 and 169, the small block 167 follows the movements of the block 150 until the contact 172 strikes against one of the stationary contacts, the block 167 then remaining stationary while the block 150 continues its movement, until the direction of motion of the latter is reversed, the block 167 then again partaking in the movement of the block 150 until the contact 172 strikes against the other stationary contact. As every reversal in the direction of motion of the block 150 corresponds to a change in the sign of the acceleration from positive to negative or vice versa, such change will result in the making and breaking of electric circuits, which action is utilized to control the insertion of resistances 177 and 178 in the circuit comprising the armature 84 of the compass motor (Fig. 10), as will be more fully explained hereafter.

On the side of the block 150 remote from the standard 175 there is provided a plate 185 (Fig. 9) which is similar to the plate 100 of the block 70, differing therefrom merely in that it carries only one set of conducting strips 186 and 187 (Fig. 10). These strips are separated by a small insulating piece 188 and adapted to be engaged by a roller 189 (Figs. 9 and 10) carried by a standard 190 located in the vertical plane passing through the line 9—9, (Fig. 8). Cross connections 191, 192, (Fig. 10) are provided between the strips 186, 187 and the strips 123, 122 respectively, while the rollers 125 and 189 are respectively connected by wires 193 and 194 with the ends of a resistance 195 in series with the armature 164 of the gyrometer motor 18. The arrangement is such that the resistance 195 is automatically shunted at predetermined times by the above connections, thereby enabling the gyrometer motor to exert a strong "easing" action on the helm at the proper moments.

No automatic disconnecting means need be associated with the controlling mechanism 17 since the angular velocity cannot increase

indefinitely. If for any reason, such as the failure of the follow up system to operate properly, the trolley wheel 135 should ride off the strip 132 or 133, the motor 16 will stop and the controlling mechanism 17 may then be restored to operative position by means of a manual clutch 196 (Fig. 8).

The third part of the automatic device illustrated in the drawings comprises the differential gear 19 which combines and transmits to the shaft 119 the movement imparted thereto by the pinions 197 and 198 driven by the motors 14 and 18 respectively (Fig. 1). Through gears 199, 200 the shaft 119 normally drives a shaft 201 carrying the screw 120 on which the helm controlling member 20 is mounted to slide. As will be obvious to those skilled in the art the member 20 may be adapted to control a steam or hydraulic valve in the case of steam or hydraulic steering gear, or it may control the supply of current to a motor adapted to build up proper voltage in the steering plant generator if the action of the rudder is controlled electrically.

The action of the automatic steering device is as follows:—

Assuming that in the first instance the ship is on her right course, without any tendency to yaw to either side i. e. analytically;

$$\gamma \text{ (angle of deviation)} = \odot;$$

$$\dot{\gamma} \text{ (angular velocity)} = \odot;$$

$$\ddot{\gamma} \text{ (angular acceleration)} = \odot.$$

To mark the difference between deviations from her true course to port and to starboard, the first will be regarded as positive ($\gamma > \odot$) and the second as negative ($\gamma < \odot$). Angular velocity increasing the positive and decreasing the negative deviation, will be treated as positive angular velocity ($\dot{\gamma} > \odot$) and will represent an angular velocity from right to left. The opposite angular velocity (from left to right) will be counted as negative ($\dot{\gamma} < \odot$). In the same way angular acceleration will be treated as positive when directed from right to left.

Referring to Fig. 10 the line N-N indicates the position of the brushes 77, 78, 79 of the block 70 and 157, 158, 159 of the block 150 when the deviation, the angular velocity and the angular acceleration are zero. Current, which may be initially regulated by adjustable resistances 202 and 203, is supplied to the field windings 83, 163, of the motors 14 and 18, respectively, while the brushes 78, 79 and 158, 159 controlling the supply of current to the armatures 84 and 164 of the motors 14 and 18, respectively, are disconnected from the bars 50, 51, all the parts of the steering device being at rest with the helm amidships.

Assuming that the ship receives an impulse (from a wave for instance) diverting

her in the positive direction. Initially the conditions are:

$$(1) \gamma > 0; \gamma' > 0; \gamma'' > 0.$$

Deviation to port is started with ever increasing velocity and the compass and gyrometer operate the mechanisms 13 and 17, respectively, to switch on the motors 14 and 18 through the resistances 81', 82' and 161', 162' respectively. The operative position of the parts at this moment is illustrated in Fig. 10, the brushes 77, 78, 79 and 157, 158, 159 being on the lines I—I, I'—I' respectively. The blocks 70 and 150 both move in the direction of the arrow 204, and the small block 167 partakes in the movement of block 150 until contact 172 engages contact 173, thereby shunting the resistance 177 connected in series with the armature 84 of the compass motor, and enabling the latter to exert a strong "meeting" action. The resistance 195 in series with the armature 164 of the gyrometer motor is not shunted at this moment, but the gyrometer motor rotates in the same direction as the compass motor, both motors coaxing to move the rudder to port with considerable speed.

