

Sept. 23, 1958

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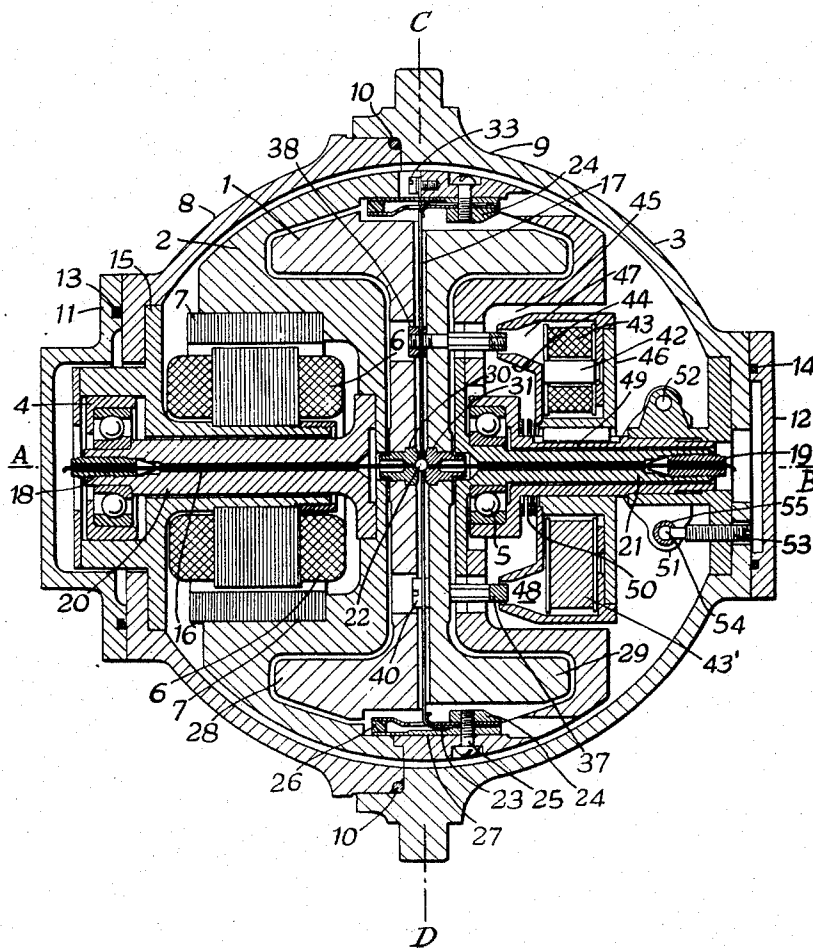
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GYROSCOPIC APPARATUS

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4 Sheets-Sheet 1

Fig. 1.



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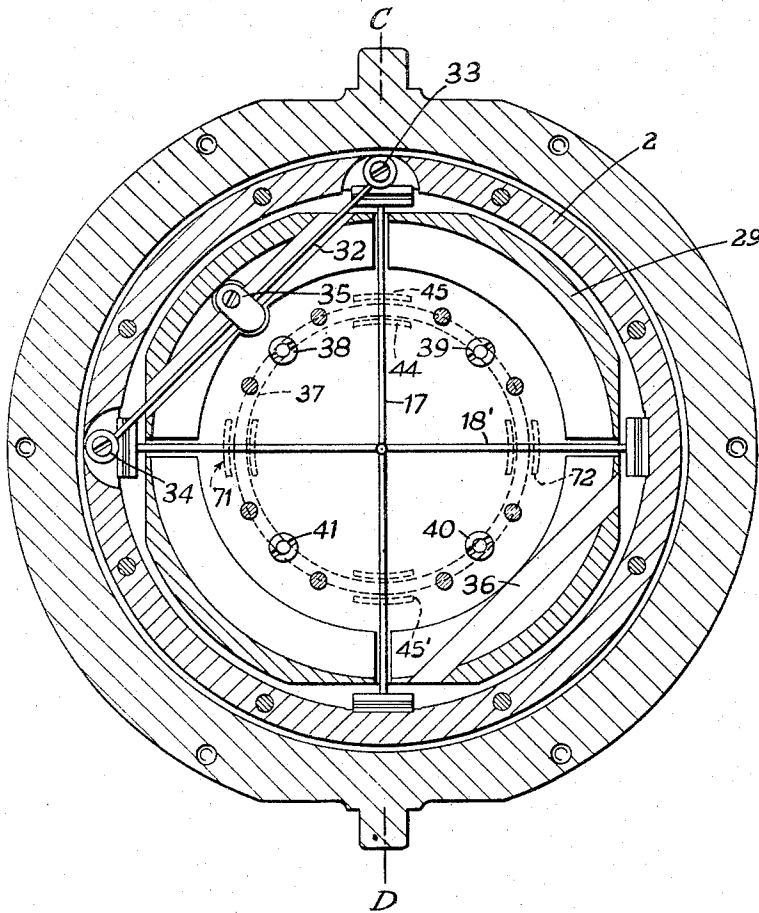
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Fig. 2.



