Aug. 8, 1950 L. HAMMOND 2,517,786

GYROSCOPES

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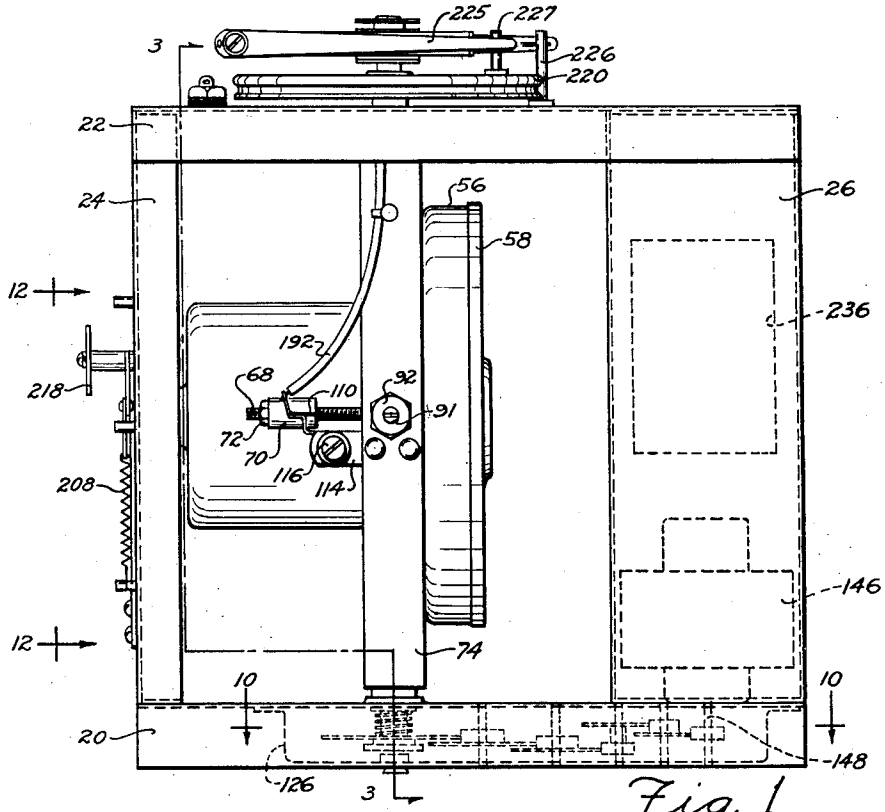


Fig. 1

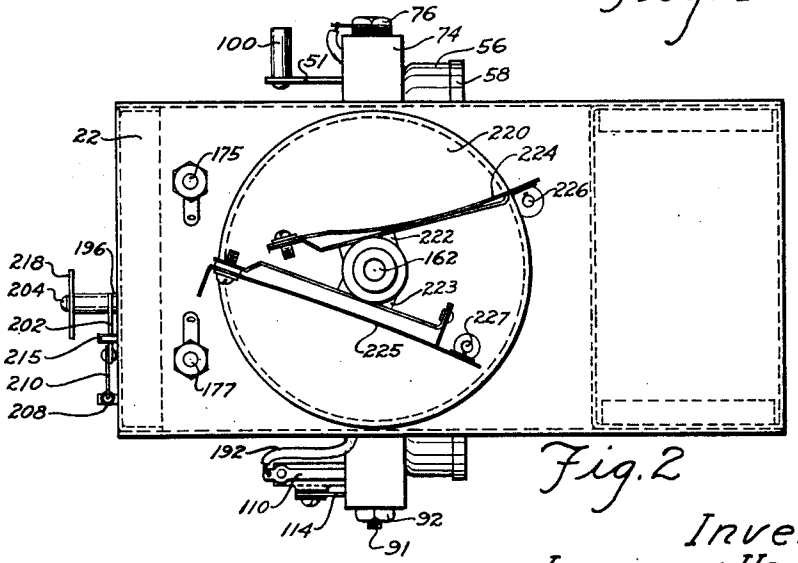


Fig. 2

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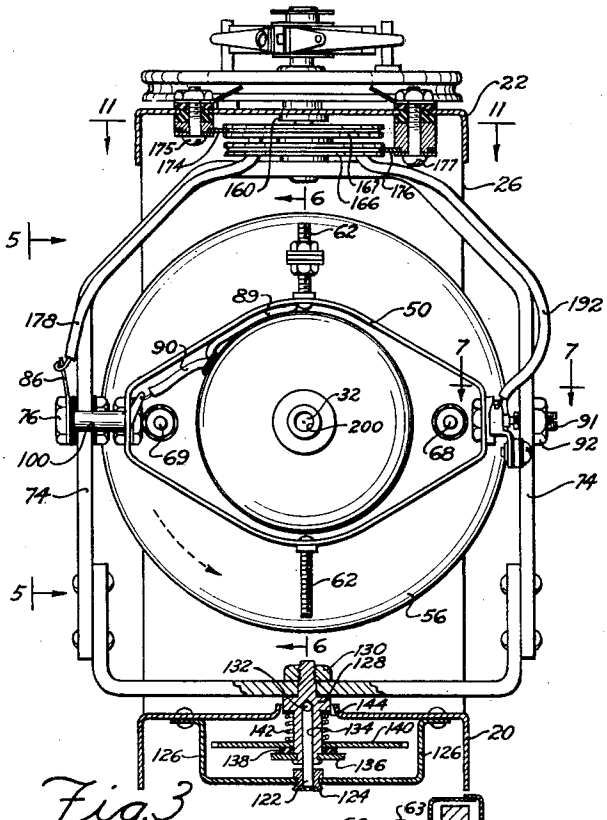


