DESIGN FEATURES OF THE G8 TWO DEGREE OF FREEDOM FLOATED GYROSCOPE

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ABSTRACT

The G8 gyro is a two degree of freedom floated instrument designed to provide a low drift reference for a stabilized platform for the inertial guidance of an ICBM. The advantages of two degree of freedom gyros are numerous. Only two gyros are required per platform, and without damping they are simple to produce and provide high performance. The G8 is a miniaturized and improved successor to the gyro in operational use in the Atlas inertial guidance system. It contains unique design features, such as a wire centering system that doubles as the power lead-in to the gimbals, a combined two axis pickoff-torquer system with iron-free secondary coils mounted outside the hermetically sealed housing, and relatively large fluid gaps between the gimbal and housing. The design features are described in detail and related to function, reliability, and producibility considerations.

INTRODUCTION

The design of any gyro is based on a series of compromises between a number of parameters. In the selection of the gyro configuration and design compromises, not only must accuracy and reliability goals be met, but also a product must be arrived at which is readily producible and which yields the simplest and most reliable associated system hardware. This paper discusses the G8 gyro, a two degree of freedom floated instrument designed to provide a low drift reference for a stabilized platform for the inertial guidance of an ICBM.

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The application of a two degree of freedom gyro has numerous advantages:

1) Only two gyros are required for complete three axis stabilization, thereby reducing cost and increasing reliability. In addition, a major feature is the fourth available signal for use as an error detector. In certain applications, the fourth axis is also used as a redundant gyro to improve accuracy about a critical axis.

2) Since damping is not an essential factor, large flotation fluid gaps and large viscosity variations are permissible. The large gaps permit relaxed manufacturing tolerances and reduced sensitivity to dirt and bubbles.

3) As a result of low damping and two degrees of freedom, error signals are produced without forced precession or appreciable lag. Thus the gyro is characterized by a very broad frequency response to angular displacements of the platform. Also, the gyro does not develop drift rates due to angular vibration of the platform either as a result of torque rectification or the well-known "coning" or "yozzling" effect on single axis gyros. This permits geared servos to be used with simplification of the associated stabilization servos coupled with improved gyro performance.

4) Preflight calibration is simplified since a single measurement of spin axis unbalance can be applied to both axes of a given gyro. Also, in some applications, such as ICBM guidance, accuracy is improved because the error resulting from drift due to spin axis unbalance on one axis is cancelled to an appreciable degree by the error resulting on the other axis due to this same spin axis unbalance.

BACKGROUND

Development of two degree of freedom floated gyros was initiated in the late 1940's, and by the mid-1950's they were to be found in a variety of shipboard and land vehicle gyrocompasses and shipboard fire control stable elements. The design approach taken was a natural result of the many years of experience since the 1920's, when mercury floated suspension for gyrocompasses and verticals were used.

In 1954, the first two-axis floated type of gyro for missile use was developed. This gyro is also used in a miniaturized gyrocompass that is currently being produced by both Arma and S. G. Brown Ltd. In 1956 this gyro was adapted for higher acceleration environment and was designated the

4×10^6 gyro.

The 4×10^6 gyro was employed in the inertial guidance systems that were flight tested in the series D Atlas missiles. These full range flights were outstandingly successful, with performance exceeding requirements. By 1959, the successor to the 4×10^6 gyro, the 10^7 gyro, had been developed. The 10^7 gyro is approximately three times as accurate as the 4×10^6 gyro and is more easily produced. All operational Atlas inertial guidance systems employ this gyro. Flight testing with this gyro started in 1961, and, as expected, flight test results show that the guidance accuracy has been improved.

In 1958 development began on a second generation inertial guidance system that has all the capabilities of the Atlas operational system, including accuracy and reliability, in a greatly reduced size. The G8 gyro was developed for this system. Basic design was performed in 1958, and by mid-1959 the first group of G8 gyros was built. Evaluation of these units was carried out into 1961, and it was demonstrated that the G8 gyro performance is superior in most respects to that of the 10^7 gyro in a package one fifth the volume and one quarter the weight.

G8 gyros were extensively sled tested at HAFB in 1961 with highly satisfactory results.