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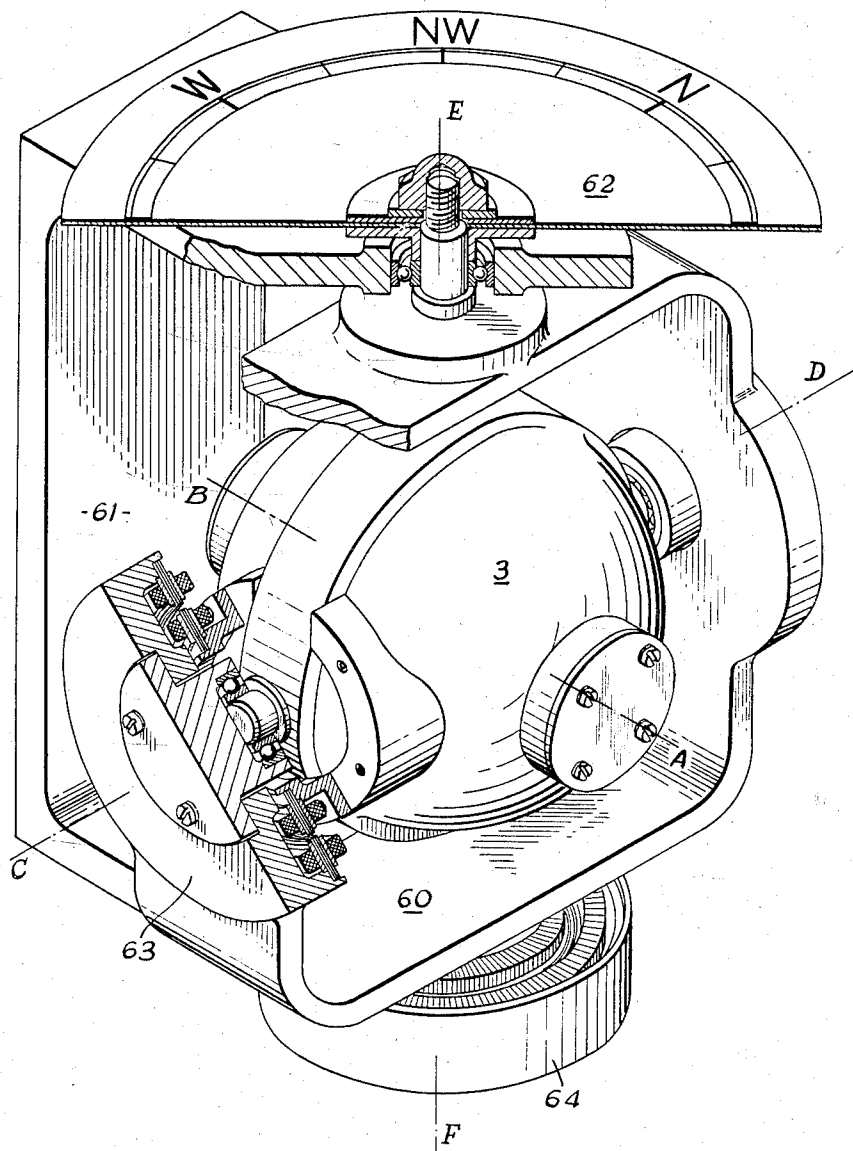
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Fig. 3.