The action of the rudder will be felt by the fact that:

$$(2) \gamma > 0; \gamma' > 0; \gamma'' = 0.$$

When the angular acceleration becomes zero the brushes controlling the motors 14 and 18 are on the lines II—II, II'—II' respectively, the block 150 being then at the end of its course. The motors 14 and 18 rotate in the same direction as previously, but at a greater speed, since the operative portions of the resistances 81', 82' and 161', 162' have decreased while the operative portions of the resistances 80' and 160' increased. The "meeting" action of the device is very energetic.

From this moment on the sign of the angular acceleration is reversed, i. e. analytically:

$$(3) \gamma > 0; \gamma' > 0; \gamma'' < 0.$$

The respective positions of the brushes controlling the motors 14 and 18 are defined by the lines III—III, III'—III'. The gyrometer block 150 begins to move backwards, that is towards the line N—N, and acts on the resistances 160', 161', 162' to decrease the speed of the motor 18. The block 167 being free to move towards the line N—N, breaks the contact between 172 and 173, thereby inserting the resistance 177 in series with the armature 84 of the compass motor 14 and considerably reducing the speed of the same. The block 70, however, continues to move in the direction of the arrow 204. The helm is still moved in the same direction as before, though with much reduced speed.

As the action of the rudder continues to

increase there will be a moment when the angular velocity of the ship is completely checked and the kinetic energy of the ship is reduced to zero, i. e.:

$$(4) \gamma > 0; \gamma' = 0; \gamma'' < 0.$$

The brushes of the two sliding systems are now on the lines IV—IV, IV'—IV' respectively, the latter line coinciding with the central or neutral line N—N. The gyrometer motor 18 stops, its armature being disconnected from the current supply 50, 51, while the compass motor continues to run slowly in the same direction as previously. The "meeting" action still exists, but it is extremely weak.

Angular velocity to starboard now appears although the deviation still remains to port, analytically:

$$(5) \gamma > 0; \gamma' < 0; \gamma'' < 0.$$

The sliding system controlled by the gyrometer begins to move to the other side of the line N—N, the gyrometer motor being switched on in the opposite direction. The brushes are now on the lines V—V, V'—V', the brushes 157, 158, 159 co-operating with the resistances 160'', 161'' and 162'' respectively. The insulating pieces 124 and 188, which are in line with the brushes on their respective carrying blocks 70 and 150, are therefore on opposite sides of the line N—N passing through the rollers 125 and 189. As soon as the roller 189 is engaged by the strip 187, the resistance 195 is shunted by the connections 193, 122, 192, 187 and 194, and the gyrometer motor 18 is operated at full speed. The compass motor rotates slowly in the same direction as before, its movement gradually dying out. Thus the action of the two motors is differential, the action of the gyrometer motor being strongly predominant and steadily increasing as the action of the compass motor diminishes. This will bring the rudder quickly to its central position or even further, thus "easing her", as does a good helmsman when he sees that the action of the helm is felt by the ship. This "easing" action may be properly adjusted on the ship's trail trip by regulating the value of the resistance 195.

The ship being still under the influence of the "meeting" action exerted during the first four periods above referred to, is then brought back to her original course, i. e.:

$$(6) \gamma = 0; \gamma' < 0; \gamma'' < 0.$$

The brushes 77, 78, 79 are now again in their initial central position, which is indicated by the line VI—VI coinciding with N—N, and the compass motor 14 has stopped. The brushes controlling the operation of the gyrometer motor are on the line VI'—VI' and moving away from the

line N—N. The speed of the gyrometer motor is still increasing.

As the angular velocity continues in the same direction owing to inertia, the ship now goes beyond her true course, her angular kinetic energy being however considerably diminished as compared with the first period considered above. Analytically:

$$(7) \gamma < \odot; \gamma' < \odot; \gamma'' < \odot.$$

The compass motor 14 is switched on in the proper direction to meet the deviation to starboard now taking place, the brushes 77, 78 and 79 co-operating with the resistances 80'', 81'', 82'' respectively. As the contact 172 came into engagement with the stationary contact 174 shortly after the direction of movement of the gyrometer motor was reversed, the resistance 178 is shunted during this period and the motor 14 is started at full speed. The movement of the block 70 bringing the insulating piece 124 to the same side of the line N—N as the piece 188, the resistance 195 is again inserted in circuit with the armature of the gyrometer motor. The lines VII—VII, VII'—VII', indicate the positions of the brushes controlling the operation of the compass and gyrometer, both of which now act in the same direction to check energetically the motion to starboard. With regard to this motion to starboard the same phases of motion (only for deviation $\gamma < \odot$) will be reproduced in the same succession and so on, except that each successive swing will have smaller amplitude on account of the damping effect of the gyrometer.