DESIGN DESCRIPTION

Gimbal Configuration

The G8 gyro contains an inner gimbal (similar to that in most floated gyros) that is a sealed floated beryllium shell containing the wheel assembly. The outer gimbal, a simple floated solid beryllium ring with no moving parts, is interposed between the inner gimbal and the housing. As illustrated in Fig. 1, one axis of rotation is provided by fine elastic centering wires between the inner gimbal and the gimbal ring, and another axis of rotation, orthogonal to the first, is provided between the ring and the housing. Both rotation axes are orthogonal to the spin axis.

Wheel Assembly

Within the spherical float the wheel is supported on precision isoelastic ball bearings. A three phase four pole motor spins the wheel at 12,000 rpm in a helium atmosphere. The combination of adequate lubrication, moderate preload, and 12,000 rpm has been demonstrated by life tests to have a mean life in excess of 33,000 hr at 30°C (86°F). Other life tests at 68°C (155°F) have demonstrated a mean life of 14,000 hr. A recent platform operates G8 gyros at 37°C, at which temperature a life of at least 28,000 hr is expected.

Flotation

The gyro is designed with a relatively large (0.040 in.) flotation space surrounding the float. This gap, filled with fluorolube, is uniform since the spherical gimbal is centered within the inner spherical surface of the housing. The large gap results in: 1) low viscous coupling between housing and float; 2) relaxed tolerances in the fabrication of the float and housing spherical surfaces; 3) noncritical centering of the float in the housing; and 4) reduced sensitivity to dirt and bubbles in the fluid.

Pickoffs and Torquers

Pickoff and torquing devices operate about two orthogonal axes perpendicular to the spin axis. The pickoff and torquing devices, located at both ends of the spin axis, consist of primary electromagnets mounted on the float and secondary coils on the housing. These devices are translation devices, as illustrated in Fig. 2 for one axis. The secondary coil sets at the opposite ends of the spin axis are connected so that they add outputs during rotation and so that the tangential forces of the torquing coils form a couple.

The two primary electromagnets serve both the pickoffs and torquers on the two axes. A combined A-C plus D-C current supplied to the magnets sets up a field that is symmetrical about the spin axis. Each of the two secondary coil assemblies contains four coil sets: two for pickoff on the two axes and two for torquing on two axes. The A-C field, normally at 400 cps, induces pickoff coil voltages that are functions of the rotation of the housing relative to the float. D-C currents fed through the secondary torquing coils set up fields that react with the primary D-C field to create the torquing couples.

The magnets are mounted inside the float shell, and the secondary coil assemblies are mounted to the outside of the housing, as shown in Fig. 2. The advantages of having neither the primary nor secondary elements in the fluid are: 1) continuation of the 0.040-in. fluid gap in the pickoff and torquer region; 2) elimination of fluid contamination due to the additional assembly of parts, outgassing from the coils, soldering residues, and hookup wire deterioration; 3) no possibility of inner gimbal mass shift due to fluid absorption in the magnet assemblies; 4) increased reliability resulting from elimination of housing seals to bring out secondary leads; and 5) ease of adjustment of pickoffs without breaking housing seals.

Other features to be noted are as follows:

1) The absence of iron on the secondary reduces pickoff and torquer magnetic reaction torques to negligible levels.

2) The magnets not only serve a dual function as the pickoff and torquing primaries, but also serve as the nuts on the central shaft that locks up the float assembly. This multiplicity of function is in the direction of a minimum number of parts. In this same direction, not a single commercial fastener (screw or nut) is employed in the entire float assembly.

3) The sum of the A-C and D-C excitation is a total of only 1 w. The A-C excitation may be derived from the 400 cps wheel supply, thereby eliminating a power supply. The motor and magnets are both on the float so that field interaction cannot cause disturbing torques.

Suspension Centering

At perfect buoyancy, the flotation fluid exactly supports the weight of the floated gimbals. At temperature other than the buoyancy temperature, a force equal to the difference between the gimbal weight and the buoyancy force is required to keep the gimbals centered. The difference force is proportional to acceleration and the deviation from buoyancy temperature.

In the G8 gyro, the centering force is supplied by tensioned wires, as shown in Fig. 1. The proportions of the wires, the tensioning, and the deflection limits are selected within the bounds of stress consideration to attain: 1) a maximum of centering stiffness; 2) a minimum of torsional restraint about both rotation axes; and 3) a maximum of torsional restraint about the spin axis.