Fig. 3

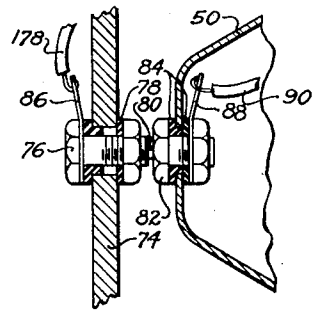


Fig. 4

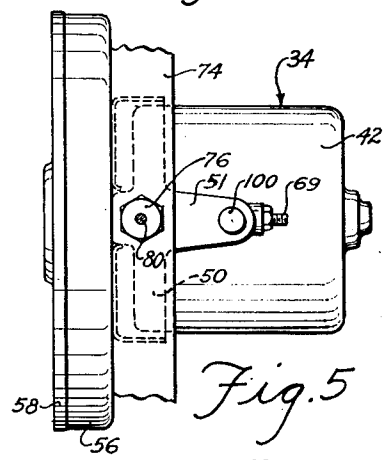


Fig. 5

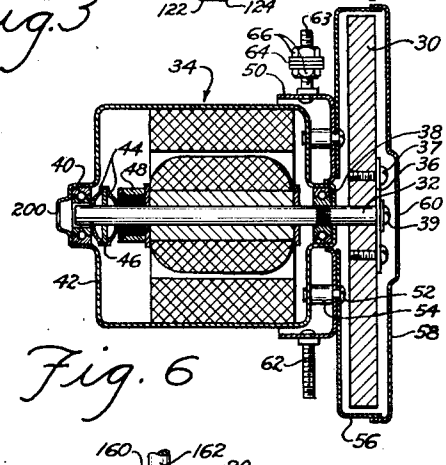


Fig. 6

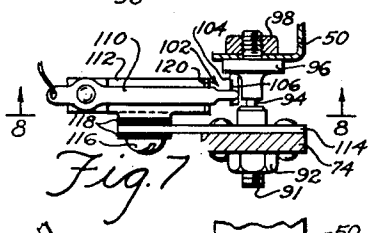


Fig. 7

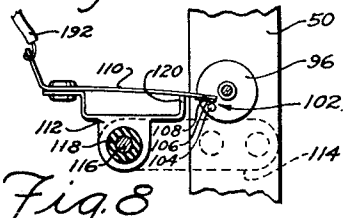


Fig. 8

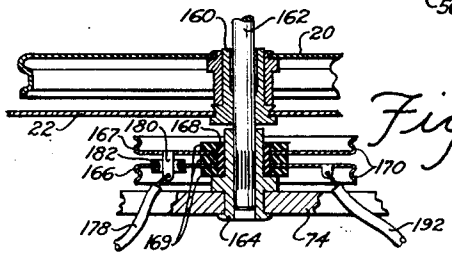


Fig. 9

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GYROSCOPES

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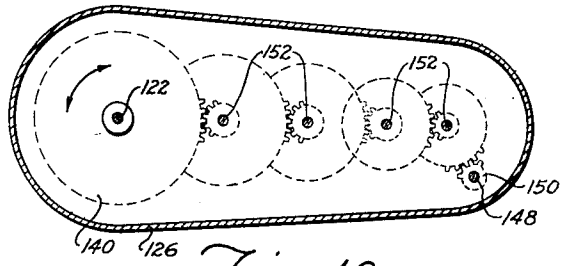


Fig. 10

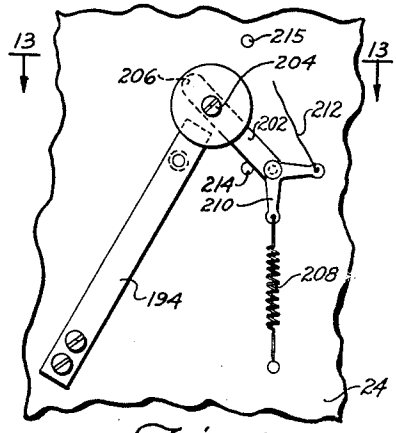


Fig. 12

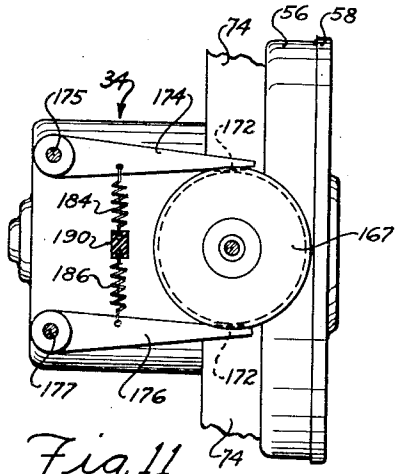


Fig. 11

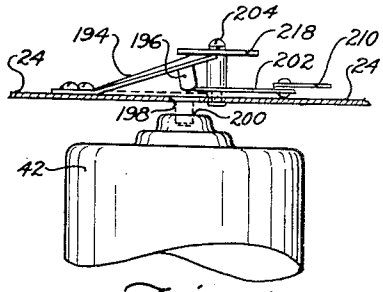
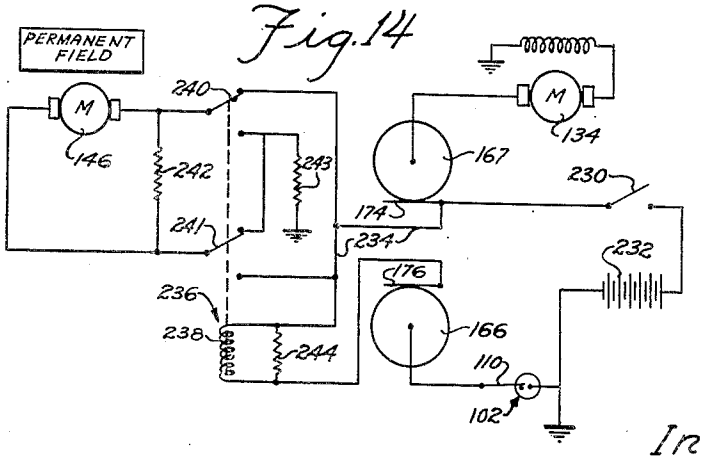