Thus the compass and the gyrometer operate concurrently to impart the required motion to the helm, the speed of the member 20 being subjected to a gradual regulation by the control of the resistances 80'—80'', 81'—81'', 82'—82'', 160'—160'', 161'—161'', and 162'—162'', and, at predetermined times, to the additional sudden action of the connections controlling the resistances 177, 178 and 195.

The foregoing action will in reality take place in a very brief period of time and the rudder will be slightly moved round its central position. If, according to circumstances, the ship must carry a certain amount of rudder, this is done automatically as it will be clear from the foregoing description that the angle of the rudder is regulated by the inherent conditions of motion so as to satisfy the desired course. Thus every action on the part of the external perturbing force is closely followed by a very energetic counteraction on the part of the rudder, thus stopping the deviation at its very inception. This reaction is started almost instantaneously ("meeting her") on the least tendency on the part of the ship to

effect an angular movement and ceases directly there is no further need for it ("easing her"). It is clear that if instead of one perturbing impulse setting the device in action as above described there is a whole series of such impulses following one another in every kind of succession, (which is exactly what takes place in reality) to every primary perturbing impulse the device produces a counter-effort thus cancelling the original impulse before it can affect the ship's course.

The resultant effect of the device on the helm is determined by the extent to which the compass and the gyrometer control are caused to affect the differential gear. If the influence of the compass predominates in the device the ship will yaw more or less out of her course and the oscillations will be rapid and will die out slowly, whereas, if the gyrometer is predominant in the device the damping of the yaw will be energetic. On a rough sea, therefore, the compass action might be slightly predominant and, in quiet weather, the gyrometer. This effect can be easily attained by introducing into the respective electric circuits of the compass and the gyrometer motors more or less resistance, or inductance if alternating current is employed. Thus, in the embodiment illustrated, the adjustable resistances 202 and 203 afford a convenient means of varying the relative importance of the factors co-operating in the double control. Apart from this the sensitiveness of the whole device may be modified according to the conditions. If great accuracy in steering is not the main object and it is chiefly desired to obviate moving the steering gear too often in opposite directions, in short, if a certain looseness in steering is not objected to, for example when in a very rough sea the vessel is pitching, rolling and yawing at the same time, the sensitiveness of the device may be diminished by the introduction of the resistance or inductance into both circuits simultaneously. If, on the contrary it is desired to steer a dead course e. g., during target practice, full voltage may be applied across both circuits and the rudder will thus be frequently moved and will quickly check with the utmost energy the angular motion at its very inception, so that the steering will be very accurate. Under such circumstances the vessel after yawing is immediately brought back to her course without any oscillations at all, if an appreciable amount of yaw is produced for an unforeseen reason, such as a very sudden impulse.

It is obvious that the device described above may be used also for controlling the operation of the rudder or the plane controlling the vertical movements of submarines, airships, and the like. In this case

the direction indicating apparatus will comprise a vertical line indicating apparatus, such as a gyroscopic horizon, instead of a compass. The angular velocity indicating apparatus may be identical with that above referred to but its position with respect to the ship should of course be such that it would respond to variations in the velocity of the pitching or vertical motion of the ship instead of responding to variations in the velocity of the yawing or horizontal motion of the ship. Thus, where a gyrometer is employed, the pivotal axis 130 of the gyrometer frame or case should be horizontal and at right angles to the longitudinal centre line of the ship when the device is to control the yawing of the ship, while the axis 130 should be vertical when the device is to control the pitching of the ship or the vertical motion of an airship or of a submarine. In both instances the spinning axis of the gyro-wheel should be parallel to the longitudinal centre line of the ship. As to the controlling mechanisms and driving means for operating the helm these obviously may be identical in both instances, the operation of the device being the same whether it is adapted to steer a body's course in a horizontal or in a vertical plane.

By providing an airship or a submarine with two steering devices according to this invention, one adapted to respond to the horizontal movements of the ship and the other adapted to respond to its vertical movements, it will therefore be possible to steer a straight course at a uniform elevation or depth.

Since, as far as I am aware, this invention is based on the utilization of a principle not hitherto applied to the steering of vessels or other bodies, I wish to be understood that all matter contained in the above description or shown in the accompanying drawings should be interpreted as illustrative and not in a limiting sense, as many apparently widely different embodiments of my invention could be made without departing from the scope of the appended claims.

I claim:—

1. An automatic steering device including helm controlling means responsive to both the positional and dynamical elements of the angular motion of the body to be steered.

2. An automatic steering device including means responsive to the positional elements of the angular motion of the body to be steered, means responsive to the dynamical elements of its angular motion, and means for combining the movements of both said means.

3. An automatic steering device for ships and the like including means responsive to changes in the direction of motion of the ship, means responsive to variations in the angular velocity of the ship, and means for

combining the movements of both said means.