A rugged stop system limits the gimbal freedom about each axis to ± 2° and limits the translations to ± 0.015 in. The stress levels in the wires at the maximum deflections are at the same safe levels irrespective of whether or not the gyro has been filled with flotation fluid. Thus in gyro handling prior to filling, the stops transmit all the shock loads on the gimbals, and it is impossible to damage the centering wires. This is dramatically opposite to the handling of unfilled pivot centered gyros.

The centering wires are straight short $\frac{1}{4}$-in. filaments of heat treated beryllium copper. Because of the simple shape and high strength material, they are not subject to distortion and contribute to the stability of G8 nonacceleration sensitive drift.

The wire tensioning springs readily take up all tolerance buildups along the wire axes. Thus no end play can occur. A consequence of this is that an aluminum housing is mated to the beryllium gimbals without incurring any difficulties due to temperature extremes. This is a major cost advantage compared to a beryllium housing.

The centering wires are electrically insulated and provide four electrical paths from housing to gimbal ring and from gimbal ring to float. Wires embedded in the gimbal ring complete the circuit. No flex leads are required with increase in reliability and elimination of flex torques.

The major advantages of these suspension centering techniques are: 1) no small gaps as with pivots, no friction, dirt cannot cause hangup; 2) low elastic restraint about the sensitive axes; 3) withstands rough handling even without fluid in the gyro; 4) excellent stability of wire twist torques; 5) no end play permits cheaper aluminum housing to be mated to beryllium float; and 6) no flex leads are required.

Balance Adjustment

Float balance is adjusted along three orthogonal axes. In all, the float contains six balance weights, two per axis. Three weights are used for preliminary adjustment at assembly. The other three are adjusted at test.

Three rotary couplings based on a flexed offset bellows mechanism are mounted on the housing. These devices are sealed by metal to metal joints only. No O-rings are used. This results in a very high seal reliability and eliminates the need to cap-seal the O-rings. These devices are miniaturized devices similar to the units employed so successfully in the Arma 10[7] gyro for final balance adjustment.

DESIGN SUMMATION

Among the prime design features that contribute to the accuracy, reliability, and production advantages of the G8 gyro are the following.

1) Two degrees of freedom: only two gyros per platform with four useable axes; simpler hardware in stabilization loop; and insensitive to angular oscillation inputs.

2) Very long life spin bearings.

3) Large fluid gaps: relaxed manufacturing tolerances; and insensitive to dirt and bubbles.

4) Air core pickoff and torquing coils outside housing: negligible reaction torques; and fewer seals.

5) Wire centering: no friction; no handling damage; and no flex leads.

FUNCTIONAL CHARACTERISTICS

The basic functional behaviour (1 and 2)[2] of a two degree of freedom gyro is that the inner gimbal maintains a fixed angular orientation in inertial space. Output signals are produced by angular motions of the housing relative to the inner gimbal about the pickoff axes. Since the housing is mounted to a platform, the output signals are indications of the deviation of the platform from the reference directions established by the gyro. Therefore these signals are servoed to a null to stabilize the platform.

Damping is not an essential factor in the response of the instrument. Thus a large fluid gap is permitted. Because of two degrees of freedom and the large fluid gap, angular motions of the housing do not force precession or otherwise significantly torque the gimbals. The gyro is insensitive to platform oscillation. This permits the use of geared servos with reduction in electronics and drive power.

PERFORMANCE (3, 4)

A very extensive performance evaluation of the G8 has been completed with highly satisfactory results.

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[2]Numbers in parentheses indicate References at end of paper.

Stability of Drift Parameters

The emphasis in the testing was on the long term stability of the unbalance and nonacceleration sensitive (fixed) drift rates. The testing included the effects of numerous shutdowns and high level (14g peak) vibration.

Random drift tests were performed at various orientations to gravity. The test results were analyzed to determine the stability of the various fixed and unbalance drift factors with continuous gyro operation.

The result is that the fixed drifts and the radial unbalances, that is the unbalances along the stabilization axes, are sufficiently stable that for the ICBM application no calibration of these parameters is required, following that at final acceptance test, for the life of the gyro.