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Fig. 4.

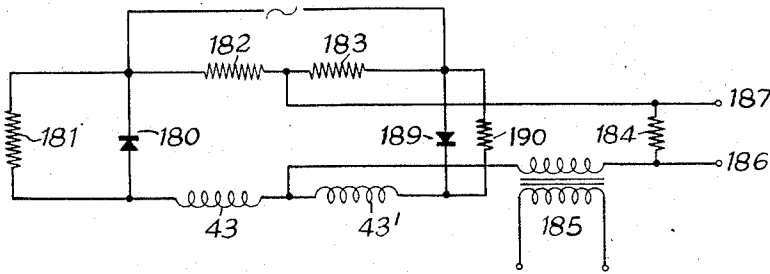
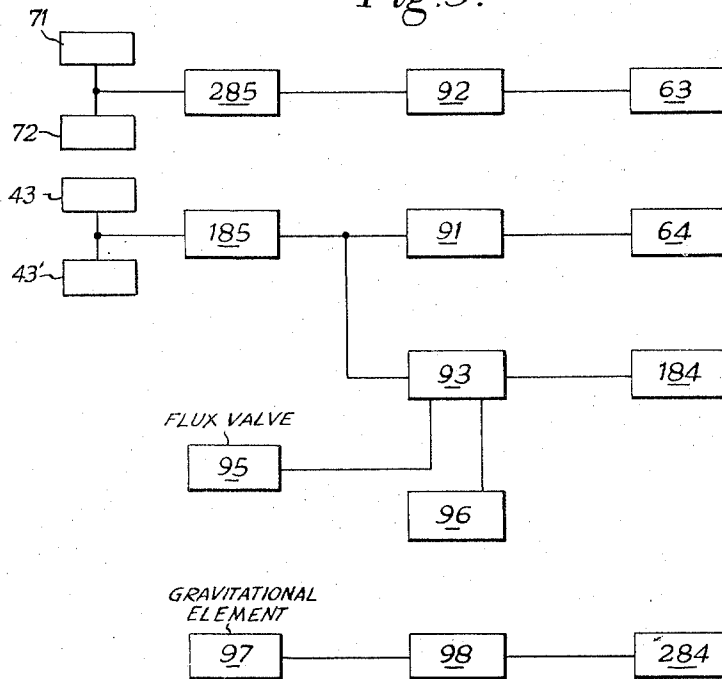


Fig. 5.



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GYROSCOPIC APPARATUS

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8 Claims. (Cl. 74—5.7)

This invention relates to gyroscopic apparatus.

In gyroscopic apparatus a rotor is usually mounted for spinning in a rotor-bearing frame which is itself mounted for angular freedom of movement about at least two mutually perpendicular axes relatively to a support or housing in which the apparatus is carried. Previously in such apparatus the mounting of the rotor-bearing frame providing such freedom of angular movement has usually consisted of a gimbal frame in which the rotor-bearing frame is pivotally mounted in bearings about an axis which is itself pivotally mounted in bearings about a perpendicular axis in the support.

It is well known to those skilled in the art that if the spin axis of the rotor in gyroscopic apparatus of the kind referred to is pointed along a predetermined set direction in space it will keep pointing along this direction in the absence of disturbing torques applied directly or indirectly to the rotor-bearing frame, causing it to precess away from the preset direction. It is more or less impossible to avoid some disturbing torques and it is accordingly extremely difficult to construct gyroscopic apparatus in which the rotor will maintain its spin axis pointing in a predetermined set direction in space for any appreciable length of time.

Various factors, connected with the construction and mounting of the rotor, are responsible for the disturbing torques acting directly or indirectly on the rotor causing it to precess. One of the chief factors is the fact that frictional torques act at the bearings supporting the rotor-bearing frame and gimbal frame when the relative angular movement of the rotor-bearing frame and its support or housing takes place. Another factor responsible for the disturbing torques is the fact that unbalanced torques result from a shifting of the centre of gravity of the rotor relatively to the intersection of the axes of support of the rotor-bearing frame. The resultant of acceleration and gravity forces acting at the displaced centre of gravity cause the application of an unbalance torque about one or both axes causing the rotor to precess away from the set direction in space.