4. An automatic steering device for ships and the like including means responsive to changes in the direction of motion of the ship, means responsive to variations in the angular velocity of the ship, and a helm controlling member subjected to the combined action of both said means.

5. An automatic steering device for ships and the like, including means responsive to changes in the direction of motion of the ship, means responsive to variations in the angular velocity of the ship, means responsive to variations in the angular acceleration of the ship adapted to influence the movement of one of said means, and a helm controlling member subjected to the combined action of all of said means.

6. In an automatic steering device, a direction indicating apparatus, an angular velocity indicating apparatus, controlling means operated in synchronism with each of said apparatus, driving means controlled by said controlling means, and helm controlling means adapted to be operated by said driving means.

7. In an automatic steering device, a direction indicating apparatus, an angular velocity indicating apparatus, driving means controlled by said direction indicating apparatus, driving means controlled by said velocity indicating apparatus, and helm controlling means subjected to the combined action of said driving means.

8. In an automatic steering device, a direction indicating apparatus, an angular velocity indicating apparatus, an electric motor controlled by said direction indicating apparatus, an electric motor controlled by said velocity indicating apparatus, a differential gear adapted to combine the movements of said motors, and helm controlling means adapted to be driven by said differential gear.

9. In an automatic steering device, a direction indicating apparatus, an angular velocity indicating apparatus, controlling means connected and adapted to move in synchronism with each of said apparatus, driving means controlled by said controlling means respectively, and helm controlling means subjected to the combined action of said driving means.

10. In an automatic steering device for ships and the like, a direction indicating apparatus, an angular velocity indicating apparatus, means operated by said velocity indicating apparatus responsive to changes in the sign of the angular acceleration of the ship, driving means controlled by said direction indicating apparatus and said velocity indicating apparatus respectively, one of said driving means being further controlled by the means responsive to changes in the sign

of the angular acceleration, and a helm controlling member subjected to the combined action of said driving means.

11. In an automatic steering device for ships and the like, two electric motors, means for controlling the speed of one of said motors to keep the same proportional to the angular deviation of the ship from a predetermined course, means for controlling the speed of the other motor to keep the same proportional to the angular velocity of the ship, and a helm controlling member subjected to the combined action of said motors.

12. In an automatic steering device for ships and the like, two electric motors, means for controlling the speed of one of said motors to keep the same proportional to the angular deviation of the ship from a predetermined course, means for controlling the speed of the other motor to keep the same proportional to the angular velocity of the ship, means adapted to vary the speed of one of said motors every time the sign of the angular acceleration varies from positive to negative or vice versa, and a helm controlling member subjected to the combined action of said motors.

13. In an automatic steering device, a compass, a gyrometer, driving means controlled by the compass and the gyrometer respectively, and helm controlling means subjected to the combined action of said driving means.

14. In an automatic steering device for ships and the like, means responsive to changes in the direction of motion of the ship, means responsive to variations in the angular velocity of the ship, a helm controlling member subjected to the combined action of both said means, and means for temporarily increasing the action of the first mentioned means during the "meeting period".

15. In an automatic steering device for ships and the like, means responsive to changes in the direction of motion of the ship, means responsive to variations in the angular velocity of the ship, a helm controlling member subjected to the combined action of both said means, and means for temporarily increasing the action of the last mentioned means during the "easing" period.

16. In an automatic steering device for ships and the like, means responsive to changes in the direction of motion of the ship, means responsive to variations in the angular velocity of the ship, a helm controlling member subjected to the combined action of both said means, and means for varying the combined action of said means.

17. In an automatic steering device for ships and the like, means responsive to changes in the direction of motion of the

ship, means responsive to variations in the angular velocity of the ship, a helm controlling member subjected to the combined action of both said means, and means for varying the individual action of either of said means.

18. An automatic steering device for ships and the like, including means responsive to changes in the direction of motion of the ship, means responsive to variations in the angular velocity of the ship, a helm controlling member subjected to the combined action of both said means, and means for stopping the normal operation of the device when the deviation of the ship to either side of her course exceeds a predetermined angle.

19. An automatic steering device for ships and the like, including means responsive to changes in the direction of motion of the ship, means responsive to variations in the angular velocity of the ship, a helm controlling member subjected to the combined action of both said means, means for automatically stopping the normal operation of the device when the deviation of the ship to either side of her course exceeds a predetermined angle, and means for returning the device to its operative position.

20. The combination, with the elements recited in claim 9, of means for returning the direction indicating apparatus and the controlling mechanism connected therewith to their initial positions, respectively, when the direction indicating apparatus records a deviation exceeding a predetermined angle.

21. The combination, with the elements recited in claim 9, of means for restoring synchronism between the velocity indicating apparatus and the controlling means connected therewith when such synchronism has been disturbed.

22. The combination, with the elements recited in claim 7, of means for automatically disconnecting the helm controlling means from the driving means when the direction indicating apparatus records a deviation exceeding a predetermined angle.