Fig. 13

Fig. 14



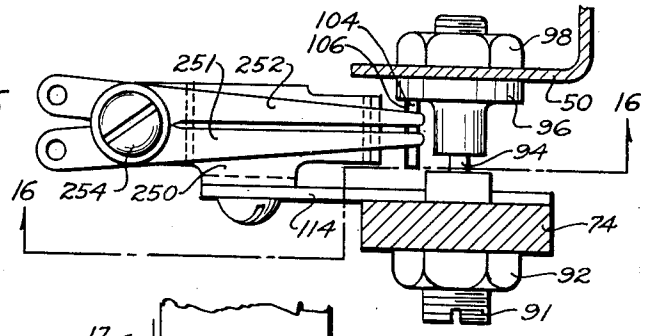
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GYROSCOPES

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Fig. 15



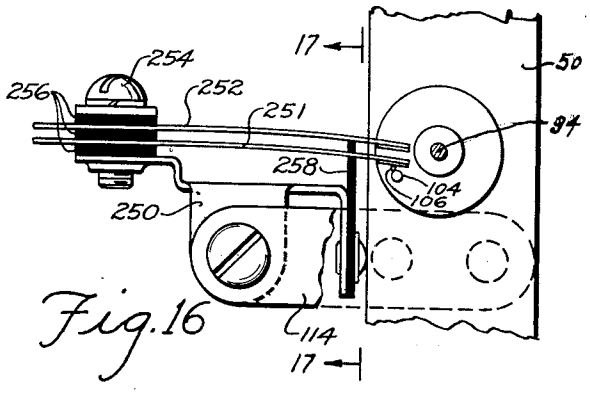


Fig. 16

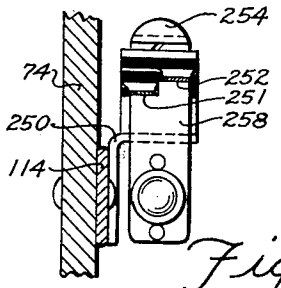


Fig. 17

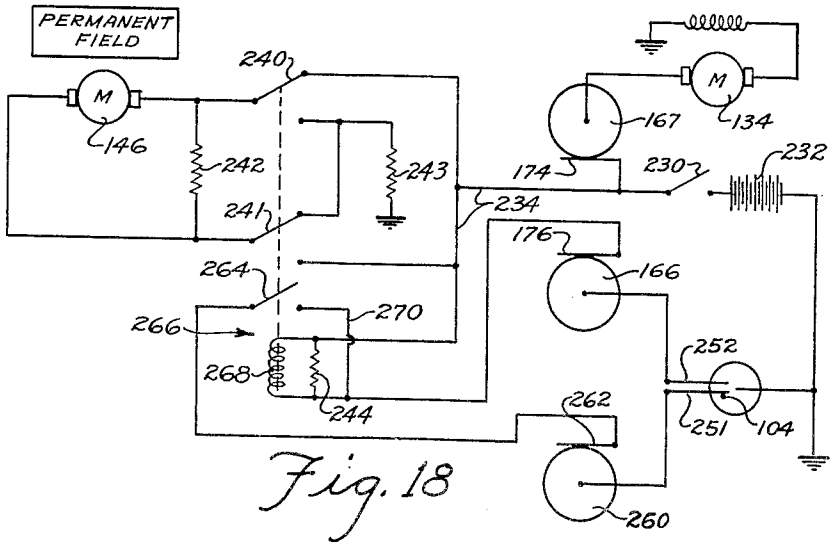


Fig. 18

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UNITED STATES PATENT OFFICE

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GYROSCOPE

Laurens Hammond, Chicago, Ill., assignor to Hammond Instrument Company, Chicago, Ill., a corporation of Delaware

Application October 28, 1942, Serial No. 463,643

7 Claims. (Cl. 74—5.47)

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My invention relates generally to gyroscopes and more particularly to improvements in gyroscopic mechanisms suitable for use in gyro-pilot systems.

It is an object of my invention to provide a gyroscopic mechanism incorporating improved erecting means.

A further object is to provide an improved gyroscopic mechanism which is electrically operated and controlled, and in which the directional gimbal is relatively insensitive to externally applied torques, while at the same time has its position in space very accurately controlled by the gyro.

A further object is to provide an improved electrical gyro erecting apparatus.

A further object is to provide an improved gyroscope which is relatively insensitive to temperature changes and will maintain its accuracy when used at the low temperatures prevalent at high altitudes.

A further object is to provide an improved directional gyroscope which is extremely simple and rugged in construction, and which may be economically manufactured.