In some cases it is extremely desirable to produce gyroscopic apparatus in which the rotor will maintain its spin axis directed substantially in a predetermined set direction in space for a considerable length of time. For example, it may be desirable to provide an absolute reference in space for a period of time sufficient to enable a craft to be guided over a long range. For this purpose it is essential that the disturbing torques be kept down to a minimum.

To overcome some of the disadvantages of other forms of gyroscopic apparatus, gyroscopic apparatus has been proposed that comprises a rotor mounted for spinning about a first spin axis and adapted to be driven from a driving shaft mounted for spinning about a second spin axis in a support, the first spin axis normally coinciding with the second spin axis but being arranged for relative angular movement about a point on the second spin axis through a limited angle with respect to the

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second spin axis about any axis perpendicular to the first spin axis. Such gyroscopic apparatus will be hereinafter referred to as gyroscopic apparatus of the kind specified.

A number of different types of gyroscopic apparatus of the kind specified are known, in the majority of which the rotor is mounted on the driving shaft by means of a ball joint comprising a ball mounted on the driving shaft and a co-operating spherical surface mounted on, or forming part of, the rotor. In some known apparatus this ball joint is the support for the rotor in addition to being the means of transferring the drive from the driving shaft to the rotor. To reduce frictional effects the apparatus is arranged so that there is some slip between the ball and the spherical surface surrounding it. Gyroscopic apparatus is also known in which the rotor is driven through a Hooke's joint.

In some forms of known gyroscopic apparatus of the kind specified a servo control follow-up system is provided for causing the second spin axis to align itself continuously with the first spin axis.

Apparatus according to the present invention may use a ball joint for mounting and/or driving the rotor, or the rotor may be mounted by means of a wire and spider suspension of the kind described in more detail hereinafter.

One object of the invention is to provide improved driving and/or mounting means for the rotor of gyroscopic apparatus of the kind specified.

A further object of the invention is to provide improved gyroscopic apparatus of the kind specified in which the forces applied to the rotor by its mounting and driving suspension are located more accurately with respect to the centre of gravity of the rotor than in previous designs, so that disturbing torques causing wander of the rotor are reduced.

A further object of the invention is to provide improved gyroscopic apparatus of the kind specified in which control torques may be readily and accurately applied to the rotor of the gyroscope to enable it to be controlled in a predetermined manner.

A still further object of the invention is to provide improved gyroscopic apparatus of the kind specified in which the second spin axis is caused to align itself continuously with the first spin axis in a novel manner.

In one of its aspects the present invention consists in gyroscopic apparatus of the kind specified in which the drive is transferred from the driving shaft to the rotor by means of a flexible connection.

In another of its aspects the present invention consists in gyroscopic apparatus of the kind specified in which the rotor is mounted on a member forming part of, or rigid with, the driving shaft by means of a flexible mounting comprising an axially extending wire and a radially extending spider.

In yet another of its aspects the present invention consists in gyroscopic apparatus of the kind specified in which the driving shaft is formed as, or rigid with, a hollow container or frame within which the rotor is mounted.

In yet another of its aspects the present invention consists in gyroscopic apparatus of the kind specified in which control of the direction of the first spin axis is exercised by means of torque motors acting to produce precessional torques acting on the rotor.

In yet another of its aspects the present invention consists in gyroscopic apparatus of the kind specified in which means are provided for detecting relative angular movement between the first and second spin axes.

In yet another of its aspects the present invention consists in gyroscopic apparatus of the kind specified in which the casing in which the second axis is located is supported in a universal mounting comprising a gimbal ring in which

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the casing is pivoted for rotation about a first gimbal axis perpendicular to the second spin axis and which is itself pivoted for rotation about a second gimbal axis perpendicular to the first gimbal axis and the second spin axis, and in which the driving shaft has appreciable mass so that it may be considered to be the rotor of a gyroscope.

In yet another of its aspects the present invention consists in gyroscopic apparatus of the kind specified in which precessional torques are applied to the rotor to control the direction of the first spin axis and in which corresponding torques are applied to the driving shaft to compensate for reaction from the rotor on the driving shaft.

