C. M. PAXTON.

GYROSCOPIC DEVICE AND METHOD.

APPLICATION FILED OCT. 29, 1920.

1,380,335.

Patented May 31, 1921.

6 SHEETS—SHEET 1.

Fig. 1.

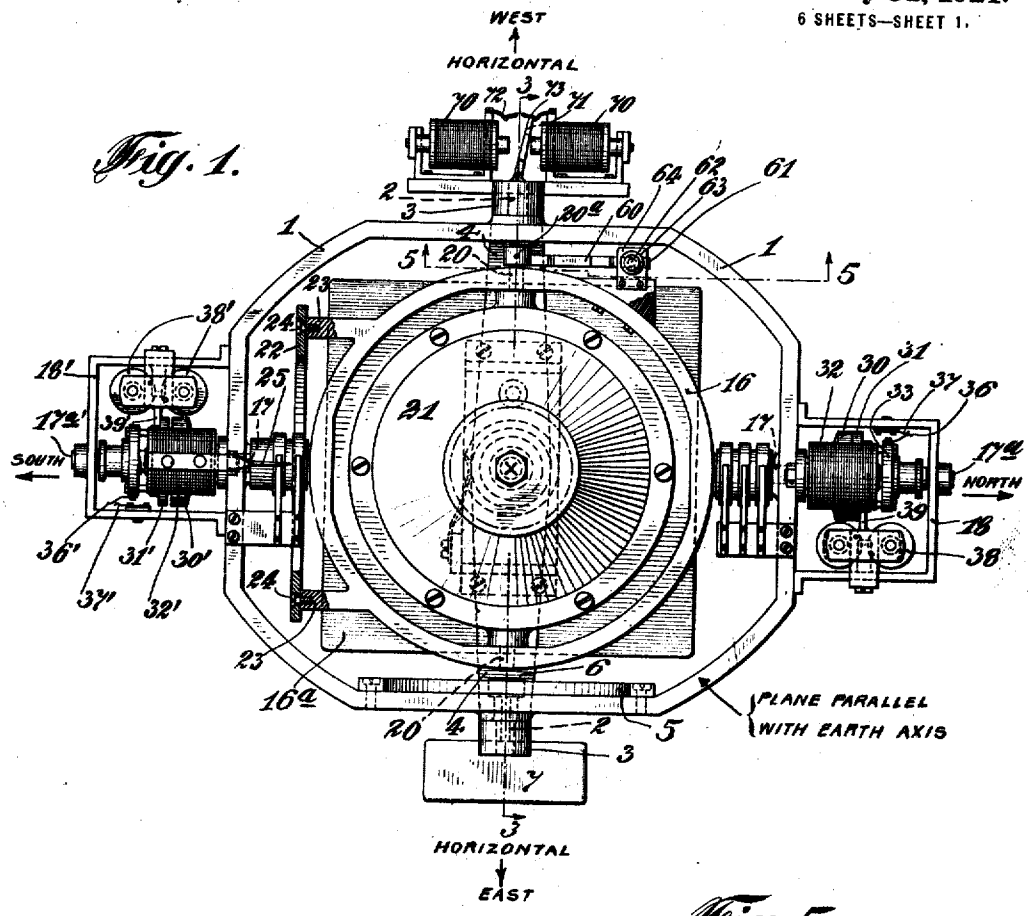


Fig. 4.

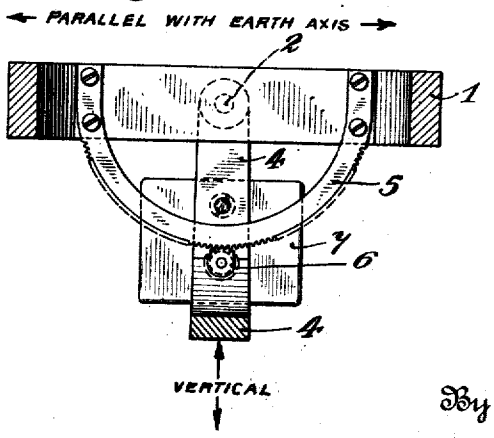
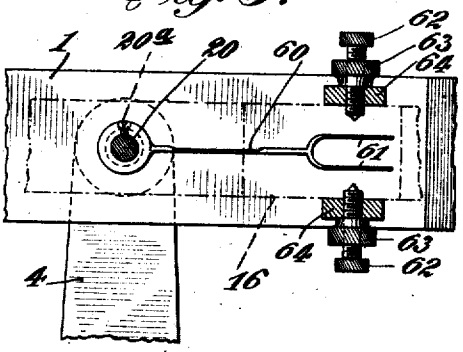


Fig. 5.



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6 SHEETS—SHEET 2.

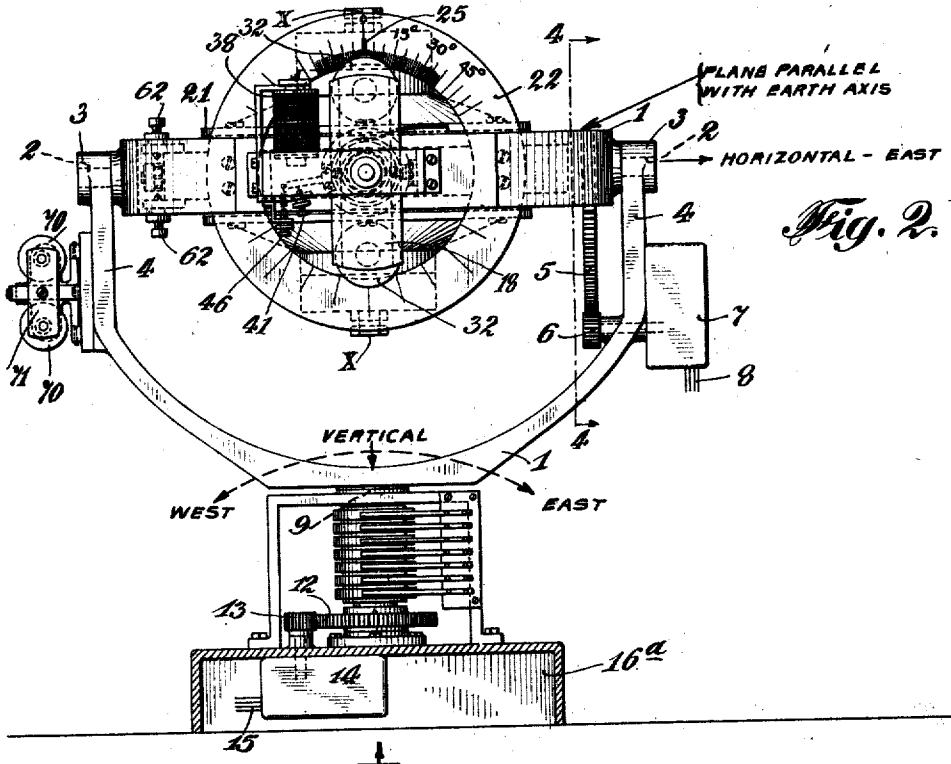


Fig. 2.

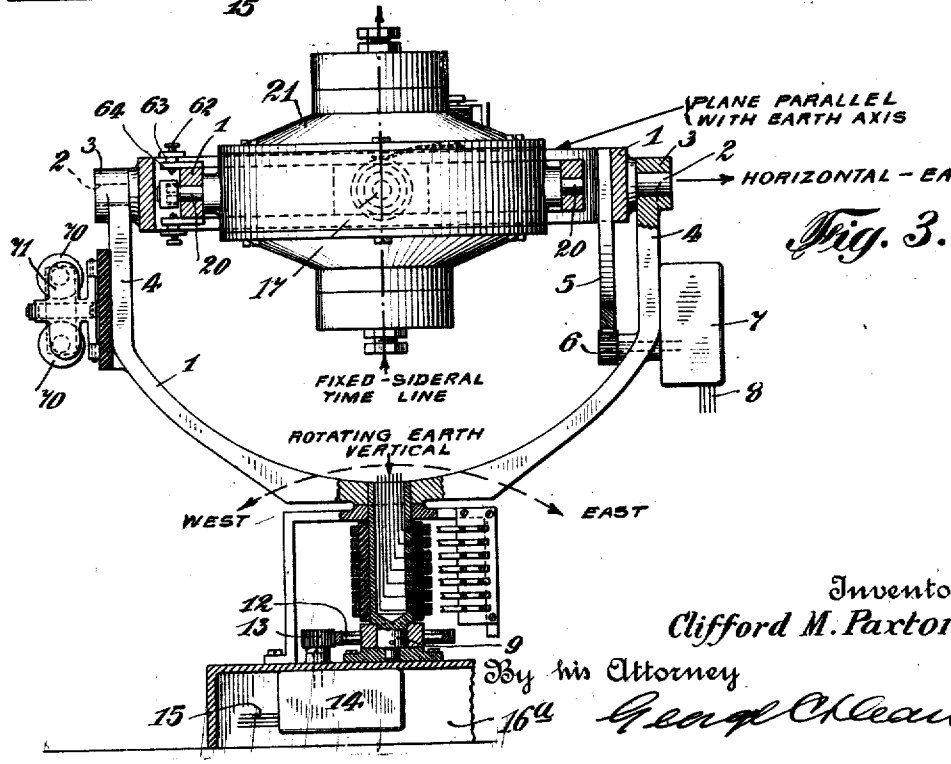


Fig. 3.