Other objects will appear from the following description, reference being had to the accompanying drawings in which:

Figure 1 is a side elevational view of the gyroscopic mechanism;

Figure 2 is a plan view thereof;

Figure 3 is a fragmentary sectional view taken on the line 3—3 of Fig. 1;

Figure 4 is a fragmentary sectional view showing the insulated pivot bearing for the gyro casing;

Figure 5 is a fragmentary side elevational view of the gyro casing taken generally on the line 5—5 of Fig. 3;

Figure 6 is a longitudinal sectional view taken on the line 6—6 of Fig. 3;

Figure 7 is a fragmentary sectional view taken on the line 7—7 of Fig. 3, being shown to an enlarged scale;

Figure 8 is a fragmentary sectional view taken on the line 8—8 of Fig. 7;

Figure 9 is a sectional detail showing the mounting of the slip rings;

Figure 10 is a horizontal sectional view taken on the line 10—10 of Fig. 1;

Figure 11 is a fragmentary sectional view taken on the line 11—11 of Fig. 3;

Figure 12 is a fragmentary end elevational view showing the gyro uncaging mechanism and taken on the line 12—12 of Fig. 1;

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Figure 13 is a fragmentary sectional view taken on the line 13—13 of Fig. 12;

Figure 14 is an electrical wiring diagram of the apparatus;

Figure 15 is a fragmentary horizontal sectional view showing a modified form of the erection controlling switch mechanism;

Figure 16 is a fragmentary side elevational view of the switch mechanism of Fig. 15;

Figure 17 is a sectional view taken on the line 17—17 of Fig. 16; and

Figure 18 is a wiring diagram of the electrical apparatus in which the modified form of the erection controlling switch is employed.

Referring to Figs. 1, 2 and 3, the gyroscopic apparatus is illustrated as mounted in a suitable frame comprising a flanged base 20, a flanged top 22, suitable flanged end wall 24, and partial side walls 26, these portions of the frame being preferably welded together to form a strong rigid structure.

The gyro rotor 30 (Fig. 6) is secured to an armature shaft 32 of an electric motor 34 by a fastening plate 36 attached to the rotor 30 and shaft 32 by screws 37, 39. The shaft 32 is mounted in anti-friction bearings 38, 40 illustrated as ball bearings, the shaft being secured to the inner race of the ball bearing assembly 38, such fact being indicated in Fig. 6 by striations on the shaft. The shaft is, however, free to move longitudinally relative to the ball bearing assembly 40, such fact being indicated by exaggerated clearance between the shaft and bearing 40. The outer races of ball bearings 38 and 40 are fixedly secured in the motor housing 42, and the position of the shaft 32 with respect to the motor housing 42 is maintained by a pair of spring washers 44 and a flat washer 46 which are slightly compressed longitudinally of the shaft 42 so as continuously to exert a force between the inner race of ball bearing assembly 40 and the shaft 32, one of the washers bearing against the end of the commutator 48 but of course being suitably insulated from the segments thereof.

The bearing 38 is located substantially at the center of gravity of the gyro and parts spinning therewith. When the assembly is subjected to temperature changes, the resulting thermal expansion of the parts will therefore not cause a material shift in the center of gravity of the spinning gyro parts. This is because the longitudinal position of the shaft 32 and parts carried thereby is determined solely by the ball bearing 38, the shaft being continuously pressed

to the right (Fig. 6) by the spring washers 44 so as to take up any clearance in the bearing 38. The rotating parts are thus located at the center of gravity, thermal expansion will be outward from the center of gravity in both directions, and thus will have a minimum effect upon the location of the center of gravity.

A flanged frame 50 is rigidly secured to the motor housing 42 by a plurality of screws 52 which are threaded in studs 54, the studs being staked to the motor housing 42. The screws 52 also secure a rotor housing part 56 to the frame 50 and motor housing 42. The housing for the gyro rotor 30 is completed by a flanged cap 58 which is pressed over the housing part 56. The gyro rotor housing formed by the part 56 and cap 58 is preferably not airtight, such fact being indicated by a vent opening 60 formed in the cap 58. A pair of studs 62, 63 are riveted to the flanges of the frame 50 and extend vertically to provide supports for adjustable balancing weights 64 which may be held in adjusted position by lock nuts 66. The screws 62 and 63 are located in a vertical plane passing through the axis of the gyro shaft 32, and thus are utilized to balance the gyro assembly with respect to this plane.

Studs 68, 69 are riveted in the frame 50 and lie in a horizontal plane passing through the axis of the shaft 32, these studs being provided with adjustable weights 70 threaded on the studs and held in adjusted position by lock nuts 72. If desired, one of each of the pair of the adjusting studs 62, 63 and 68, 69 may be omitted, since accurate balance of the gyro casing assembly may readily be obtained by the use of only one of each of these pairs of studs.

The gyro casing assembly is mounted for pivotal movement in a vertical gimbal 74. The terms "vertical" and horizontal" are used herein merely in their relative sense, since the apparatus may of course be mounted in any desired position. Pivotal mounting for the gyro casing assembly comprises an insulating bearing (Fig. 4) composed of a bolt 76 secured to the vertical gimbal 74 and insulated therefrom by suitable washers 78, the bolt being bored to provide a bearing for pivot pin 80 projecting from a bolt 82 which is secured to the flange of frame 50, being suitably insulated therefrom by washers 84.

Soldering lug washers 86 and 88 are in electrical connection with the bolts 76 and 82 respectively. The contact of the pivot pin 80 with the bearing formed by bolt 76 thus provides an electrical connection between the soldering lugs 86 and 88. The soldering lug 88 is connected by a conductor 90 to the motor 34, the other terminal of the motor being grounded to the frame 50 by a conductor 89. The frame 50 is grounded to the vertical gimbal 74 through its other horizontal bearing which comprises a stud 91 threaded in the vertical gimbal 74 and locked by a nut 92. The stud 91 provides a bearing for a pivot pin 94 projecting from a stud 96 which is secured to the flange of frame 50 by a nut 98. Pivotal movement of the gyro casing assembly with respect to the vertical gimbal 74 is limited by the engagement of a stop pin 100 (Fig. 5) with the edge of the gimbal 74, the pin 100 being riveted to an arm 51 extending from the frame 50. The stop pin 100 thus limits pivotal movement of the gyro casing with respect to the gimbal 74 to an angle of approximately 120°.