One embodiment of the present invention will now be described with reference to the accompanying drawings in which:

Fig. 1 is a horizontal section of a directional gyroscope embodying the invention;

Fig. 2 is a sectional view of the same embodiment taken on line C—D in Fig. 1;

Fig. 3 is an isometric projection of the apparatus in its mounting with portions cut away to illustrate other parts more clearly;

Fig. 4 is a circuit diagram showing the electrical connections to the coils of the combined pick-offs and torque motors used in this embodiment and

Fig. 5 is a block diagram showing the connections between the various pick-offs and torque motors.

The directional gyroscope shown in the drawings comprises a primary gyroscope rotor 1 and a secondary gyroscope rotor 2 mounted for rotation about a spin axis A—B in ball bearings 4 and 5 in a rotor case 3. The secondary rotor is several times (e. g. five) as heavy as the primary rotor and consequently has a much larger moment of inertia. The rotor case 3 comprises principally two hemispherical portions 8 and 9 bolted together, the joints being sealed by means of a deformable ring 10. End plates 11 and 12 are secured to the portions 8 and 9 respectively by bolts, not shown, the joints being sealed by deformable rings 13 and 14. After assembly, the rotor case is evacuated sealed, to avoid air reactions between the primary and secondary rotors.

The secondary gyroscope rotor is driven by means of an electric motor comprising a stator 6 mounted on a sleeve member 15 secured to the rotor case and squirrel cage rotor 7 secured to the secondary gyroscope rotor 2. Three-phase alternating current is applied to the stator coils 6 by connecting means not shown.

The primary gyroscope rotor 1 is suspended from the secondary gyroscope rotor 2 by means of an axial wire 16 and a spider 17, 18'. The axial wire 16, which is steel piano wire, is secured at its ends by clamping members 18 and 19, in the ends of tubular portions 20 and 21 of the secondary gyroscope rotor 2. At the centre of the axial wire 16 a small copper bead 22 is formed by electro-deposition. The spider comprises two legs of hardened beryllium copper, the ends of each of which are clamped to the secondary gyroscope rotor 2. Each clamping means comprises a resilient beam 23 having a stamped out portion over which the end of the leg is bent at right angles. The beam and the end of the leg are secured between two blocks 24 and 27 to the body of the secondary gyroscope rotor by means of a clamp screw 25. A rubber block 26 is bonded to the beam 23 and the block 27 to damp vibrations in the beam assembly. At the centre of each pair of legs of the spider is a small hole which just fits over the bead plated on the axial wire 16.

The primary gyroscope rotor 1 is constructed in two portions 28 and 29, in the centre of each of which is a hard steel boss 30 and 31. In assembly the faces of these two hard steel bosses are pressed against the plated bead which is deformed so that the whole assembly is clamped firmly at this point. The axial wire 16 and the legs of the spider pass through holes in the assembled rotor 1 allowing it a small degree of angular freedom of movement relative to the secondary gyroscope rotor 2 about any axis perpendicular to the spin axis A—B. It is advantageous

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that the legs of the spider and the axial wire should be just not in tension under operating conditions. For this reason before assembly they are cooled below operating temperature and clamped so that they are just tight. Thus under operating conditions they expand to be just not in tension. It is also desirable to ensure that the mounting arrangement has the same compliance in all directions.

The primary gyroscope rotor 1 is driven from the secondary gyroscope rotor 2 by means of a flexible connection 32 (Figure 2). This flexible connection comprises a ligament clamped at its ends by screws 33 and 34 in the secondary gyroscope rotor 2. The ligament 32 passes through a hole in the primary gyroscope rotor 1 and is clamped at its centre by clamping means 35, at a point lying in a plane passing through the centre of mass of the primary gyroscope rotor. The hole through which the ligament passes from the periphery of the primary gyroscope rotor to the clamping means 35 is large enough to allow a small degree of angular movement of the primary gyroscope rotor with respect to the secondary gyroscope rotor. The arrangement is such, that over the range of relative angular movement allowed, any force applied to the primary gyroscope rotor by ligament 32 is in a plane normal to its spin axis and consequently does not produce any disturbing torques. A second hole 36 is provided in the primary rotor to balance that provided for the driving ligament.