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GYROSCOPIC DEVICE AND METHOD.

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6 SHEETS—SHEET 3.

Fig. 6.

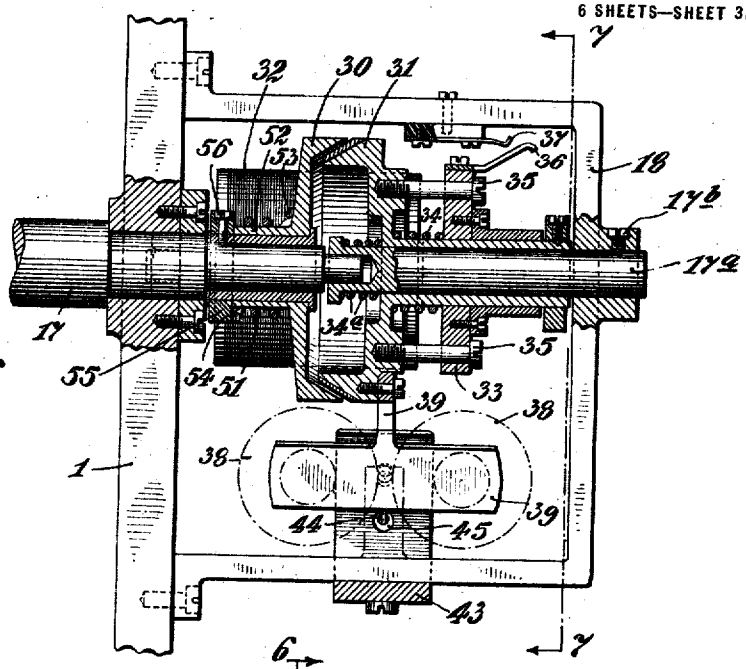
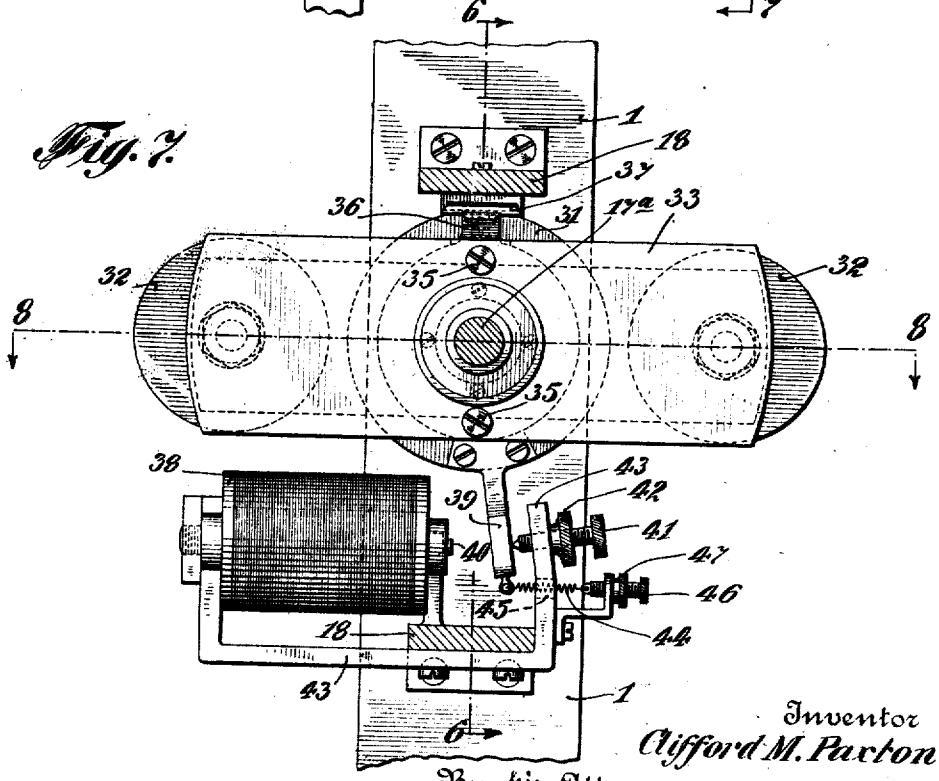


Fig. 7.



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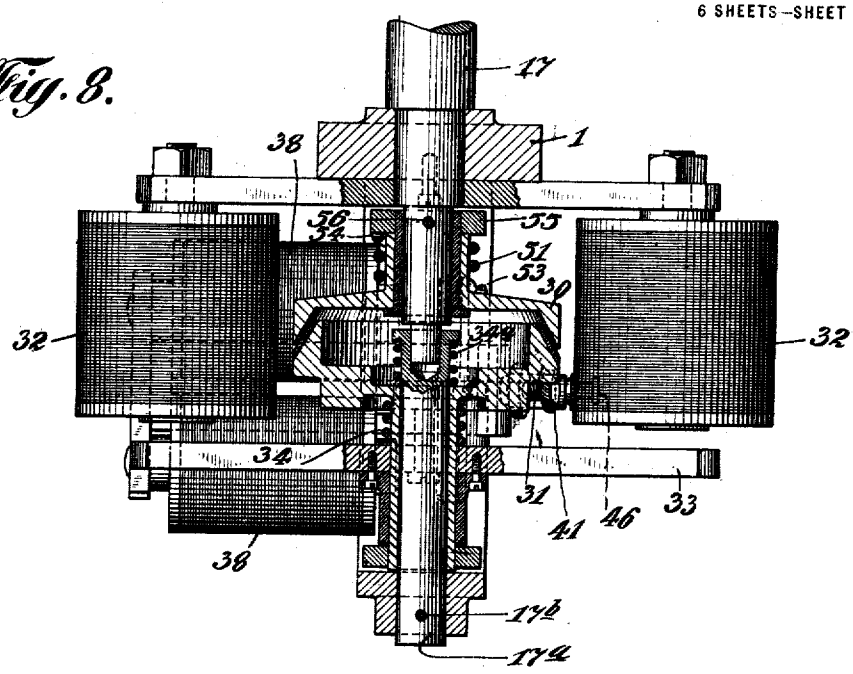
GYROSCOPIC DEVICE AND METHOD.

APPLICATION FILED OCT. 29, 1920.

1,380,335. Patented May 31, 1921.

6 SHEETS—SHEET 4.

Fig. 8.



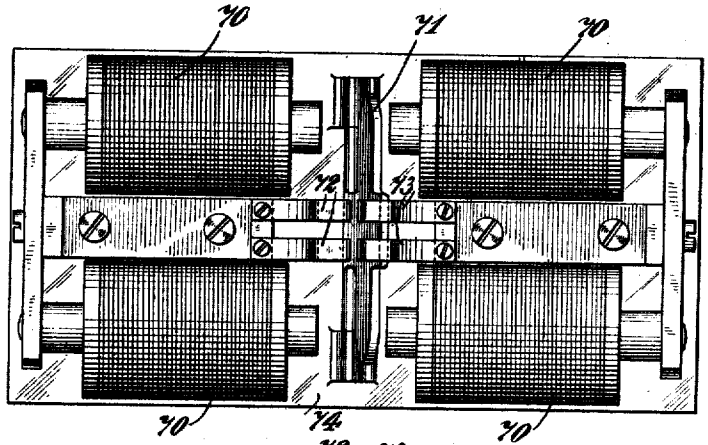


Fig. 9.

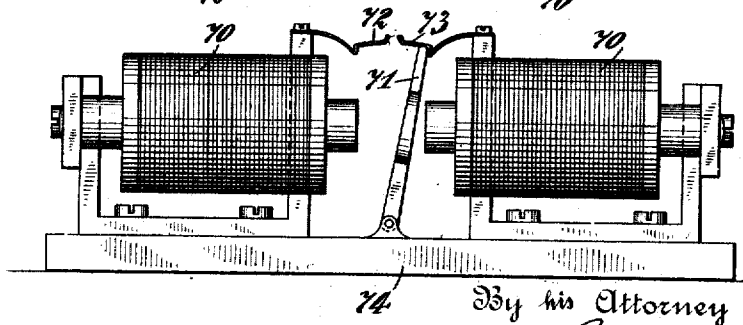


Fig. 10.