Pivotal movement of the gyro casing with respect to the gimbal 74 causes operation of an erection controlling switch 102 formed by a pin 104 projecting from the stud 96, and preferably having a contact wire 106 welded thereto. The other contact of the switch 102 is provided by a contact wire 108 welded to the end of a flexible switch arm 110. This switch arm 110 is riveted to a bracket 112 which is secured to the vertical gimbal 74, but insulated therefrom. The support for the bracket 112 comprises an arm 114 riveted to the gimbal 74 and a bolt 116 which is suitably insulated from the arm 114 by insulating washers 118. The bracket 112 is provided with a stop portion 120 which limits the extent of flexure of the switch arm 110.

The gimbal 74 is mounted for pivotal movement about its vertical axis, this mounting comprising a bearing pin 122 which is secured in a bushing 124 staked in the bottom wall of a gear housing 126, the latter being suitably secured to the base 20. A bearing member 128 is drilled to receive the bearing pin 122 and is rigidly secured to the gimbal 74 by a nut 130. A ball bearing 132 provides a thrust bearing for supporting the gimbal 74, this ball bearing 132 being located between the upper end of the hardened pin 122 and the inner end of the drilled hole 134 formed in the bearing member 128.

A washer 136 is staked to the lower end of the bearing member 128 and supports a friction washer 138 which may be made of any suitable material such as a phenol condensation product. A gear 140 rests upon the friction washer 138, being held in contact therewith by a compression coil spring 142, the upper end of which abuts against a thin steel washer 144 resting against a suitable shoulder on the bearing member 128.

The frictional engagement of the gear 140 with the friction washer 138 provides a yielding driving connection between the gear 140 and the gimbal 74, the amount of this friction being determined by the compression of the spring 142, while the spring 142 also acts partly as a torsion spring, resisting relative movement between the gear 140 and the member 128, although the latter effect of the spring is small compared with the friction between the washer 138 and gear 140. The gear 140 is driven by a reversing motor 146 which is suitably mounted on the side frame panel 26 and base 20 and has an armature shaft 148 projecting through the base 20 and carrying a pinion 150. The pinion 150 is geared to the gear 140 through a train of speed reducing gears and pinions (Fig. 10) mounted on shafts 152 which are provided with suitable bearings in the base 20 and gear housing 126.

The upper bearing for the gimbal 74 is provided by a bearing bushing 160 (Fig. 9) which is staked in the flanged top 22 of the main frame. A shaft 162 is pressed in a bushing 164 so as to be rigid therewith, and this bushing is staked in the gimbal 74, the bushing 160 and shaft 162 thus forming the upper pivot for the gimbal 74.

The bushing 164 forms a support for a pair of slip rings 166, 167 which are rigidly secured to the bushing but insulated therefrom by a sleeve 168 and washers 169. The slip rings 166, 167 are provided with grooved flanges 170 which are formed to receive contact brush wires 172 (Fig. 11) which are welded to the ends of brush arms 174 and 176. These brush arms are pivotally mounted on terminal bolts 175 and 177 respectively, being secured to but insulated from the top 22 of the main frame (Fig. 3). A wire 178 connects the soldering lug 86 with a lug 180 (Fig. 9) which is formed from the slip ring 167 and projects through a suitable opening formed in

the slip ring 166, the opening being provided with an insulating grommet 182. The brush arms 174 and 176 have their contacts 172 resiliently held in the grooves formed in the flanges 170 of the slip rings 166, 167 by a pair of tension springs 184, 186 (Fig. 11) which are anchored to an insulating block 190, the block 190 being suitably secured to the frame top 22. The slip ring 166 is connected by a conductor 192 with the switch arm 110 of switch 102.

Means are provided to lock the gyro in caged position, such means being best illustrated in Figs. 12 and 13, and comprising a leaf spring 194 secured to the end wall 24 and having a pin 196 riveted thereto. The pin 196 is adapted to project through a suitable opening 198 in the end wall 24 and into a socket 200 formed in the motor housing 42. When the gyro is caged the pin 196 engages in the socket 200 and is held in engagement by a lever 202 which is pivoted on a stud 204 and has an end portion 206 which is adapted to overlie the end of the leaf spring 194. The lever 202 is urged into gyro uncaging position by a tension spring 208, one end of which is anchored to the end wall 24, and the other end of which is secured to one arm of a bell crank lever 210 which is suitably pivoted to the end of the lever 202. The other arm of the bell crank lever 210 has a release cord 212 secured thereto.

Pivotal movement of the lever 202 is limited by a pair of stop pins 214, 215 which are secured in the end wall 24. When the gyro is locked in caged position tension is maintained upon the cord 212, the lever 202 being shifted counterclockwise from the position in which it is shown in Fig. 12 to a position in which it engages the stop stud 215, in which position its end portion will overlie the end of the leaf spring 194. When it is desired to uncage the gyro, tension upon the cord 212 is released, whereupon the spring 208, acting through the bell crank lever 210, will swing the lever 202 clockwise to the position in which it is shown in Fig. 12, thus permitting the leaf spring 194 to flex outwardly and disengage the pin 196 from the socket 200 in the motor housing 42, thereby permitting the gyro casing to move relative to its support in response to changes in heading of the vehicle upon which the apparatus is mounted. A washer 218 may be secured to the stud 204 to limit the extent of outward flexing movement of the leaf spring 194.