For the ICBM application, the spin axis balance requires calibration at infrequent intervals as long as three months. This is operationally suitable in the ICBM, since spin axis balance causes azimuth drift rate, which may be measured with aid of the optics used for ground alignment in azimuth. In addition, since one G8 gyro with its two degrees of freedom provides both roll and azimuth stabilization, the one measurement of azimuth drift rate is used to compensate the drift rate about both axes.

The random drift variations, particularly of the fixed drifts and spin axis unbalance, also determine the suitability of the G8 gyro for inertial navigators. In a level platform for aircraft, land vehicle, or shipboard, the two gyros would be mounted with spin axes horizontal and at right angles. The roll and pitch accuracy is due primarily to random variation of nonacceleration sensitive drift. The azimuth accuracy is determined essentially by spin axis balance variation. Either gyro may be used in azimuth. Accuracy improvement is obtained by using both gyros and averaging them.

Most data were taken without Earth's rate inputs for increased measuring accuracy. This is accomplished either by aligning the spin axis with Earth's axis or by mounting the gyro on an equatorially mounted sidereal rate table. This table cancels Earth's rotation mechanically by counter-rotation about an axis parallel to Earth's axis.

Anisoelasticity

The anisoelasticity drift factors were measured by vibration tests. The gyro was mounted to a horizontal linear motion table, which in turn is driven by an electromagnetic shaker. The gyro spin axis is placed in the horizontal plane at 45° to the direction of table motion, and the drift rate is measured about the horizontal precession axis. Then the gyro is rotated 90° about the spin axis to measure the major compliance in the other spin axis-stabilization axis plane.

CONCLUSION

The G8 gyro was designed as a stabilization reference for a small platform. The objective was to equal the performance of the 10^7 gyro for Atlas in a much reduced size. The design was based on that of the 10^7 gyro, that is, a two degree of freedom, wire centered, floated gyro with similar gimbal configuration, bearings, pickoffs, balance adjusters, and functional characteristics.

The performance goals were exceeded through the use of beryllium, far fewer parts, a simpler, more optimized wire centering assembly, and generally more rigid gimbal and wheel construction.

In addition to full capability of performing the stabilization function in advanced ICBM inertial guidance platforms, the G8 gyro is capable of meeting the gyro requirements for inertial navigators. Also, the G8 gyro is being applied to satellite and space probe injection guidance, azimuth alignment reference devices, and land navigation systems.

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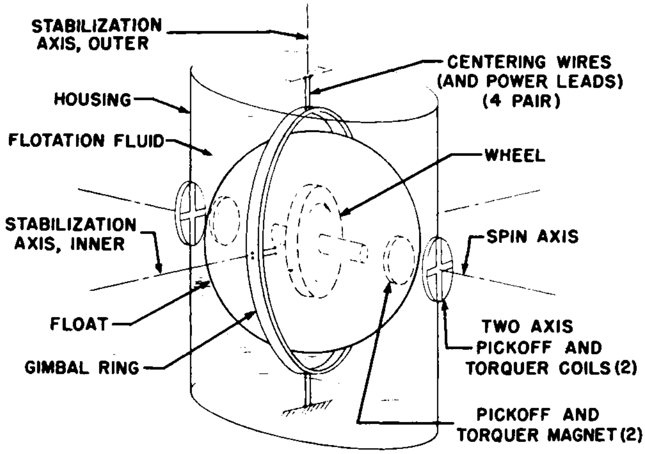

Fig. 1 Functional construction of G8 and 10^7 gyros

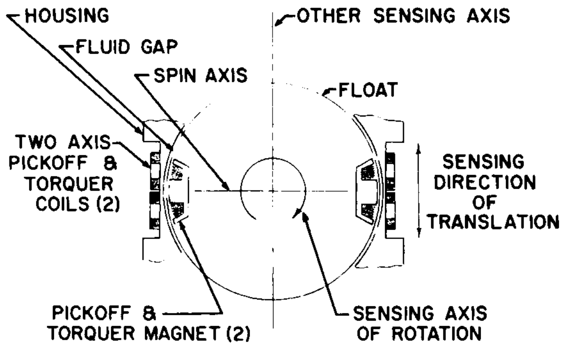

Fig. 2 Pickoff and torquer construction