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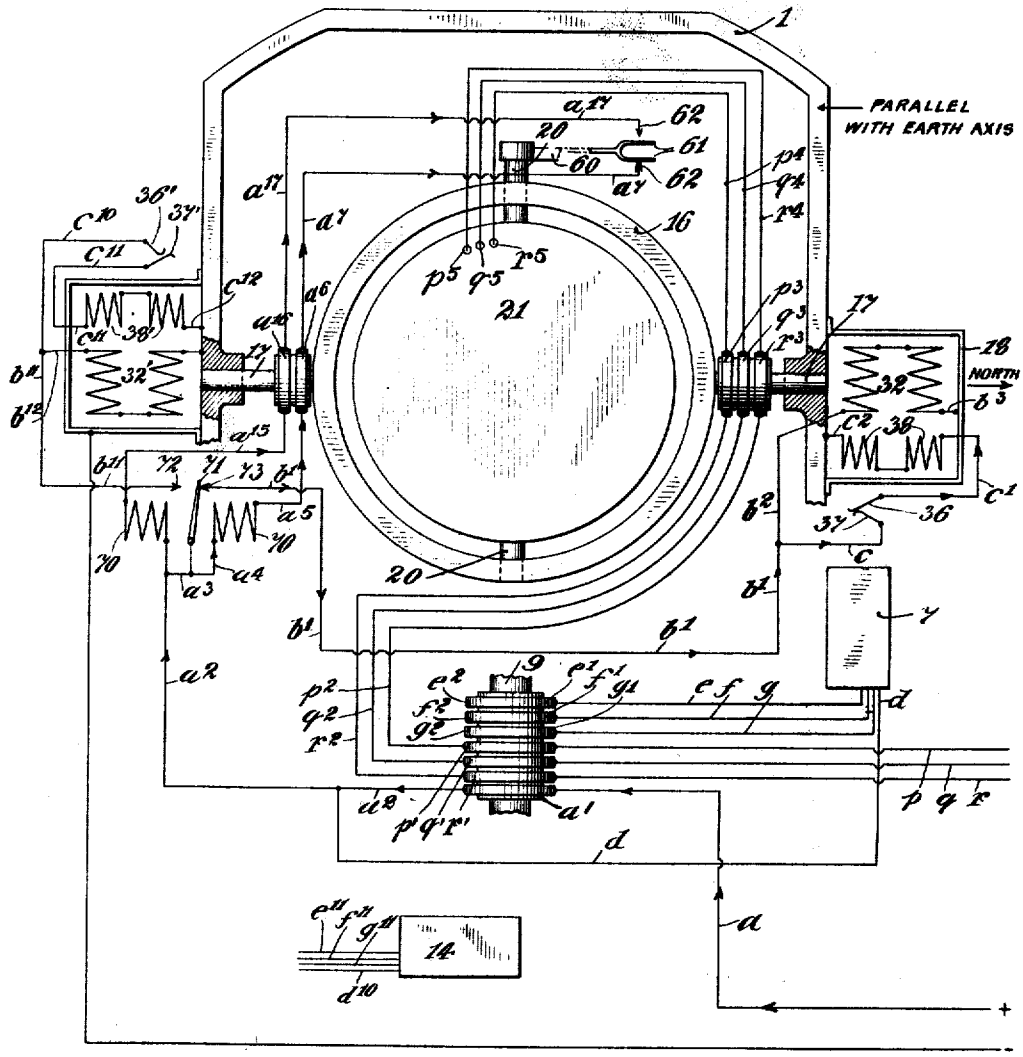
GYROSCOPIC DEVICE AND METHOD.

APPLICATION FILED OCT. 29, 1920.

1,380,335. Patented May 31, 1921.

6 SHEETS—SHEET 5.

Fig. 11.



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GYROSCOPIC DEVICE AND METHOD.

APPLICATION FILED OCT. 29, 1920.

1,380,335.

Patented May 31, 1921.

6 SHEETS—SHEET 6.

Fig. 12.

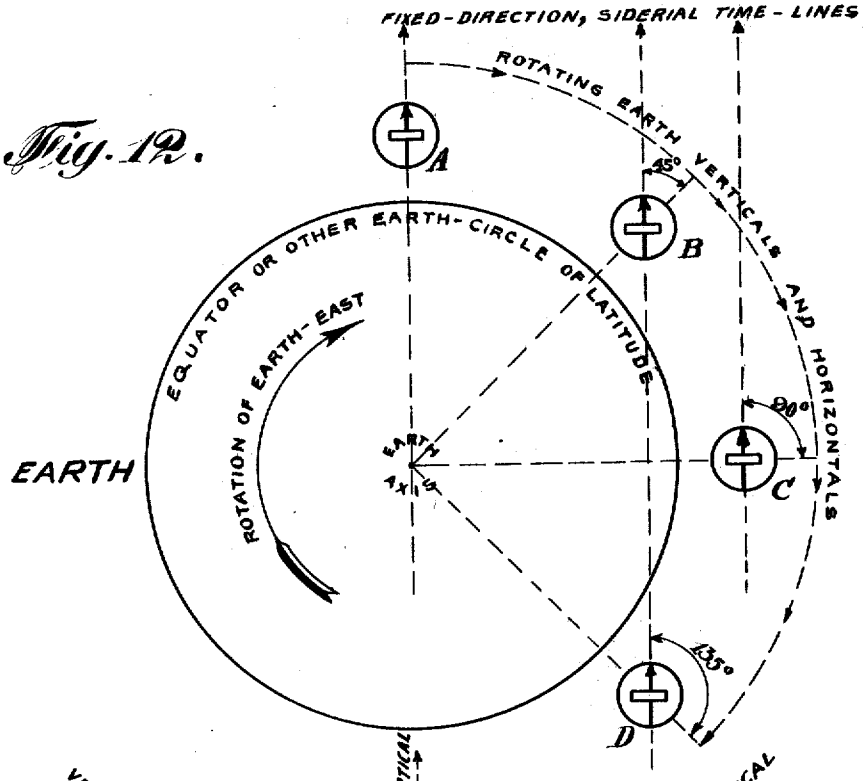
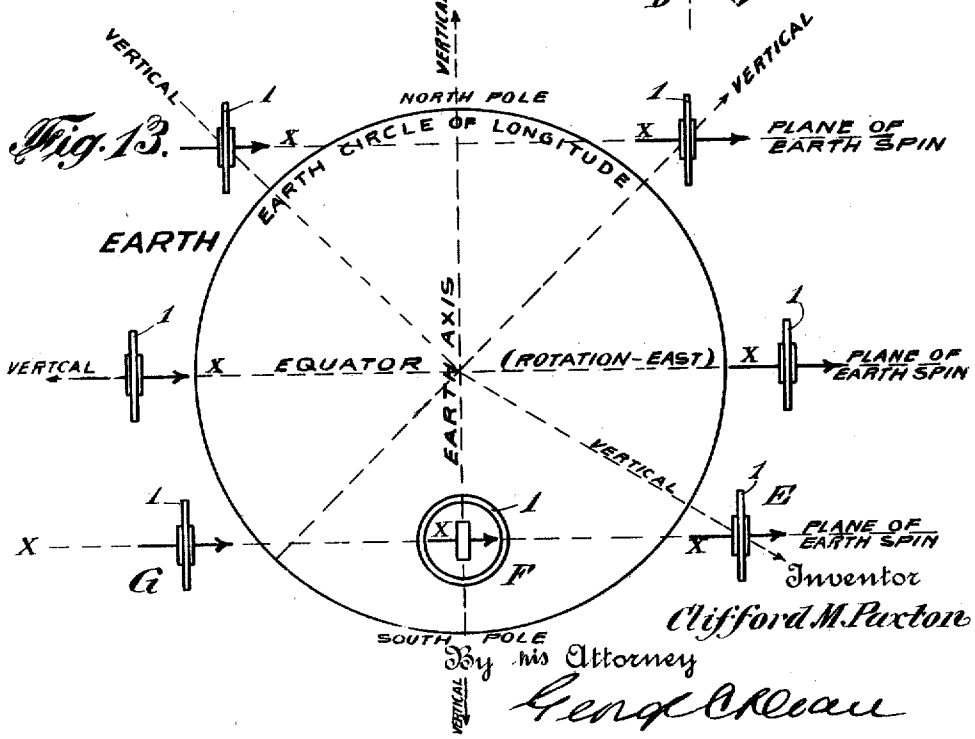


Fig. 13.



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UNITED STATES PATENT OFFICE.

CLIFFORD M. PAXTON, OF BROOKLYN, NEW YORK, ASSIGNOR TO PAXTON GYROSCOPE CORPORATION, A CORPORATION OF NEW YORK.

GYROSCOPIC DEVICE AND METHOD.

1,380,335. Specification of Letters Patent. Patented May 31, 1921.

Application filed October 29, 1920. Serial No. 420,372.

To all whom it may concern:

Be it known that I, CLIFFORD M. PAXTON, a citizen of the United States, and resident of Brooklyn, in the county of Kings and State of New York, have invented certain new and useful Improvements in Gyroscopic Devices and Methods, (Case F.) of which the following is a specification.

My present invention relates more particularly to gyroscopic devices of the type adapted to maintain or indicate a fixed direction in space during rotation of the earth.