The gyro mechanism may be utilized for any suitable purpose but is illustrated as forming part of an automatic steering mechanism more fully disclosed in my co-pending application Serial No. 463,642, filed October 28, 1942, now Patent No. 2,408,929. For this purpose a follow-up pulley 220 is mounted for free rotation upon the bearing bushing 160. Switch brackets 222 and 223 are secured to the pivot shaft 162. The bracket 222 carries a flexible resilient switch arm 224 which is cooperable with a switch contact post 226 secured to but insulated from the top frame 22, while the bracket 223 carries a flexible resilient switch arm 225 suitably insulated therefrom. This switch arm 225 cooperates with a contact post 227 which is secured to the follow-up pulley 220 and grounded to the main frame through the follow-up pulley and its bearing. The switches 224, 226 and 225, 227 may be utilized to control an automatic steering apparatus, or any other mechanism which it is desired to

operate in response to changes in the position of the frame relative to the gyro spin axis.

As shown in Fig. 14, the motor 134 is series wound and is adapted to be energized upon closure of the main switch 230 which, through the brush arm 174 and slip ring 167, connects one terminal of the motor to a battery 232, the other terminals of the battery and the motor being grounded. Closure of the switch 230 also results in the connection of a conductor 234 to the ungrounded terminal of the battery 232.

A relay 236 has one terminal of its winding 238 connected to the conductor 234 and its other terminal connected to brush arm 176 so that the relay is energized whenever the switch 102 is closed to connect the slip ring 166 to ground. The relay 236 includes a double-pole double-throw reversing switch comprising switch arms 240, 241. This switch operates to control the direction of rotation of motor 146, this motor operating in one direction when the relay 236 is energized and in the opposite direction when the relay is de-energized. Suitable anti-spark resistors 242, 243 and 244 are provided to inhibit arcing at the various contacts of the circuits. Such protection against arcing is particularly desirable when the apparatus is to be used in a rarefied atmosphere.

In using the apparatus the main switch 230 is closed, thereby energizing the gyro motor 134. After the gyro motor has attained its normal operating speed, and the apparatus positioned in space so that the gyro spin axis points in a desired direction, the normally tensioned cord 212 is released to permit the spring 208 to swing the lever 202 clockwise (Fig. 12), and thereby remove its end portion 206 from obstructing position adjacent the leaf spring 194, whereupon the later will flex outwardly and withdraw the caging pin 196 from the socket 200 in the gyro motor housing 42. Upon being thus released, the gyro casing will be free to swing about its horizontal pivot (to the extent limited by the stop pin 100) and will be relatively free to swing on its vertical pivot. For the purposes of this description, it will be assumed that the gyro spins counterclockwise as viewed in Fig. 3, and that at the instant of uncaging of the gyro, the switch 102 happens to be closed.

The relay 236 will therefore be energized and the motor 146 will be rotating in a direction to drive the gear 140 clockwise (Fig. 10). The gear 140, through the spring 142 and friction washer 138, exerts a clockwise torque upon the gimbal 74. The application of this torque causes the gyro to precess counterclockwise (Fig. 1) and such precession results in the opening of the switch 102, with consequent reversal of the direction of rotation of the motor 146 and application of a counterclockwise torque to the gimbal 74. The application of counterclockwise torque to the gimbal 74 causes the gyro to precess clockwise (Fig. 1) and the switch 102 closes to repeat the cycle.

Thus, when the frame of the apparatus is stationary, or continues to move in the same direction it was moving at the instant the gyro was uncaged, the gyro will precess through a very small angle, first in one direction and then the other, at very short intervals. The result will be that a torque will be applied to the vertical gimbal 74 first in one direction, and then in the other, in rapid alternation, with the ultimate effect that the frictional torque and the torque due to the flexure of switch arms 224, 225

will be opposed by an equal and opposite torque applied to the vertical gimbal by motor 146 through gear 140. The vertical gimbal bearings will, in effect, be frictionless, and the torque applied through the gear 140 will be available for the operation of the switches 224—226 and 225—227, or for operating any other devices. It will be noted that the position of the stop portion 120 of the bracket 112 determines the angular position of the gyro casing (relative to gimbal 74), at which switch 102 opens as well as the position at which this switch closes, and that as a result, the angle through which precession takes place is very minute. The horizontal axis bearings are thus subjected to continuous agitation and the effect of static friction is substantially eliminated, since rolling and sliding friction are predominant.

If the gyro casing is properly balanced it will continue to oscillate on its horizontal pivots through the minute angle, as above described, and the vertical gimbal 74 will accurately maintain its orientation in space. This fact is of considerable significance in that it makes the balancing of the gyro casing about its horizontal axis a very simple operation. It is necessary merely to adjust the weights 70 on the screws 68, 69, until the gimbal 74 remains stationary. This balancing operation may thus be performed in a very short time. The frame may then be placed on end and adjustment of the weights on the screws 62, 63 quickly made in a similar manner. Such balancing also adjusts for the rotation of the earth for the particular latitude at which the adjustment is made.

It will now be assumed that the vehicle upon which the apparatus is installed is acted upon by a force which causes it to turn the apparatus clockwise (Fig. 2). Such movement, due to friction, results in the application of a clockwise torque to the gimbal 74 and as a result the gyro will tend to precess counterclockwise (Fig. 1), thereby holding the switch 102 open for longer periods than it is closed. The motor 146 will thus operate in a manner such that it will, through the friction washer 138, apply a counterclockwise torque to the gimbal 74 through longer intervals than the clockwise torque is applied. The clockwise torque applied to the gimbal due to the change in direction of the vehicle is thus opposed by an equal (on the average) and opposite torque and, as a result, the gimbal will maintain its directional position in space.

While for purposes of description the action of the gyro was described as if substantial precession took place upon a change in orientation of the vehicle, such will seldom be the case. This is because the gear 140 is driven at an angular velocity which is greater than any angular velocity of the vehicle which may normally occur. The erection of the gyro takes place continuously during the time that the vehicle is changing direction and the gyro will be in substantially erect position at all times. The only occasion upon which the gyro could precess through a substantial angle would be if the vehicle changed direction violently at an angular velocity as great or greater than that at which the gear 140 is driven. The apparatus is so designed that the angular velocity at which the gear 140 may be driven is greater than any angular velocity which the vehicle may have.