23. In an automatic steering device for ships and the like, a compass having a movable element, controlling means adapted to move in synchronism with said element, driving means controlled by said means, a helm controlling member, a mechanical connection between said driving means and helm controlling member, and means for transmitting to said connection movements corresponding to the variations in the angular velocity of the ship.

24. The combination, with the elements recited in claim 23, of automatic means for returning the movable element of the compass and the controlling means to their respective initial positions when the deviation of the ship exceeds a predetermined angle.

25. In an automatic steering device, a compass having a movable element, a follow up motor, means for operating said motor in synchronism with said element, a controlling mechanism actuated by said motor, an electric motor controlled by said mechanism, and a helm controlling member actuated by the last mentioned motor, the arrangement being such that the helm controlling member may occupy any position between its extreme positions irrespective of the position of the movable element.

26. In an automatic steering device, a helm controlling member, an electric motor for actuating same, means for controlling the speed of said motor, a movable member controlling said means, a compass having a movable element responsive to deviations of the body to be steered, and means for driving said member in synchronism with said element, the arrangement being such that no predetermined relation exists between the position of said helm controlling member and the magnitude of the deviation at any particular time during the operation of the device.

27. In an automatic steering device for ships and the like, a helm controlling member, and means whereby the said member is caused to move the rudder due to the deviations of the ship under the action of perturbing forces, said means being adapted to cause said member to continue to move the rudder when the ship is returned to her true course until the action of said perturbing force ceases.

28. In an automatic steering device for ships and the like, a helm controlling member, means for driving said member, and means for controlling the speed of said driving means, said speed controlling means being responsive to deviations of the ship under the action of a perturbing force, said driving means being adapted to influence said helm controlling member as long as the action of said perturbing force persists, irrespective of the course steered by the ship.

29. In an automatic steering device for ships and the like, a helm controlling member, an electric motor for driving said member, a direction indicating apparatus, a rheostat, connections between said rheostat and said electric motor controlled by said direction indicating apparatus to vary the speed of said motor as a function of the variations in the angular position of the ship due to the action of a perturbing force, said motor being adapted to continuously control the movements of said helm controlling member until the action of said perturbing force ceases.

30. In an automatic steering device, a compass having a movable element, a follow up motor, an electrical connection between said movable element and motor whereby

the latter is caused to operate in synchronism with the former, and an electrical connection adapted to reverse the rotation of the motor when the deviation indicated by the compass exceeds a predetermined angle.

31. The combination, with the elements recited in claim 30, of mechanical means adapted to connect the armature of the follow up motor with the movable element of the compass when the rotation of the motor is reversed.

32. In an automatic steering device, a compass having a movable element, a follow up motor adapted to move in synchronism with said element, and a speed controlling mechanism driven by said motor, said mechanism including a sliding block having two parallel longitudinal grooves connected at their ends by arc-shaped grooves, a roller normally engaging one of said longitudinal grooves, a pivoted arm carrying said roller, a switch operatively connected with said arm, and electrical connections co-operating with said switch to reverse the rotation of the follow up motor when the roller drops from one longitudinal groove into the other.

33. In an automatic steering device, a compass having a movable element, a follow up motor, an electrical connection between said movable element and motor whereby the latter is caused to operate in synchronism with the former, and a speed controlling mechanism driven by said motor, said mechanism including a sliding block, a pair of conducting strips on said block, a piece of insulating material between said strips, a contact member adapted to ride over said strips, a switch adapted to break the connection between the follow up motor and the movable element of the compass and make a connection between the follow up motor and one of said strips, and means for operating said switch when the block has reached the end of its path.

34. In an automatic steering device, an electric motor, a member driven by said motor, and means for reversing the rotation of said motor including a switch adapted to be operated by said member, a pair of conducting strips on said member, a piece of insulating material between said strips, a contact member adapted to ride over said strips, and electrical connections controlled by said switch between the said motor and strips.

35. In an automatic steering device, an angular velocity indicating apparatus, a helm controlling member, an electric motor for actuating said member, and means operated by said apparatus for varying the speed of said motor as a function of the angular velocity of the body to be steered.

36. In an automatic steering device for ships and the like, an electric motor, a rheostat in circuit with the armature of said mo-

tor, a sliding member controlling the operation of said rheostat, the rheostat being disconnected from said armature when said member is in its neutral position, and means for controlling the movements of said member in such a manner that the distance from said member to its neutral position is proportional to the angular velocity of the ship.

37. In an automatic steering device for ships and the like, an electric motor, a variable resistance in circuit therewith, and means for automatically varying said resistance in proportion to the variations in the angular velocity of the ship.

38. In an automatic steering device for ships and the like, an electric motor, a circuit therefor, a resistance, and means responsive to changes in the sign of the angular acceleration of the ship for controlling the insertion of said resistance in said circuit.