In my prior application, Serial No. 351,236, filed January 13, 1920, I have described among other things two different classes of units having this object in view. One of them is the "parallel" gyroscope so called because it is so constructed and operated that the rotary movement of the earth about its axis is utilized to cause the spinning axis of the gyroscope to maintain a position parallel with the axis of the earth. Thus it maintains a fixed direction which is that of the celestial poles, thereby constituting a compass indicating north and at the same time giving a direct indication of the latitude of the place. As described in said application, this unit comprises a compass for holding the spinning axis of the parallel gyro in the north and south or meridian plane, while the parallel gyro operates to maintain parallelism in said plane. In other applications, Serial No. 361,257, filed February 25, 1920, Serial No. 416,409, filed October 12, 1920, and Serial No. 426,600½, filed November 26, 1920, I have shown and described single-gyro units in which the gyroscopic reactions of a single rotor are utilized so as to make it seek and maintain both the meridian plane and also the position of parallelism in said plane.

Said application, Serial No. 351,236, filed January 13, 1920, discloses how such parallel gyros may be employed in combination with another fixed-direction gyro unit which I have called the "meridian gyro." My present invention as also Serial No. 356,045, filed February 3, 1920, relates to the meridian gyro, so called because it is adapted to maintain or indicate a fixed direction at an angle, preferably a right angle to the fixed direction shown by the parallel gyro. The plane including these two fixed directions so indicated, constitutes in effect a fixed celestial meridian or longitude plane for the earth through which all meridian or longitude planes of the earth must rotate once in twenty-four hours. Hence with these two directions, any location or change of location on the earth can readily be determined.

The fixed meridian plane to be selected for indication by the meridian gyro may be the meridian plane of any place on the earth at any hour of the day. For general purposes the position of the meridian plane at Greenwich at noon is preferable, although for special purposes the noon position of the meridian plane of the place where the instrument is located, may be preferable. Such a meridian gyro can be used for many purposes, but the primary purpose which I had in mind is use in combination with a parallel gyro as a means for indicating the longitude of the place where the instrument is located, the latitude being indicated by the parallel gyro.

The availability of the meridian gyro for such preferred purpose depends upon the fact that it constitutes a clock directly indicating sidereal time. Such a sidereal clock has important uses entirely independent of longitude indication.

Clocks measure the sub-divisions of a "day," but there are two distinct days of different lengths, both based on one revolution of the earth about its axis. One is the solar day, representing one complete revolution of the earth with respect to the sun, and hence takes into account the change of angle of the earth with respect to the sun resulting from the earth's orbital motion around the sun. Thus the solar day involves a rotation of an average of nearly 361° as regards space, but the excess over the 360° varies with the position of the earth in its orbit. The other kind of day is the sidereal day representing one revolution of the earth with reference to a fixed point in space. As rotation of the earth is uniform it follows that the sidereal days are all of equal length and the length is the same for all points on the earth's surface. This, as measured by an ordinary clock time, is approximately 23 hours, 56 minutes and 4.1 seconds.

Obviously it is sidereal time that will be

kept by any device adapted to maintain and indicate a fixed-direction meridian plane. For instance, such time would be kept by a gyro freely and frictionlessly suspended in perfectly neutral equilibrium and its spinning axis in the plane of spin of the earth, which is of course at right angles to the axis of the earth. The spinning axis of such a gyro would appear to rotate end over end, once in each sidereal day, the real motion of course being the rotation of the mounting and of the observer on the rotating earth, with respect to the gyro maintaining its fixed direction in space. The sidereal time may be read simply by observing the angle of the apparent rotary movement of the gyro spinning axis with reference to a fixed point on its mounting.

Such frictionless gyro is impossible, however, and friction in the pivotal mountings operates to apply a slight but continuous torque of the rotating earth in the plane of rotation of the earth which is east. Such a torque, as explained in my parallel gyro application referred to above, tends to cause precession of the spinning axis toward parallel with the earth's axis. Hence a gyro even if properly set in a plane at right angles to the plane of the earth's axis and in a direction corresponding to a fixed meridian plane would immediately begin to show yield in the direction of the rotation of the earth and precess out of the plane of spin of the earth or other plane at right angles with the earth's axis.

My present invention includes means for automatically preventing and compensating for such factors of error and inoperativeness. The principles of my invention and the novelty of my methods and means for obviating the effects of rotation of the earth and overcoming the pole-seeking tendency of the gyro will be better understood from the following reference to well known laws of gyroscopic action.

A high speed rotor develops the mechanical reactions and the peculiar resultant movements characteristic of the gyroscope only when mounted so as to be free for angular movement out of the plane of its spin, and when subjected to a force or torque which will actually cause such angular movement. This angular torque is usually applied through the spinning axis which is of course perpendicular to the plane of the spin.

It is a law of the gyroscope that the movement or "dip" in the direction of the displacing force will be small, but such movement or dip compounded with the power of momentum of the high speed rotor will cause a resultant movement of the spinning axis at approximately right angles to the direction of the primary displacing effort. This resultant motion is called "precession" and is peculiar to gyroscopes.

The mechanics, geometry and mathematics of the development of precession are well known to scientists and extended consideration of them is unnecessary for present purposes. It may be noted, however, that the direction of precession depends upon the direction of the "dip", in its relation to the direction of spin of the gyroscope. For instance, as viewed endwise, a downward dip of the axle will cause precession to the left if the rotor is spinning clockwise, or the right if the rotor is spinning counter-clockwise; or an upward dip would cause precession to the right if the rotor is spinning clockwise, or to the left if spinning counter-clockwise.

Furthermore, if precession is opposed, as by friction in the pivotal axis about which the precessional movement must develop, the direction of the precession will be correspondingly less than a right angle to primary displacement torque. That is to say, there will be a porportional yield or loss of position in the direction of the primary displacement torque. In the special case, where the friction or other opposition to precession is prohibitive as where the torque is so small or so slowly or so rigidly applied that it cannot overcome the initial starting resistance on the precessional axis, there will be no precession at all; no gyroscopic opposition to angular movement will be developed; the displacement torque will be unopposed; and the movement will be wholly yielding in the direction of the torque.

The precessional movements and efforts are purely mechanical resultants dependent upon inertia and rotary momentum. This is important, since a gyro spinning axis tends to maintain fixed direction in space, and in so doing may appear to have important angular movements when considered with reference to the surface of the rotating earth on which it is located, and vice versa, a gyro axis having fixed direction on the earth's surface may have and usually will have important angular movements in space.

In this and certain other connections the axis of the earth may be reckoned as a fixed direction in space, substantially unchanged by the earth's orbital motion around the sun. The slight shift represented by the precession of the equinoxes is too slow to produce appreciable effects and is therefore negligible.

With the above principles as a basis my gyroscopic sidereal clock and its possible uses as a clock when located in a fixed position on the earth; or as a longitude indicator when moved about over the surface of the earth, may be explained as follows:—

The gyro has its spinning axis mounted for free end-over-end rotation in the plane of spin of the earth, that is, in the latitude plane of the place. At the equator this

is the equatorial plane and is the east and west vertical plane of the place. In other latitudes the planes of spin of the earth will be planes parallel with the equatorial plane and at right angles to the axis of the earth. This involves different inclinations from the vertical, for different latitudes. For instance, in latitude 30° north the horizontal plane of the place is at an angle of 30° to the earth's axis. Hence, the plane of earth spin will be one which includes an east and west horizontal line, and a line at right angles thereto slanting upward but inclined south at an angle of 30° from the vertical of the place. In latitude 30° south the same thing is true, except that the inclination away from the vertical of the place, is toward the north instead of toward the south. These are simple geometrical relations easily observable by slicing an orange at right angles to its core, the skin of the orange representing the horizontal of the place, the core the axis of rotation and the cut surface the plane of spin of the earth.

In order to permit the end over end rotation of the spinning axis in the plane of the earth's spin, there must be a pivotal mounting affording a pivotal axis in the north and south or meridian plane, parallel with the earth's axis. These north and south pivots may be called the "parallel pivots" and their axis the parallel axis.

In order that the gyro may develop its peculiar tendency to maintain fixed direction of its spinning axis, said spinning axis must be mounted for freedom to precess in the direction of the meridian plane which is at right angles to the plane of spin of the earth. Hence, the north-and-south "parallel" pivots carry a ring supporting other pivots having their axis in the plane of rotation of said parallel pivots, which is also the plane of spin of the earth. Hence these second pivots rotate end-over-end with the gyro spinning axis carried thereby, but permitting the latter the required freedom for precession in the north and south planes. These end-over-end mounting pivots should be as frictionless as possible so as to afford the least possible resistance to precession in reponse to the earth torque applied in the plane of the earth's spin, through friction in the "parallel" pivots.

The gyro, gyro casing, and the pivots and pivot rings constituting the universal mounting therefor, are all carefully balanced with respect to all three of the axes of possible movements so that the gyro is in neutral equilibrium with respect to gravity.

The "parallel" pivot bearings have appreciable friction, so that the rotating earth applies considerable frictional torque tending to rotate the gyro axis in the direction of earth spin. In order to permit this to take effect as precession, and do so with minimum yield in the direction of the torque, which is east, and in order to automatically restore the north or south loss of position due to the precession, I employ a device for applying a continuous succession of torques on the spinning axis in the plane of the earth's rotation. The alternating resilient torque is made relatively great, as compared with the torque of the earth which is applied through friction around the parallel pivots, and as compared with the frictional resistance to precession around the "end-over-end" pivots. This continuously operating alternating torque is of sufficient power to cause relatively wide precessional movements of the spinning axis to and fro, approximately in the meridian plane, and approximately equal distances across and on each side of the plane of spin of the earth.