Since the amount of relative angular movement between the spin axes of the primary and secondary gyroscope rotors that can be permitted is small, a follow up system is provided for causing the spin axis A—B of the secondary rotor 2 to align itself continuously with the spin axis of the primary rotor 1. To provide signals for operating this follow up system, four pick-offs are arranged for detecting angular movement between these spin axes. The main body portion of these pick-offs are mounted in the casing 3 and these portions co-operate with a ring of magnetic material 37 secured to the primary rotor 1 by bolts 38, 39, 40 and 41 (two of which are shown in false section in Figure 1 indicated by reference numerals 38 and 40). Each pick-off comprises a central core 42, on which is wound a coil 43 and two hole pieces 44 and 45 extending from the two ends of the central core 42 towards the ring 37. These pole pieces straddle the ring 37 and the spacing is adjusted, by means to be described hereinafter, so that the pole pieces terminate half way across the ring. The pick-offs are secured to the casing 3 by means of a brass sleeve portion 46, and leads, not shown, are provided for supplying currents to the coils 43. Two of the pick-offs 47 and 48 which lie in the plane of the paper are shown in Figure 1 and two further pick-offs 71 and 72 (shown only in Fig. 5) are provided in similar relation to the axis A—B but displaced 90° around it from the pick-offs 47 and 48.

To enable the overlap between the pole pieces 44 and 45 and the ring 37 to be adjusted, the sleeve 46 is arranged to slide on a sleeve 49 fixed in the casing 3 and is urged towards the right-hand side of Figure 1 by means of a spring 50, movement in this direction being resisted by a cam 51 hinged on a pivot 52. A grub screw 53 having a ball end engages in a socket 55 in the cam 51. Clockwise movement of the cam 51 about its pivot 52 and the cam face forces the sleeve 46 to the left. If the grub screw 53 is turned in an anti-clockwise direction, the spring 50 moves the sleeve 46 to the right.

Referring to Figure 3 of the drawings, the rotor case 3 is shown mounted for rotation about an axis C—D in a gimbal ring 60 which is itself mounted for rotation about an axis E—F in a frame 61. A compass card 62 is shown attached to the gimbal ring 60 which is arranged to give an indication of the direction of a line in the frame 61 relative to the direction of the spin axis A—B.

To enable the secondary gyroscope rotor 2 to be precessed torque motors 63 and 64 are provided, the former being arranged when energised to produce a torque about

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the axis C—D and thus to produce precession of the secondary rotor about the axis E—F, and the latter being arranged when energised to produce a torque about the axis E—F and hence to produce precession of the secondary rotor about the axis C—D. Slip rings, not shown, are provided for supplying the necessary signals to the torque motor 63 and also for supplying the currents required for the driving motor and pick-offs within the casing 3. Clearly the compass card 62 may be replaced by any other device for giving the required indications or by a repeater device for giving indications at a remote point or for controlling other apparatus such as an automatic pilot.

The apparatus so far described will operate as a stable reference in azimuth over comparatively short periods and, if the spin axis A—B is initially set to point, for example, North, it will remain pointing in that direction until disturbing torques causes precession of the primary gyroscope rotor. In order that it may operate as an azimuth reference for longer periods, arrangements are made for slaving or monitoring it from a magnetic-field-responsive device such as a flux valve. To this end the pick-offs 47 and 48 are used also as torque motors for applying precessional torques to the primary gyroscope rotor.

The circuit arrangement that enables these devices to be used as combined pick-offs and torque motors is shown in Figure 4. Figure 4 shows the coils 43 and 43' of pick-offs 47 and 48 connected across an A. C. source through the parallel combination of rectifier 180 and of resistor 181 and a further parallel combination of rectifier 189 and resistor 190. The A. C. source may conveniently be the same as that used for energising the motor stator 6. As a result of the inclusion of the rectifiers 180 and 189 in the circuit the current flowing through the coils 43 and 43' has a D. C. component. This D. C. component produces a D. C. magnetic flux across the gap between the pole pieces and the ring 37, as a result of which there is a force tending to increase the overlap between the pole pieces and the ring. As this force acts in the same direction in the case of each pick-off, there is no torque tending to cause relative angular movement of the spin axis of the primary rotor 1 relative to the spin axis A—B. Similarly, the alternating components of the magnetic flux in each gap are in phase and do not produce any resulting torque on the primary rotor. Also connected across the A. C. supply is a pair of series-connected resistors 182 and 183 of equal value and the mid-point of these resistors is connected through a further resistor 184 to one end of the primary of a transformer 185 the other end of which is connected to the mid-point of coils 43 and 43'.