If the vehicle upon which the apparatus is mounted changes its direction so as to have a component about the horizontal axis of the gyro casing, let us assume in a counterclockwise direction (Fig. 1), the effect will be the same as if the gyro had precessed clockwise, so that the erecting means will operate in the same manner as previously described, to cause the gyro spin axis to align itself with the new direction of movement of the vehicle in the vertical plane.

Thus, irrespective of the character of the changes in direction of the vehicle, the spin axis of the gyro will be maintained in a given horizontal orientation in space, although the spin axis will change with changes of direction of the vehicle in the vertical plane. The position of the gyro axis, and hence that of the gimbal 84, thus provides an indication of the azimuthal component of the change in direction heading of the vehicle relative to the orientation of the vehicle at the time the gyro was uncaged.

The above described switch mechanism for controlling the operation of the procession correcting motor 146, whereby the precession of the gyro ordinarily takes place through a very minute angle, is satisfactory and advantageous provided the horizontal bearings for the gyro casing pivots are formed with a very high degree of precision and have their bearing surfaces very smoothly finished, or if the apparatus is used on a vehicle which is very frequently changing its heading, as for example, on a small boat traveling in a choppy sea. If, however, the horizontal pivot bearing surfaces for the gyro casing are not finished with extreme accuracy, or if a small particle of dirt, lint, or the like happens to get between the bearing surfaces, such irregularity in these bearings may introduce a factor tending to decrease the accuracy of the apparatus.

In order to make it possible to manufacture the apparatus as economically as possible, without requiring high precision finishing of the horizontal bearings of the gyro casing, and to make the apparatus more reliable and accurate when used on a vehicle which maintains its heading steadily, as for example, a glider in flight through relative quiescent atmosphere, or a large ship traveling in a calm sea, I have provided the switch mechanism shown in Figs. 15 to 17 and the control circuit shown in Fig. 18. Generally speaking, this mechanism permits oscillatory precession of the gyro through a greater angle than that permitted by the previously described mechanism, and such oscillation has a longer period. But the ultimate effect is that of eliminating friction in the horizontal bearings.

In Figs. 15 to 18, such parts as correspond to previously described parts of the apparatus bear corresponding reference characters, and the detailed description thereof will not be repeated.

The switch mechanism is supported by a bracket 250 which is secured to the arm 114 carried by the gimbal 74. A pair of flexible resilient switch arms 251, 252 are secured to the bracket 250 by a screw 254, but are suitably insulated therefrom, and from the bracket 250, by insulating washers 256. The switch arms 251, 252 are resiliently biased to engage a stepped insulating stop 258 which is riveted to the bracket 250. These flexible switch arms 251, 252 have their contact ends in position to be engaged by the contact wire 106 on the pin 104 which projects from the stud 96.

It will be apparent, particularly from Fig. 16, that as the gyro casing precesses clockwise, the switch arm 251 will first be engaged by the contact pin 104, and as the gyro casing precesses further clockwise, the switch arm 252 will

be engaged. Upon counterclockwise precessional movement of the gyro casing from the position in which both switches are closed, flexure of the switch arm 252 will first be arrested by the insulating stop 258 and contact with the pin 104 thus broken, while upon further counterclockwise precessional movement of the gyro, the flexure of the switch arm 251 will be arrested and its contact with the contact pin 104 broken.

The effect of the operation of the switch arms 251, 252 will best be understood by reference to Fig. 18, from which it will be noted that the switch arm 251 is connected through a third slip ring 260 and brush 262 to a switch arm 264 which forms part of a relay 266 and is closed when the winding 268 of the relay is energized. The switch arm 264 is adapted to complete a holding circuit for relay 266, this circuit including a conductor 270.

Let us assume that the main switch 230 has been closed and the apparatus is in operation, and a torque is applied to the gimbal 74 through the friction washer 138 (or because of friction in the vertical gimbal bearings, or due to the operation of switches 224, 226 or 225, 227), in a direction such as to cause clockwise precession of the gyro casing from its position as indicated in Fig. 16 by the location of the contact pin 104. As the pin 104 makes electrical contact with the switch arm 251, the relay 266 is not energized and the switch 264 is thus open, and the grounding of the switch arm 251 thus has no immediate effect. As the gyro casing continues clockwise precession the switch arm 252 is engaged by the pin 104 and thus connected to ground. This completes an energizing circuit for the relay 266, which may be traced as follows: from battery 232, through switch 230, conductor 234, relay winding 268, brush 176, slip ring 166, switch arm 252, and contact pin 104 to the grounded terminal of battery 232.

The energization of the relay 266 results in reversal of the direction of rotation of the motor 156 through operation of the reversing switches 240, 241, and causes closure of switch 264 which, it will be noted, establishes a holding circuit for the relay. The holding circuit may be traced as follows: from battery 232, through switch 230, conductor 234, relay winding 268, conductor 270, switch 264, brush 262, slip ring 260, switch arm 251, and contact pin 104 to the grounded terminal of battery 232. The reversal of the direction of the motor 146 will, as previously described, result in the application of a torque to the gimbal 74 in a direction to cause counterclockwise precession of the gyro casing, whereupon the contact pin 104 will move away from switch arm 252, opening the initial relay energizing circuit. However, the relay will remain energized until upon further counterclockwise precession of the gyro casing, the contact pin 104 moves away from the switch arm 251 as flexure of the latter is arrested by the stepped stop 258. The latter results in opening the holding circuit for the relay 266, whereupon the relay is de-energized to permit return of the switches 240, 241 to the position shown in Fig. 18, with the resultant reversal of the direction of rotation of the motor 146 and consequent repetition of the above described cycle.