As a simple way of making the precessional movement of desired amplitude and also of equal amplitude on both sides of said plane of spin of the earth, I provide an automatic cut-out and torque-reversing device operating only when precession has carried the spinning axis the desired predetermined distance in either direction.

In the initial construction of the instrument, the resilient means for applying the torque in one direction is made as nearly as possible identical in construction with that which applies the torque in the other direction, so that initially, and except for subsequent adjustments, the torques in opposite directions though entirely independent, will be the same in power and rate of application. One of the torques will work in the same direction with the earth torque, however, and the other torque will work in opposition to the earth torque. Hence the primarily equal torques would be gradually increasing in one direction and decreasing in the other direction. According to my invention this may be corrected by adjusting the tension of the torque-applying springs until the precession in opposite directions are accomplished in equal times. Now we have equal torques producing absolutely equal-time, equal-distance precession, but the torque in the one direction represents the alternating torque plus the one-direction earth torque, while the torque in the other direction represents the alternating torque minus the earth torque. An important feature of my invention is that all of the variables can be taken care of by trial regulations of the adjusting means, until the instrument keeps approximately correct sidereal time, within the limits required for other accurate chronometers.

The principle seems clear enough, but may be arithmetically explained as follows:—

Let x equal the value to which the earth

torque builds up during the time the alternating torque is applied in one direction. Suppose the friction tending to oppose precession in response to the torque is also x. In this situation suppose we apply an alternating torque equal to $150x$ about the same axis as the earth torque. The torques on the gyro spinning axis both being at $150x$ but the torque applied in the direction of the earth torque builds up to $151x$ while that in the direction opposing earth torque falls to $149x$. We may now adjust the resilient torque-applying means until the one operating with earth torque applies an initial torque of $149x$. Such torque beginning at $149x$ will be gradually built up by the increasing earth torque to a final value of $150x$ while the torque in the opposite direction beginning at $150x$ will fall to a final value of $149x$. It is the x difference in the initial torques that is important, and so far as concerns this, the actual values might be $129x$ as against $130x$ or $164x$ as against $165x$.

In either case the alternating torques actually exerted will be of equal average value and equal total value as well as for equal times and through equal distances. Moreover the time rate of change will be identical for the increasing values in one direction as for the decreasing values in the other direction. The important point is that the one-direction earth torque has been taken care of by reciprocal precessions approximately within the fixed-direction meridian plane which it is the purpose of the instrument to preserve and indicate. The "precessional momentum" and "curl" phenomena described in my application, Serial No. 426,600½, filed November 26, 1920, in so far as these phenomena may be developed, will also be equal, symmetrical and opposite, and hence mutually compensating.

So far as concerns these aspects of the matter, the value of alternating torque applied by the local source of power might be much greater or less than $150x$; up to a point where precession becomes too rapid and down to the limit where other factors such as the resistance to precession, would not be taken care of properly.

In the case supposed above, where earth torque and the resistance to precession are both equal to x the yield in the direction of the torque would be equal to the precession at right angles to the torque. It is to improve this situation that the reciprocating torque is made very great as compared with the resistance opposing the precession. Also, as pointed out in my said application, Serial No. 426,600½, filed November 26, 1920, the powerful alternating torque of proper frequency and power should be applied through a properly designed resilient member, such as will operate to cause instantaneous clean-cut "dip" followed by restoration of dip permitted by the resilience of said member, and a resultant precession at an angle of almost exactly 90° to the torque. Then the x earth torque being superposed on and submerged in the equal ($150x$) alternating torques all the friction and inertia oppositions to precession are taken care of and the earth torque precession expends itself as part of existing precession in the fixed direction meridian plane which it is the purpose of the instrument to maintain. Moreover any possible yield in the direction of the torque disappears as being part of the yield which is equal and opposite for two directions of the alternating precessional oscillations; as also any possible "curl" at the ends of the precessional movements.

The alternating torques on the pivots causing precession in the fixed meridian plane and the amount of precession allowed in either direction before the cut-outs will operate to reverse the torque and reverse the precession may be varied considerably, but a precessional movement of 3° and 6° or more degrees across and on either side of the earth's spinning plane can do no harm since all such movement is approximately within a fixed plane and cannot show up as a substantial disturbance so far as concerns correct indication of the direction of the fixed meridian plane. The duration of the torque in either direction may also be varied within considerable limits, but three to six complete oscillations per minute may be found practically convenient.

Applying the torque through a resilient medium is of great advantage since it permits sudden application of a maximum effort while decreasing the yield or loss of position of the spinning axis in the direction of the torque. That is to say, the "dip" in the direction of the torque is followed by gyroscopic recovery, or return movement against the resilience of the torque, so that the precessional resultant is more nearly at right angles to the torque, and therefore more exactly in the meridian plane which it is the purpose of the instrument to indicate. The same torque rigidly and unyieldingly applied would absolutely prevent any gyroscopic recovery of dip. Moreover, according to my investigations, the torque when slowly applied through a rigid member that cannot follow up the dip and does not permit recovery thereof, results in relatively large yield in the direction of the torque and relatively small precession at right angles to the plane of the torque.

There remain for consideration only the instants between reversal of torque. With the apparatus shown herein the gyro is free and subjected directly to earth torque during these instants, and collectively, in the

course of time, this might show an accumulated yield in the direction of the earth's rotation. To compensate for this, the movement against the earth torque should be slightly lengthened as to time so that the torque will be correspondingly less than that acting with the earth torque.

When my meridian gyro is used on a ship, submarine or other transport, as a means for finding longitude, it is necessary to have ordinary mechanical chronometers keeping sidereal time in any usual way, as by carefully regulated spring and escapement mechanism. Preferably the dial or indicator will be graduated as a 360° circle, but if graduated in hours, translation into degrees is a simple matter. The difference between the time as shown by the mechanical chronometers, as compared with the apparent time shown by the gyro chronometer, will be the number of degrees of longitude that the ship has been moved east or west.

A rough appreciation of this may be had from a consideration of the gyro chronometer carried entirely around the earth at the equator. If it were carried east in the same direction with rotation of the earth it would apparently gain a whole day in the course of the journey, and if carried west it would lose a whole day. This is because the mounting index being kept "right side up" during the journey, is necessarily rotated one complete revolution around the parallel pivot mounting of the fixed direction gyro, while the mechanical clock so carried around the world would gain or lose nothing by reason of the transportation. So a journey one degree or a fraction of a degree east or west, will show a degree or a fraction of a degree gain or loss by the gyro chronometer as compared with the mechanical chronometer; and conversely observation that such gain or loss has been made will prove that such distance has been traveled.

Theoretically there is room for possible error due to movement of the instrument on the earth in directions having an east or west component which might require corrections for speed if the error were perceptible over a period of days, but such error would be so slight as to be negligible for the following reasons. In applying the mechanical torque we are multiplying the earth torque (as it affects a gyro) many, many times and the movement of a ship over a few feet during the engagement of the clutches each time, would not vary the precessional path sufficiently to lead to error during any reasonable period of time.

Putting the device on ship board, however, requires special means for maintaining the north-and-south pivots parallel with the axis of the earth so that the gyro spinning axis can turn end over end in the spinning plane of the earth. A means for accomplishing this on a ship or other unstable platform, is fully disclosed in my prior applications above referred to. It may be stated, however, that such means includes a parallel gyro on a stabilized base adapted to maintain itself parallel with the axis of the earth. The mounting of this parallel gyro is provided with commutators in operative relation to its compass index and its latitude index respectively. These close successive circuits whenever there is relative movement due to rotation of the ship mounting with reference to the parallel gyro. These circuits operate to close circuits, causing corresponding rotary movements of the meridian gyro support so as to keep its main pivotal axis always in the north and south or meridian plane, and parallel with the axis of the earth. The meridian gyro support may include a base which is stabilized gyroscopically or otherwise and this may be the same base that is used to stabilize the parallel gyro.

Repeaters may be employed to repeat the motions of the gyro—or its apparent motions, to other mechanisms, such as a differential commutator as described in my original application, Serial No. 351,236, filed January 13, 1920, or any other device or mechanism, including astronomical instruments.

In addition to the above described basic features of novelty and invention, my meridian gyro includes certain important improvements in the details of construction and operation, as for instance, the electromagnets as means for applying the alternating torque in the direction of earth torque. They are of special advantage as affording means for instantly applying, continuing and removing torque of a desired predetermined amount; also for applying said torque with a resilient follow-up and return, such as is required to produce approximately ideal dip, complete recovery of dip and precession at right angles to the torque; also as a means for instantly winding up the torque spring to the desired predetermined tension; also for easily regulating said tension by varying the stroke of the magnet armature. By this means of operating through properly selected torque springs the instrument can be regulated for the purposes above described, as accurately as any chronometer. When the strokes of the magnet armatures have been properly regulated, the battery or other source of energy for the electro-magnets may vary in strength through a considerable range provided only that it remains sufficient to afford a full, quick stroke of the armature.