If there is relative rotation between the spin axis of the primary rotor 1 and the axis A—B having a component in the plane containing the axes of the coils 43 and 43' the inductance of the two coils will be changed differentially, since the reluctance of the gap in one pair of pole pieces will be increased, while the reluctance of the other gap will be decreased, as a result of movement of the ring 37. Consequently the A. C. potential at the junction of coils 43 and 43' will differ from that at the junction of the resistors 182 and 183 and an alternating current will flow in the primary of transformer 185. A voltage will be induced in the secondary of this transformer which is applied through amplifying means 91 to the torque motor 64 that will produce precession of the secondary gyroscope rotor to reduce the tilt between the two spin axes.

If a D. C. potential is applied to terminals 186 and 187 across the resistor 184 direct current will flow through coils 43 and 43' in one case in the same direction as the D. C. component of the current from the A. C. source and in the other case in the opposite direction to this D. C. component. Consequently the D. C. flux between the pole pieces in one pick-off will be increased and in the other pick-off will be decreased, with the result that

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a torque will be applied to the primary rotor about an axis normal to the plane containing the axes of the two pick-offs, which torque will produce precession of the primary rotor, and hence of the secondary rotor, about an axis in the plane containing the pick-off axes.

To give the apparatus maximum directional stability to control it so that the axis A—B is maintained either substantially horizontal or else perpendicular to the axis E—F. In either case it is necessary to provide a torque-applying arrangement for applying torques to the primary rotor about an axis perpendicular to both the axis A—B and the axis C—D. For this purpose the pick-offs 71 and 72 (which are not visible in Figure 1, but, as previously stated, are displaced by 90° around the axis A—B from the pick-offs 47 and 48 shown in that figure) are used as torque motors to provide the necessary precessional torques, being connected in a circuit similar to that in Figure 4.

The method of connecting the pick-offs and torque motors is shown diagrammatically in Figure 5. In this figure the components associated with the pair of combined pick-offs and torque motors 47 and 48 are indicated by reference numerals numbered between 100 and 200 and the components associated with the pair of combined pick-offs and torque motors 71 and 72 are indicated by reference numerals numbered between 200 and 300. The output of transformer 185, which provides the signal measuring tilt between the spin axis of the primary rotor and the axis A—B in the plane containing the axes of the pick-offs 47 and 48, is applied through amplifier 91 to the torque motor 64, which torque motor causes the secondary rotor 2 to precess in the plane of the pick-offs 47 and 48 to reduce the tilt measured by these pick-offs. Similarly, the output of transformer 285 which provides the signal measuring tilt between the spin axis of the primary rotor and the axis A—B in the plane containing pick-offs 71 and 72 is applied through amplifier 92 to the torque motor 63, which torque motor causes the secondary rotor 2 to precess in the plane of the pick-offs 71 and 72 to reduce the tilt measured by these pick-offs.

The output of a flux valve 95 which provides an azimuth misalignment error signal is fed through a suitable mixer amplifier 93 to terminals 186 and 187 across resistor 184 to energise torque motors 47 and 48, to produce a torque about the axis C—D and thus produce precession of the primary rotor about an axis perpendicular to both axis A—B and axis C—D. To compensate for the mechanical constraint of the legs of the spider 17, 18 and the axial wire 16, a signal proportional to the output from transformer 185 is fed to the mixer amplifier 93 at such a point in the amplifier that the signal forms only a small proportion of the amplifier output. A further signal may also be fed to the mixer amplifier 93 from a signal generator 96 the output of which is adjusted to have the value necessary to compensate for any unbalance in the primary rotor.