39. In an automatic steering device for ships and the like, a motor, means responsive to changes in the direction of motion of the ship, means responsive to changes in the angular acceleration of the ship, and means for varying the speed of said motor controlled by both said means respectively.

40. In an automatic steering device, a motor and means for varying the speed of said motor including a movable member, a movable contact in frictional engagement therewith, and stationary contacts adapted to limit the movement of said movable contact and to co-operate therewith to time the variations in the speed of said motor relatively to changes in the direction of motion of said movable member.

41. In an automatic steering device for ships and the like, an electric motor, a resistance in circuit therewith, and means for alternately shunting and inserting said resistance, comprising a sliding member having a rate of motion proportional to the variations in the angular velocity of the ship, a movable contact in frictional engagement with a groove in said member, and stationary contacts adapted to co-operate with and limit the movement of said movable contact.

42. In an automatic steering device for ships and the like, an electric motor, a resistance in circuit therewith, and means for shunting said resistance when the sign of the angular acceleration of the ship changes from positive to negative and vice versa.

43. In an automatic steering device, a motor, and means for varying the speed of said motor including two movable members, a pair of conducting strips on each member, a piece of insulating material between the strips of each pair, a stationary contact member adapted to engage each pair of strips, and cross connections between the respective pairs of strips.

44. In an automatic steering device for ships and the like, an electric motor, a resistance in circuit therewith, and means for shunting said resistance comprising a sliding member having a rate of motion proportional to changes in the direction of motion of the ship, a sliding member having a rate of motion proportional to variations in the angular velocity of the ship, a pair of conducting strips on each member, a piece of insulating material between the strips of each pair, a stationary contact member adapted to engage each pair of strips, said contact members being respectively connected to opposite ends of said resistance, and cross-connections between the respective pairs of strips.

45. In an automatic steering device for ships and the like, an electric motor, a resistance in circuit therewith, two members each adapted to move on both sides of a central position, one of said members being responsive to changes in the direction of motion of the ship and the other to variations in the angular velocity of the ship, and means adapted to shunt said resistance when said members are on opposite sides of their respective central positions.

46. In an automatic steering device for ships and the like, two motors, means for combining the movements of said motors, means for gradually varying the speed of one motor according to changes in the direction of motion of the ship, and means for gradually varying the speed of the other motor according to variations in the angular velocity of the ship.

47. The combination, with the elements recited in claim 46, of means for suddenly varying the speed of one of said motors when the sign of the angular acceleration of the ship changes from positive to negative and vice versa.

48. The combination, with the elements recited in claim 46, of means for suddenly varying the power applied to one of said motors when the sign of the angular velocity of the ship changes from positive to negative and vice versa.

49. In an automatic steering device for ships and the like, two motors responsive, respectively, to changes in the direction of the ship and to variations in its angular velocity, and a differential gear for combining the movements of said motors.

50. In an automatic steering device for ships and the like, a compass, a gyrometer, two electric motors, means for keeping the speed of one motor proportional to the deviation recorded by the compass, means for keeping the speed of the second motor proportional to the angular velocity recorded by the gyrometer, means for varying the power supplied to the first mentioned motor when the sign of the angular acceleration

of the ship varies, and means for varying the power supplied to the second motor when the sign of the angular velocity varies.

51. In an automatic steering device for ships and the like, a helm controlling member, and means continuously responsive to the action of a perturbing force on the ship to successively impart a "meeting" and an "easing" action to said helm controlling member.

52. In an automatic steering device for ships and the like, a helm controlling member, means operative when the ship deviates from her course to successively impart a "meeting" and an "easing" action to said helm controlling member, and means for regulating the "meeting" and the "easing" action of said means.

53. In an automatic steering device, a helm controlling member, means for imparting a "meeting" action thereto when the ship deviates from her course, and means for increasing such action until the angular velocity of the ship begins to decrease.

54. In an automatic steering device for ships and the like, a helm controlling member, means for imparting a "meeting action" thereto when the ship deviates from her course, and means for checking such action when the angular velocity of the ship begins to decrease.

55. In an automatic steering device for ships and the like, a helm controlling member, means for imparting a "meeting" action thereto when the ship deviates from her course, means for checking such action when the angular velocity of the ship begins to decrease, and means for imparting an "easing" action to the helm controlling member when the sign of the angular velocity is reversed.

56. In an automatic steering device for ships and the like, a helm controlling member, means for imparting thereto a "meeting" action proportional to the deviation of the ship from her course, and means for checking said action when the deviation and the angular acceleration of the ship have different signs.

57. In an automatic steering device for ships and the like, a helm controlling member, means for imparting thereto a "meeting" action proportional to the deviation of the ship from her course, and means for imparting an "easing" action to said member as soon as the deviation and the angular velocity of the ship have different signs.