It will be noted that while the functioning of the alternating torques applied as above described, resembles the resilient

rocking device described in my prior application, Serial No. 426,600, filed November 26, 1920, in that it magnifies the effects of earth torque and causes efficiently executed precession in response thereto, causing such precession to be nearly at right angles to the torque and with minimum "yield" or loss of position in the direction of the torque, nevertheless, the functioning in the present case is quite different in detail. Here the one-direction earth torque is superposed on unequal alternating torques of such values that the effective net alternating torques are equal, similar, and opposite, for the purpose and with the result of completely canceling the effect of earth torque. Whereas in the prior application the rocking device is carefully designed to apply torques which are initially equal so that the superposed earth torque will make them unequal for the purpose and with the result of making the earth torque as effective as possible in causing rapid precession away from the plane of spin of the earth and toward parallel with the axis of the earth. Also in the prior case the rocking device operates many times during a single period of continuous application of increasing earth torque. In this latter aspect it will be noted that a rocking device could be actually added to my present device to operate a number of times during each precessional movement, even though in practice such rocking device might not be necessary or desirable. Also the electro-magnet as a means for winding up a spring to apply a predetermined torque, could well be used in place of the crank and link rocking device of said prior parallel gyro application; or the magnets could be used directly as the resilience element of the torque applying means, the armature gap, retracting spring and strength of magnetizing current being adjustable to vary the strengths of the resilient magnetic pull.

The above and other features of my invention may be more fully understood from the following description in connection with the accompanying drawings, in which:—

Figure 1 is a top plan view of the instrument, the parts in this and other figures being shown in the positions they would have at noon at the equator, and the several geographical relations and indications being indicated by legends;

Fig. 2 is an elevation of the same apparatus looking north;

Fig. 3 is a partial section and side elevation on the line 3—3, Fig. 1;

Fig. 4 is a detail on the line 4—4, Fig. 2;

Fig. 5 is a detail on the line 5—5, Fig. 1;

Fig. 6 is a detail section on the line 6—6, Fig. 7;

Fig. 7 is a detail section on the line 7—7, Fig. 6;

Fig. 8 is a detail section on the line 8—8, Fig. 7;

Fig. 9 is a plan view of the electro-magnetic switch for cutting out the circuit of one torque magnet and cutting in the circuit of the other;

Fig. 10 is a side elevation of the same;

Fig. 11 is a diagram of the circuits with the parts conventionally indicated;

Fig. 12 is a diagram indicating geographical relations with respect to the earth as view endwise with respect to the axis; and

Fig. 13 is a similar diagram of the earth viewed edgewise of the equatorial plane.

In these drawings the primary support of the apparatus, functionally considered is the rigid frame 1 which is maintained in a plane, of which the east and west lines are horizontal and the north and south lines, parallel with the axis of the earth. If the instrument is used in a fixed location, as for astronomical purposes, the frame 1 may be fixed on an earth foundation. It may, however, be supported as shown since the automatic means described below as necessary for use on ships, may be kept inoperative, thus holding the parts in fixed position.

When the device is to be used on ship board, however, the frame 1 is provided with pivots 2, the axis of which is horizontal, east and west. These pivots are supported in bearings 3 in the fork 4 having a vertical pivot 9, supported on base 16^a, in the same plane as horizontal pivots 2. The primary support being unstable and capable of horizontal turning movements, the frame 1 is kept with its pivots 2 east and west by rotation of the vertical pivot 9 and with its north and south lines parallel with the axis of the earth by rotation about the horizontal pivots 2. The latter movement is by means of segmental rack 5 operated by pinion 6 driven by motor 7 controlled through circuits 8 connected with the latitude-indicating elements of a parallel gyroscope such as shown in my prior applications, above referred to. The east and west is preserved by gear 12 driven by pinion 13 rotated by motor 14, controlled through circuits 15, by commutator circuits connected with the north indicating elements of the parallel gyro. Repeating circuits for this purpose may be those well known in the art or may be the special repeater circuits described in my prior application.

The frame 1 supports in the north and south or meridian plane, the pivots 17 of gimbal ring 16. These are the "parallel pivots". Ring 16 supports pivots 20 with their axis perpendicular to the axis of said pivots 17 and hence adapted to rotate end over end in the plane of spin of the earth. These pivots permit the to and fro precessional movements in the fixed plane, and may be called the precessional pivots"

Said precessional pivots 20 are in the form of studs on the gyro motor case 21, the spinning axis x of which is vertical in the position shown, which is that of noon at the equator. But it is free to rotate end over end in the plane of spin of the earth about pivots 17. The rotor within the casing is of any known or desired construction, comprising the usual gyro wheel, and means for driving it, the latter being preferably a three-phase motor the field of which is stationary and the armature of which is located on the rotor.

The parallel pivots 17 are the ones around which the frame 1 must rotate while the spinning axis maintains its fixed-direction meridian plane and it is the friction in these pivots which tends to apply the earth torque which would cause yield in the east and west plane and precession in the north and south plane, the former constituting erroneous indication and the latter operating eventually to bring the gyro parallel with the earth's axis where it could not function as a meridian gyro. Hence, it is around the pivot 17 that I apply the alternating torque. The means for applying it, see Figs. 1, 6 and 8, include two similar but oppositely acting assemblies at opposite ends of the parallel or torque pivots 17. Each comprises a clutch member 30 longitudinally fixed but rotatable on shaft 17 and a clutch member 31 longitudinally movable on stud shaft 17^a, which latter is held fixed in bracket 18, on frame 1, by a set screw 17^b.

The clutch member 30 applies torque to shaft 17 through spring 51 surrounding hub sleeve 52, secured at 53 to said clutch 30 and at 54 to a collar 55 secured to shaft 17 by set screw 56.

The movable clutch 31 is operated by clutch magnets 32 attracting armature 33 which is slidable on the hub of member 31 but which operates on 31 through a relatively strong spring 34 in opposition to another weaker spring 34^a. Hence, on compression spring 34^a acts first and on expansion 34 acts first.

The movable clutch member carries parallel guide screws 35 on which the armature 33 is slidable. The arrangement is such that when the magnet 32 is energized, the spring 34 being at first unyielding the armature 33 forces clutch member 31 into firm engagement with member 36, then spring 34 yielding, further movement closes contacts 36—37 of the torque-applying magnet. When magnet 32 is deënergized the stronger spring 34 first forces armature 33 rearward; thus disengaging contacts 36, 37; then further expansion of spring 34 being prevented by the heads of guides 35, the weaker spring 34^a will expand disengaging clutch 31. Thus the torque applying magnet cannot possibly start to apply torque until the clutch is locked, and the torque is released before the clutch is disengaged.

Contacts 36—37 control the circuit that energizes torque magnet 38, the armature 39 of which is rigidly secured to clutch member 31. The initial position of armature 39 with respect to stop 40 on the magnet pole is regulated by set screw 41 secured by lock nut 42 on support 43, which is also the support for the electro-magnet and which is in turn supported by bracket 18 on frame 1. The length of the stroke of armature 39 as determined by screw 41, will fix the amount of torque applied to torque spring 51 when the torque magnet 38 is energized.

The armature 39 is restored to the retracted position, in contact with screw 41, by spring 44 connected to the armature 39, extending freely through passage 45 in support 43, and adapted to be adjustably tensioned by set screw 46, secured by lock nut 47.

The set screw 41 for adjusting the initial gap between torque armature 39 and the pole of torque magnets 38 regulates the respective torques that will be applied to shaft 17 through spring 51 in one direction, and the corresponding spring operating on said shaft in the opposite direction. The magnets 38′ and all other parts for producing torque in the opposite direction to 38 are located on the other pivot 17, the corresponding parts being indicated by the same numerals with a prime mark added. The longer the armature gap, the more the torque springs will be wound up, when the electro-magnet 38 or 38′ attracts the corresponding armature 39 or 39′. Preferably the electro-magnets are strong enough to throw the armature, the full distance, with an instantaneous snap when the circuit is closed through contacts, 36, 37.

The apparent end over end rotation of the spinning axis in the east and west spinning plane of the earth, which is really rotation of frame 1 around the parallel, torque pivot 17 may be accurately indicated and read by means of an index 25 secured on frame 1 in operative relation to a dial 22 secured to ring 16 by projections 23 and screws 24.

The means for cutting out one torque and applying the other at the end of the respective precessional movements include a contact maker on the precessional axis 20 in combination with an ordinary relay on the frame of the machine. The contact maker comprises an arm 60 having end forks 61 in operative relation to fixed contact screws 62, 62 held by lock nuts 63, 63 on brackets 64, 64, on ring 16. The contact maker 60

is rigidly secured to shaft 20 by set screw 20ª. Its shank is preferably of somewhat flexible spring steel so as to permit of slight yield upon making contact with either of the stationary screws 62, 62, at the end of a precessional movement. This permits the gyro to terminate its precessional movement naturally, without material counter pressure such as would be developed if the contact were rigidly made. The screws 62 are adjusted for the purpose of predetermining the extent of the desired precessional movement and for causing them to extend precisely equal distances across and on both sides of the plane of spin of the earth.