To keep the axis A—B horizontal, a gravity-responsive device 97 (Figure 5, such as a pendulum or liquid level—not shown in Figure 3) is provided on the casing 3. This device may be of any known kind and provides a signal having a magnitude and sense dependent on the magnitude and sense of tilt of the casing 3 about the axis C—D. This signal is applied through an amplifier 98 across resistor 284 to energise torque motors 71 and 72 to produce a torque about an axis perpendicular to both axis A—B and C—D and thus cause precession of the primary rotor about the axis C—D.

Since many changes could be made in the above construction and many apparently widely different embodiments of this invention could be made without departing from the scope thereof, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

I claim:

1. Gyroscopic apparatus including a driven outer rotor and a rotor within said outer rotor and concentric therewith, means universally supporting the inner rotor within the outer rotor at the common center of both, a flexible connection between said rotors to cause the inner rotor to revolve at the same speed as the outer rotor, pick-off means detecting relative tilt between said rotors comprising a pair of diametrically spaced electromagnets, a ring on the inner rotor concentric therewith and which is positioned adjacent said electromagnets whereby the magnetic reluctance of the electromagnets is oppositely varied upon relative tilt of said rotors, said pick-off means producing a signal which varies with both the direction and amount of relative tilt between the rotors.

2. Gyroscopic apparatus comprising a rotor bearing frame mounted with freedom about at least one axis, an outer hollow rotor journaled to spin about a second axis on said frame having an axial opening along its spin axis, an inner rotor arranged within the outer rotor to spin about an axis normally coincident with the axis of the outer rotor having axially spaced parts, and means for universally mounting said inner rotor at its center within said outer rotor including a wire connected at its ends to said outer rotor extending along the axial opening therein having a central bead to which the respective parts of the inner rotor are connected in axially spaced relation on opposite sides of the bead, and a plurality of wires extending radially of the spin axis between the spaced parts of the inner rotor connected to said central bead at one end and resiliently connected to said outer rotor at the other end.

3. Gyroscopic apparatus as claimed in claim 2, in which the radial wires of the mounting means are connected to the outer rotor by a resilient beam having a free end with a damping element thereon engaging the outer rotor.

4. A gyroscope as claimed in claim 2, including means for mounting said rotor to permit relative movement therebetween about the spin axis comprising a flexible ligament connected at its respective ends to the outer rotor and connected at an intermediate point to the inner rotor.

5. Gyroscopic apparatus as claimed in claim 2, including two part pick-off means having a part mounted on the inner rotor and a part mounted on said frame operable to produce signals upon relative tilt of the rotor and frame, and follow-up means actuated by the signals of said pick-off means for causing said frame to follow the plane of rotation of the inner rotor.

6. Gyroscopic apparatus comprising a bearing frame, an outer hollow rotor journaled on said frame, a second rotor mounted on said frame within said outer rotor for limited tilt with relation to the frame, variable inductive means for exerting a torque on the second rotor having diametrically opposite electromagnets on said frame and a ring concentric with and on said second rotor, and means for correcting the relative tilt between the second rotor and frame including control means operable to supply an unbalanced direct current signal to the windings of the electromagnets of said inductive means.

7. Gyroscopic apparatus comprising a bearing frame, an outer hollow rotor journaled on said frame, a second rotor mounted on said frame within said outer rotor for limited tilt with relation to the frame, variable inductive means for producing a signal in accordance with the relative tilt between the second rotor and frame having a pair of diametrically opposite electromagnets on said frame and a ring concentric with and on said second rotor, and a follow-up motor operatively connected to said frame responsive to the signal of said inductive means.

8. Gyroscopic apparatus comprising a bearing frame, an outer hollow rotor journaled on said frame, a second rotor mounted on said frame for limited tilt with relation to the frame, variable inductive means for exerting a torque on the second rotor, variable inductive means for producing a signal in accordance with the relative tilt between the second rotor and frame, the torque exerting and the signal producing inductive means each having diametrically opposite electromagnets on said frame and a common ring concentric with and on said rotor, means for correcting the relative tilt between the second rotor and frame including control means operable to supply an unbalanced direct current signal to the winding of the electromagnets of said torquing inductive means, and a follow-up motor operatively connected to said frame responsive to the signal of said signal producing inductive means.

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