58. In an automatic steering device for ships and the like, a helm controlling member, means for imparting thereto a "meeting" action proportional to the deviation of the ship from her course, and means for increasing such action while the deviation and the angular acceleration of the ship

have the same sign, the last mentioned means being adapted to check said action when the deviation and the angular acceleration of the ship have different signs.

59. In an automatic steering device for ships and the like, a helm controlling member, means for imparting thereto a "meeting" action proportional to the deviation of the ship from her course, and means for increasing such action while the deviation and the angular acceleration of the ship have the same sign, the last mentioned means being adapted to impart an "easing" action to said member when the deviation and the angular velocity of the ship have different signs.

60. In an automatic steering device for ships and the like, a helm controlling member, means for imparting thereto a variable "meeting" action when the ship deviates from her course, and means responsive to the rate of the angular motion of the ship for timing the variations in said "meeting" action.

61. In an automatic steering device for ships and the like, a helm controlling member adapted to exert a "meeting" action when the ship deviates from her course, and means for imparting to said member a variable "easing" action as soon as the initial angular kinetic energy of yawing is extinguished, said means being responsive to the rate of subsequent angular motion of the ship to time the variations in said "easing" action.

62. In an automatic steering device for ships and the like, means adapted to act concurrently on the helm to influence same according to variations in the angular position of the ship and in the rate of its angular motion.

63. In an automatic steering device for ships and the like, means for imparting a "meeting" action to the helm when the ship deviates from her course, and means responsive to the angular velocity of the ship for correcting said "meeting" action.

64. In an automatic steering device for ships and the like, means for imparting a "meeting" action to the helm when the ship deviates from her course, and means responsive to the angular acceleration of the ship for correcting said "meeting" action.

65. In an automatic steering device for ships and the like, means for successively imparting a "meeting" and an "easing" action to the helm when the ship deviates from her course, and means responsive to the angular velocity of the ship for correcting said "meeting" and "easing" actions.

66. In an automatic steering device for ships and the like, means for imparting a "meeting" action to the helm when the ship deviates from her course, and means respon-

sive to a dynamical element of the angular motion of the ship for varying the extent of said "meeting" action.

67. In an automatic steering device for ships and the like, means for imparting a "meeting" action to the helm when the ship deviates from her course, and means responsive to a dynamical element of the angular motion of the ship for varying the duration of said "meeting" action.

68. In an automatic steering device for ships and the like, means for imparting a "meeting" action to the helm when the ship deviates from her course, and means responsive to a dynamical element of the angular motion of the ship for "easing" the helm as soon as the initial angular kinetic energy of yawing is extinguished, the last mentioned means being adapted to vary the "easing" action on the helm.

69. In an automatic steering device for ships and the like, a helm controlling member, means for influencing said member in proportion to variations in an element of the angular motion of the ship, and means for influencing said member in proportion to variations in an element measured by a continuous function of the first mentioned element.

70. In an automatic steering device for ships and the like, a helm controlling member, means for influencing said member in proportion to variations in an element of the angular motion of the ship, and means for influencing said member in proportion to variations in an element measured by a derivative of the first mentioned element.

71. In an automatic steering device for ships and the like, a helm controlling member, means responsive to variations in the angular position of the ship for imparting a "meeting" action to said member when the ship is deviated from her course by a perturbing force, and means tending to synchronize the variations in said "meeting" action with the variations in the action of said perturbing force on the ship.

72. In an automatic steering device for ships and the like, a helm controlling member, means for imparting a "meeting" action thereto when the ship is deviated from her course under the action of a perturbing force, and means responsive to variations in the angular kinetic energy of the ship for imparting a variable "easing" action to said member as soon as the initial kinetic energy due to the action of the perturbing force has been extinguished, the last mentioned means also tending to synchronize the variations in said "easing" action with the variations in the angular kinetic energy due to the "meeting" action of the helm.

73. Means for steering a ship or the like including means for moving the rudder, and

for permitting the ship or the like to carry an amount of rudder to keep it on its course.

74. Means for steering ships or the like including means responsive to movement of the ship off her course to move the rudder, said means being adapted to introduce the amount of rudder required to keep the ship on her course.

75. In an automatic steering device for ships and the like, a helm controlling member, means for imparting thereto "meeting" and "easing" movements when the ship is deviated from her course under the action of an external force, and means tending to synchronize the "meeting" movements of said member with the variations in the action of said perturbing force on the ship, and the "easing" movements of said member with the variations in the angular kinetic energy of the ship due to the "meeting" action of the helm.

76. Means for steering ships or the like including means for controlling the speed of movement of the rudder in response to conditions of movement of the ship off her course.

77. In an automatic steering device, means responsive to a dynamical element of motion of the body to be steered, and a helm controlling member controlled by said means.

78. In an automatic steering device for ships and the like, means for steering a course between certain limits, and means responsive to a dynamical element of motion of the ship for influencing said steering means.

79. In an automatic steering device for ships and the like, torque generating means responsive to variations in the angular position of the ship, torque generating means responsive to variations in a dynamical element of the angular motion of the ship, and a shaft controlled by the differential action of said means.