The circuits for accomplishing the above purpose are diagrammatically indicated in Fig. 11. The clutch-operating and torque-applying circuit is from any suitable source of power through wire a, collector ring a^1 on vertical pivot 9, wires a^2, a^3, a^4 to one of the electro-magnets 70 of the relay; thence through wire a^5, ring a^6 on the parallel or torque pivot, wire a^7, stationary contact 62, and precessional contact-maker 60 to ground through the frame of the machine. This holds relay switch 71 in contact with 73, closing circuit through wires b^1, b^2, to clutch magnet 32 thence through wire b^3 to ground. The clutch magnet having operated the branch circuit is closed from b^1, through c, contacts 37, 36, wire c^1 to torque magnet 38, then wire c^2 to ground.

This situation continues while precessional movement is moving the precessional contact fork 60, 61 from one position shown, into contact with the other stationary contact 62. This closes circuit through the other coil 70 of the relay magnet, wire a^{15}, collector ring a^{16}, wire a^{17} through 62 and 60 to ground. This throws relay switch 71 into contact with 72 thus closing circuit through wire b^{11}, clutch magnet 32′ and wire b^{13} to ground. The clutch having operated, contacts 36′, 37′ will be closed thereby closing a branch circuit through wire c^{10}, contacts 36′, 37′, wire c^{11}, torque magnet 38′ and wire c^{12} to the ground.

The three-phase current for spinning the gyro, is brought through wires p, q, r collector rings p', q', r', wires p^2, q^2, r^2, rings p^3 q^3, r^3, wires p^4, q^4, r^4, to terminal p^5, q^5, r^5, on the gyro casing, and thence to the interior motor in the usual way. Ring connections upon the precessional pivot 20 are not necessary because the precessions are merely rocking movements within the limits permitted by contacts 62, 62.

When the device is used as a clock in a fixed location so that the frame 1 can be readily set on a fixed earth foundation the shaft 9 and ring connections thereon, may be eliminated.

When the device is used with repeater circuits for maintaining frame 1 parallel with the earth the circuits for vertical repeater motor 14 may be through wires d^{10}, e^{11}, f^{11}, g^{11}, without the need of ring connections. Repeater motor 7, however, for maintaining frame 1 parallel with earth's axis will require ring contacts on the vertical axis 9. As shown these circuits comprise a branch from a^2 through d to repeater motor 7, and thence through wires e, f, g to rings e^1, f^1, g^1, then through e^2, f^2, g^2, to the commutator segments on the latitude indicating elements of the parallel gyro.

In operation the device may be constructed, assembled substantially as shown in the drawings, the frame 1 being parallel with the earth's axis and the gyro spinning with its spinning axis free for end over end rotation in the plane of spin of the earth. The screws 62 on the parallel frame 1 will be adjusted to permit equal precessional movements on both sides of the spinning plane of the earth. The arc of the precessional movements will preferably be considerable so as to reduce percentage of the error introduced by any inaccuracy of this adjustment. For instance, if the precessional movement should be through an angle of 5 seconds on one side of the plane of earth spin and 10 seconds on the other, the error would be a large percentage, whereas if the precession were 5°—59′—55″ one way as against 6°—0′—10″ the other way, the percentage error would be very small. Errors introduced by such asymmetry of the precession are likely to be small in any event because earth torque on a gyro axis in the spinning plane of the earth has only slight change of value for small angles on either side of the spinning plane of the earth. The regulation of the contacts 62 will be conjoined with regulation of the stroke of torque armatures 39, 39′ which determine the amount of wind-up that will be applied to the torque springs 51, 51′, as soon as the clutches are firmly engaged. These two adjustments particularly the stroke of the torque armature will take care of a multiplicity of inaccuracies which it might be impractical or impossible to discover and measure, all of them being properly taken care of and compensated for by trial adjustments until the gyro keeps substantially correct sidereal time throughout a sidereal day. The geometrical relations of the device with respect to the earth are indicated by legends on the diagrammatic views, Figs. 12 and 13. Fig. 12, when the axis of the earth is viewed end-on, shows how the gyro spinning axis maintains its fixed direction in space during rotation of the earth. Assuming position A to be noon at the equator, the spinning axis is vertical, an inclination of 45° as at B will show that three hours has elapsed; the horizontal position of C shows that six hours has elapsed

and the downward inclination at D shows that nine hours has elapsed. The diagram also indicates how these apparent changes of inclinations are in fact movements of the mounting and of the observer with the earth, the gyro spinning axis maintaining fixed direction in space.

Fig. 13 which represents earth viewed edgewise of the equatorial plane shows how the frame 1, maintained parallel with the axis of the earth, appears to have different inclinations for different latitudes, the position at the equator being horizontal and the apparent slant for positions north and south of the equator being opposite. This view also indicates how the frame 1, being maintained parallel with the earth and with its east and west lines horizontal, must describe a cylinder successive positions of which are indicated at E, F and G. The fixed direction spinning axis x which remains within limits either side of the plane of spin of the earth, considered from earth view point appears to rotate end over end in said plane, whereas it is really the frame 1 which is being rotated around the fixed-direction spinning axis of the gyro.

The meridian gyro as herein described, when used on ship board to calculate longitude, will be of very great practical value even though poorly regulated. For instance, if the yield or loss of position due to earth torque is inefficiently compensated for or is over compensated for so that the clock shows a gain or loss of time during a day or a succession of days, the error can easily be kept track of and allowed for, as this is what navigators are well accustomed to doing in the case of their ship's chronometers when navigating by astronomical observation in the usual way. Moreover, if the north and south axes are not exactly parallel with the earth's axis so that the end-over-end apparent movement of the gyro's spinning axis shows an apparent wabble across the plane of spin of the earth, the only effect will be that the gyro will show a cyclic gain followed by a compensating loss during each twenty-four period, the indication being exactly accurate twice every twenty-four hours. Moreover, the intermediate variations can be tabulated and allowed for by comparison with the ordinary ship chronometers, preferably at times when the ship is stationary. Similarly, error due to having the oscillatory precessions inequal distances on either side of plane of spin of the earth or even wholly on one side of said plane of spin can be tabulated and allowed for.

In a device properly constructed and regulated none of these errors are necessary and the above is merely to show how a somewhat disordered meridian gyro may be made of incalculable value to navigators without the necessity for attempting readjustment or regulation during a voyage.

I claim:—

1. The method of enabling a freely mounted gyro to maintain its spinning axis approximately in a fixed-direction celestial meridian plane, which method consists in applying counter-torque to obviate the effects of earth torque, as regards tendency to rotate the gyro axis in the plane of earth spin, and as regards tendency to cause precession at right angles to said plane.

2. In the method specified by claim 1 the further feature of applying, in the opposite direction to the earth torque another torque substantially equivalent to the first torque in total value, average value, duration and time rate of change of values.

3. In the method specified by claim 1, the further feature of permitting the earth torque to cause precession for a definite period; then applying in the opposite direction, a torque adapted to produce counter-precession, the time, distance and speed of which are similar to and compensating for those of said precession.

4. In the method specified by claim 1 the further feature of permitting the earth torque to act cumulatively and resiliently for a predetermined period and then for an equal period applying a similarly-resilient, opposite torque having an initial value equal to the final cumulative value of the first applied torque and the earth torque at the end of said first-mentioned period.

5. In the method specified by claim 1 the further feature of applying in the same direction with the earth torque, for a predetermined period, a resilient torque having a predetermined value much greater than that of the earth torque and then for an equal period applying in the opposite direction a similar resilient torque less than said first-mentioned predetermined torque, by an amount equal to the value of the earth torque, for the purpose and with the result of making the net torques equal in value, time and time rate of change.

6. In the method specified by claim 1 the further feature of applying resilient torques alternately with and against the earth torque adjusted so as to cause equal and opposite precessional movements.

7. In the method specified by claim 6 the further feature of applying the alternating torques during equal times.

8. In the method specified by claim 6 the further feature of having the precessional movements extending substantially equal distances on either side of the plane of spin of the earth.

9. In the method specified by claim 6 the further feature of utilizing the precessional movements to reverse the torque.

10. In the art of operating gyroscopic

apparatus, the method of modifying yield in the direction of an applied torque tending to rotate the gyro out of the plane of its spin and of modifying the precession against resistance in response to said torque, which method consists in causing said torque to take effect through a resilient medium having an initial predetermined tension.

11. In the art of operating gyroscopic apparatus, the method of modifying yield in the direction of an applied torque tending to rotate the gyro out of the plane of its spin and of modifying the precession against resistance in response to said torque, which method consists in periodically applying in opposition to said torque, a torque which is approximately uniform throughout each period of its application.

12. In the art of operating gyroscopic apparatus, the method of modifying yield in the direction of an applied torque tending to rotate the gyro out of the plane of its spin and of modifying the precession against resistance in response to said torque, which method consists in periodically applying in the same plane with said torque, an alternating torque of much greater amount for periods sufficient to produce opposite equal distance precessions.