By virtue of the spacing of the switch arms 251, 252 the precessional oscillation of the gyro casing will take place through a small angle, in the order of 12°. Such oscillation takes place continuously while the apparatus is in operation. The period of such oscillation may be in the order of 10 to 15 seconds, depending upon the particular use to which the apparatus is to be put.

Since the angle through which the gyro casing may oscillate is accurately determined by the operation of the switches 251, 252, the effect of a frictionless horizontal bearing for the gyro casing is obtained. This may be explained by the fact that the torque, due to actual bearing friction, is applied to the gyro casing for equal intervals of time in opposite directions, and since the torque due to friction is the same during the clockwise and counterclockwise precession of the gyro casing, the frictional torques cancel each other and thus over a period of time have no effect whatsoever upon the gyro casing. The energy necessary to overcome the friction in the horizontal bearings is supplied through the friction washer 138 from the motor 146. As previously pointed out, the motor 146, through the friction washer 138, also supplies the energy necessary to overcome friction in the vertical pivot bearings for the gimbal 74 as well as to overcome any torque on the gimbal resultant from the flexure of the switch arms 224, 225. Thus, though the vertical and horizontal pivot bearings are of rugged construction, the actual friction thereof cannot have any effect upon the directional characteristics of the gyro, and the result is the same as if these bearings were frictionless. The gyro axis can thus maintain its orientation with a very high degree of precision.

Because of this frictionless characteristic of the horizontal and vertical axis bearings, the gyro rotor need not be as large, nor need it spin as fast, as would otherwise be required, and the apparatus as a whole may be of relatively rugged and simple construction with consequent low cost of manufacture.

While I have shown and described particular embodiments of my invention, it will be apparent to those skilled in the art that numerous modifications and variations may be made in the form and construction thereof, without departing from the more fundamental principles of the invention. I therefore desire, by the following claims, to include within the scope of my invention all such similar and modified forms of the apparatus disclosed, by which substantially the results of the invention may be obtained by substantially the same or equivalent means.

I claim:

1. In a gyroscopic apparatus having, a support, a vertical gimbal mounted for pivotal movement on a vertical axis in said support, a gyro case mounted for pivotal movement on a horizontal axis in said gimbal, and a gyro rotor and motor therefor mounted for rotation within said case on a normally horizontal axis perpendicular to the pivotal axis of the case; the combination of a gyro erecting reversible electric motor, a yielding driving connection between said erecting motor and said gimbal, a relay having a winding, having switches for reversing the direction of rotation of said erecting motor, and having a holding switch, a pair of control switches closed sequentially as said gyro case rotates in one direction with respect to said gimbal and opened in reverse sequence as said gyro case rotates in the opposite direction, an energizing circuit for said relay including said winding and the last closed and first opened of said pair of switches, and a holding circuit for said relay including the other of said pair of switches and said holding switch.

2. In a gyroscopic apparatus, a gyro case, an

electric motor housing forming part of said case, a rotary motor armature having a shaft, a gyro rotor secured to said shaft, a pair of shaft bearings in said motor housing, one of said bearings being located substantially at the center of gravity of the gyro case assembly, and means to yieldingly urge said shaft longitudinally against said last named bearing, whereby the latter bearing fixes the longitudinal position of said shaft in said case.

3. The combination set forth in claim 2 in which said means comprises a compressed spring exerting its force between said motor housing and said shaft.

4. In a gyroscope, a shaft, a gyro wheel secured to said shaft, a frame, a motor for driving said gyro wheel, said motor having a rotor part secured to said shaft and having a stator part secured to said frame, a thrust bearing for said shaft secured to said frame close to the center of gravity of the assembly including said frame and all parts carried thereby, and yielding means urging said shaft longitudinally against said thrust bearing, whereby the center of gravity of said assembly will not be materially shifted upon thermal expansion of the various parts of said assembly.

5. In a gyroscope, a rotary gyro wheel assembly including a gyro wheel, a shaft and a motor part, a gyro casing having a thrust bearing for said shaft, said thrust bearing being positioned in a plane perpendicular to said shaft passing through the center of gravity of the assembly and being carried by said casing, and resilient means acting longitudinally of said shaft to hold the latter in engagement with said thrust bearing, whereby thermally produced changes in the dimensions of the rotating parts of said assembly will not materially change the position of the center of gravity of the assembly.

6. In a position determining control device the combination of a movable controlling element, a pair of switches A and B closed successively by said element upon movement of the element in one direction and opened in a reverse order upon movement of the element in the reverse direction, a relay having a winding and two contactors C and D; a source of electrical energy; a holding circuit including the source, switch A, contactor C and the relay winding; a second circuit including the source, switch B, and the relay winding; an electromagnetic motor; and a third circuit including the source, contactor D, and the electromagnetic motor.

7. In a gyroscopic apparatus having a supporting frame, a vertical gimbal mounted for pivotal movement on a vertical axis in said frame, a gyro case mounted for pivotal movement in said gimbal on a horizontal axis, and a gyro rotor and motor therefor mounted for rotation within said case on a normally horizontal axis perpendicular to the pivotal axis of the case; the combination of a reversing gyro erecting motor, a frictional driving connection between said gyro erecting motor and said gimbal, a pair of switches operated respectively as said gyro precesses through predetermined angles in opposite directions from its normal position, circuits including a relay energized when said gyro precesses through said predetermined angle from normal position in one direction and which is de-energized upon precession of the gyro through said predetermined angle in the opposite direction, and circuit means including said relay to cause said gyro erecting motor to apply a torque to said gimbal through said frictional connection in a direction to correct for the precession of the gyro.

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