80. In an automatic steering device for ships and the like, a helm controlling member, and means responsive to the instantaneous effect of a perturbing force on the ship for causing said member to move the rudder until the effect of said perturbing force ceases to influence the movement of the ship.

81. In an automatic steering device for ships and the like, means responsive to the angle of deviation of the body to be steered from its direction or course, means responsive to its angular velocity, means responsive to its angular acceleration, and means for combining the action of all these means.

82. In an automatic steering device for ships and the like, a helm controlling member, means responsive to the angle of deviation of the body to be steered from its direction or course, means responsive to a

derivative with respect to time of the angle of deviation, and means for combining the action of said means into a resultant action on the helm controlling member.

83. In an automatic device having a member for affecting the position of ships or the like, means for controlling the member comprising means responsive to the angle of deviation of the ship from the desired position, means responsive to its angular velocity, and means for combining the action of these means.

84. In an automatic device for controlling the position of ships or the like, means for maintaining the body in a constant position with respect to a reference line, comprising means responsive to the angle of deviation from the desired position, means responsive to its angular velocity, means responsive to its angular acceleration, and means for combining the action of all these means.

85. In an automatic steering device for ships and the like, a helm controlling member, means responsive to the angle of deviation of the body to be steered from its direction or course, means responsive to a plurality of higher derivatives with respect to time of the angle of deviation, and means for combining the action of said means into a resultant action on the helm controlling member.

86. In a system for controlling the conditions of relative movement of two elements, means responsive to the extent of departure from a predetermined condition, means responsive to the velocity of the departure, means for adjusting the relative effects of both these means, and means for combining the effect of these means to control the conditions.

87. In a system for controlling the conditions of relative movement of two elements, means responsive to the extent of departure from a predetermined condition, means responsive to the value of a derivative with respect to time of this departure, means for adjusting the relative effects of both these means, and means for controlling the conditions in accordance with the combined effect of these two means.

88. In a system for controlling the conditions of relative movement of two elements, means responsive to the extent of departure from a predetermined condition, means responsive to the velocity of the departure, means responsive to the value of a derivative with respect to time of the velocity, and means for controlling the conditions in accordance with the combined effect of these means.

89. In a system for controlling the condition of relative movement of two elements, means responsive to the extent of departure from a predetermined relative condition, means responsive to the value of a higher

derivative with respect to time of this departure, means for adjusting the relative effects of both these means, and means for controlling the conditions of movement in accordance with the combined effect of these two means.

90. In a system for controlling the relative position of two elements, means responsive to the extent of departure from a predetermined relative position, means responsive to a higher derivative with respect to time of this departure, means for adjusting the relative effects of both these means, and means for controlling the relative position in accordance with the combined effect of these means.

91. The method of maintaining the conditions of relative movement of two elements constant, which consists in controlling the conditions in response to the extent of departure of the conditions from that desired, and to the values of a plurality of higher derivatives with respect to time of this departure.

92. In a system for maintaining a body in a constant angular position with respect to a reference line, means responsive to the angle of deviation of the body from its desired position, means responsive to a plurality of higher time derivatives of said deviation, means for combining the action of all these means, and means responsive to said resultant action for returning the body to its desired position.

93. In a system for maintaining a body in a constant angular position with respect to a reference line, means responsive to the extent of departure of the body from its desired position, means responsive to the velocity of the departure, means for combining the action of both these means, and means responsive to said resultant action for returning the body to its desired position.

94. In a system for maintaining a body in a constant angular position with respect to a reference line, means responsive to the extent of departure of the body from its desired position, means responsive to the velocity of the departure, means responsive to the acceleration of said departure, means for combining the action of all these means, and means responsive to said resultant action for returning the body to its desired position.

95. The method of maintaining a body in constant angular relation with respect to a reference line, which consists in controlling the position of the body in response to the extent of departure of the body from the desired position and to the values of a plurality of higher derivatives with respect to time of this departure.

In testimony whereof I affix my signature.

NICOLAI MINORSKY.

Certificate of Correction.

It is hereby certified that in Letters Patent No. 1,436,280, granted November 21, 1922, upon the application of Nicolai Minorsky, of New York, N. Y., for an improvement in "Automatic Steering Devices," errors appear in the printed specification requiring correction as follows: Page 1, line 46, for the word "specie" read *species*; page 3, line 76, for the symbol " $(^{\circ})$ " read (0) ; page 6, lines 95, 96, 97, 102, 105, 109, and page 7, lines 3, 30, 47, 70, 85, 122, and page 8, lines 10 and 33, in the formulas, strike out the circles and insert the symbol 0 ; and that the said Letters Patent should be read with these corrections therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 9th day of January, A. D., 1923.

[SEAL.]

KARL FENNING,
Acting Commissioner of Patents.