13. The method of preventing loss of position in operation of a gyro maintaining a fixed-direction plane, which method consists in applying resilient torque alternately with and against a disturbing torque, said alternating torques being of such amounts as to make the net opposed torques equal.

14. In the art of operating gyroscopic apparatus in which the gyro has pivotal mountings about two axes angularly related so that precession about one axis may be produced by earth torque applied about the other axis, and a resilient medium associated with the earth torque pivotal mounting, the method of superposing a predetermined alternating torque and a one direction earth torque, tending to rotate the gyro out of the plane of its spin, which method consists in periodically coupling the earth torque pivotal mounting to an earth anchorage, through said resilient medium and initially tensing said medium to a predetermined degree, against the earth torque so as to be gradually decreased thereby, and then with the earth's torque, so as to be increased thereby.

15. The method of regulating a sidereal clock gyro operating according to claim 14 which method consists in adjusting the initial tensions to unequal initial values until the gyro keeps approximately correct sidereal time.

16. In the method specified by claim 15, the further feature of adjusting the range of the precessions in response to the said resilient torques.

17. In the method specified by claim 16 the further feature of causing the precessional movements to automatically reverse the resilient torque, in accordance with the distance of the precessional movement.

18. A freely mounted gyro, means for spinning it and means to maintain its spinning axis approximately in a fixed-direction meridian plane, including means for applying counter-torque to obviate the effects of earth torque.

19. In the apparatus specified by claim 18 the further feature of means for applying, in the opposite direction to the earth torque another torque of substantially equivalent total value, average value, duration and time rate of change of values.

20. In the apparatus specified by claim 18, the further feature of releasable means for permitting the earth torque to cause precession for a definite period: and for then applying in the opposite direction, a torque adapted to produce counter-precession, the time, distance and speed of which are similar to and compensating for those of said precession.

21. In the apparatus specified by claim 18 the further feature of resiliently operating means through which the earth torque acts accumulatively for a predetermined period and means for then applying for an equal period a similarly-resilient, opposite torque having an initial value equal to the final cumulative value of the applied torque at the end of said first-mentioned period.

22. In the apparatus specified by claim 18 the further feature of means for applying in the same direction with the earth torque, for a predetermined period, a resilient torque having a predetermined value much greater than that of the earth torque and then for an equal period applying in the opposite direction a similar resilient torque which is less than said first-mentioned predetermined torque, by an amount equal to the value of the earth torque, for the purpose and with the result of making the net torques equal in value, time and time rate of change.

23. In the apparatus specified by claim 18 the further feature of means for applying resilient torques alternately with and against the earth torque and means for adjusting said torque so as to cause equal and opposite precessional movements of the gyro.

24. In the apparatus specified by claim 23 the further feature of means adjusted so as to cause the alternating torques to be applied during equal times.

25. In the apparatus specified by claim 23 the further feature of adjusting means for causing the precessional movements to extend substantially equal distances on either side of the plane of spin of the earth.

26. In the apparatus specified by claim 23

the further feature of means operated by the precessional movements, to reverse the torque.

27. A freely mounted gyro, means for spinning it and means for modifying yield in the direction of an applied torque tending to rotate the gyro out of the plane of its spin and of modifying the precession against resistance in response to said torque, said means including resiliently acting means having an initial predetermined torque through which said first torque is applied.

28. A gyro freely mounted to maintain a fixed-direction plane, means for spinning it, and means for applying resilient torque alternately with and against a disturbing torque, said alternating torques being of such amounts as to make the net torques equal.

29. An earth anchorage, a gyro mounting, a resilient medium for coupling said mounting to said anchorage, a gyro freely pivoted in said mounting, means for spinning the gyro and means for superposing a predetermined alternating torque on the one-direction earth torque which tends to rotate the gyro out of the plane of its spin, said means including a clutch element for periodically coupling the gyro mounting to said earth anchorage, through said resilient medium, and means for initially tensing said medium to a predetermined degree, against the earth torque so as to be gradually decreased thereby, and then with the earth's torque so as to be increased thereby.

30. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis and the other perpendicular to said parallel axis, in combination with means for applying alternating torques to the parallel axis.

31. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis, and the other perpendicular to said parallel axis, in combination with resilient means for intermittently applying torque about said parallel axis.

32. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis, and the other perpendicular to said parallel axis, in combination with resilient means for intermittently applying torque about said parallel axis and means for instantly tensing said resilient torque to a predetermined degree.

33. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis, and the other perpendicular to said parallel axis, in combination with independently acting resilient means for applying torque about the parallel axis, in opposite directions, alternately.

34. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis, and the other perpendicular to said parallel axis, in combination with independently acting resilient means for applying torque about the parallel axis, in opposite directions, alternately, and means on the other pivotal axis operating to cut out one torque-applying means and cut in the other, when precession in either direction has progressed a predetermined distance.

35. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis, and the other perpendicular to said parallel axis, and means affording an earth anchorage in operative proximity to said axis, in combination with similar independent, oppositely acting assemblies for applying torque to said parallel axis, each assembly comprising a spring, an electro-magnetically operated clutch for coupling said pivotal axis to said earth anchorage through said spring, a second electro-magnet for shifting the anchorage point to tension the spring when said clutch is engaged, and means for operating said torque assemblies alternately.

36. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis, and the other perpendicular to said parallel axis, and means affording an earth anchorage in operative proximity to said axes, in combination with similar independent, oppositely acting assemblies for applying torque to said parallel axis, each assembly comprising a spring, an electro-magnetically operated clutch for coupling said pivotal axis to said earth anchorage through said spring, a second electro-magnet for shifting the anchorage point to tension the spring when said clutch is engaged, and means on the other axis operated by precessional movement to release the clutch and torque spring causing the precessional movement and to clutch and tense the other assembly to cause precession in the opposite direction.

37. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis, and the other perpendicular to said parallel axis, in combination with means for applying a predetermined elastic torque about said parallel axis and means for predetermining the initial tension of said elastic means, including an electro-magnet and armature operating to tense said elastic means more or less according to the extent of relative movement of magnet and armature when the magnet is energized.

38. A gyro, means for spinning it and a mounting therefor comprising pivotal axes, means for maintaining one approximately parallel with the earth axis, and the other perpendicular to said parallel axis, in combination with means for applying a predetermined elastic torque about said parallel axis and means for predetermining the initial tension of said elastic means, including an electro-magnet and armature operating to tense said elastic means more or less according to the extent of relative movement of magnet and armature when the magnet is energized and means for adjustably limiting the extent of such relative movement.

39. A gyro, means for spinning it, and a mounting therefor affording two axes of pivotal movement angularly related so that precession about one axis may be produced by torque applied about the other axis, in combination with independently acting resilient means for applying torque about one of the axes, in opposite directions, alternately, and means on the other pivotal axis operating to cut out one torque-applying means and cut in the other, when precession in either direction has progressed a predetermined distance.

40. An earth anchorage, a gyro, means for spinning it, means for mounting said gyro in said anchorage and affording two axes of pivotal movement angularly related so that precession about one axis may be produced by torque applied about the other axis, in combination with similar independent, oppositely acting assemblies for applying torque to one of said pivotal axes, each assembly comprising a spring, an electro-magnetically operated clutch for coupling said pivotal axis to the earth anchorage through said spring, a second electro-magnet for shifting the anchorage point to tension the spring when said clutch is engaged, and means for operating said torque assemblies alternately.

41. An earth anchorage, a gyro, means for spinning it, means for mounting said gyro in said anchorage and affording two axes of pivotal movement angularly related so that precession about one axis may be produced by torque applied about the other axis, in combination with similar independent, oppositely acting assemblies for applying torque to one of said pivotal axes, each assembly comprising a spring, an electro-magnetically operated clutch for coupling said pivotal axis to the earth anchorage through said spring, a second electro-magnet for shifting the anchorage point to tension the spring when said clutch is engaged, and means on the other axis operated by precessional movement to release the clutch and torque spring causing the precessional movement and to clutch and tense the other assembly to cause precession in the opposite direction.

42. A gyro, means for spinning it, and a mounting therefor affording two axes of pivotal movement angularly related so that precession about one axis may be produced by torque applied about the other axis, in combination with means for applying a predetermined elastic torque about one of said pivotal axes and means for predetermining the initial tension of said elastic means, including an electro-magnet and armature operating to tense said elastic means more or less according to the extent of relative movement of magnet and armature when the magnet is energized.

43. A gyro, means for spinning it, and a mounting therefore affording two axes of pivotal movement angularly related so that precession about one axis may be produced by torque applied about the other axis, in combination with means for applying a predetermined elastic torque about one of said pivotal axes and means for predetermining the initial tension of said elastic means, including an electro-magnet and armature operating to tense said elastic means more or less according to the extent of relative movement of magnet and armature when the magnet is energized and means for adjustably limiting the extent of such relative movement.

Signed at New York city in the county of New York and State of New York this 26th day of October A. D. 1920.

CLIFFORD M. PAXTON.