GRAVITY PROBE B:III. *THE PRECISION GYROSCOPE*

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ABSTRACT

Gyroscopes with Newtonian drift rate less than 0.3 milli-arc-sec/year are under development for the GP-B experiment. This paper presents recent progress in the major areas of the gyro development, including rotor mass unbalance, rotor asphericity, rotor charge control and rotor spinup. All of these results are at or near the requirements of the GP-B experiment, which is expected to be launched in 1998.

1. Introduction

In this paper, we report the development progress of precision gyroscopes for the GP-B experiment[1]. Figure 1 is an exploded view of the gyroscope. The gyro rotor is a 38 mm diameter sphere of homogeneous fused quartz with a uniform layer of niobium coated on its surface. The rotor is assembled in a housing composed of two halves also made of fused quartz. Each of the halves has three electrodes for electrostatic suspension of the gyro rotor and raised support lands around each electrode to prevent electrical contact between the rotor (when not suspended) and any electrode. In addition, the readout half has a thin-film niobium readout loop located on the parting plane between the halves, and the spinup half has a spinup channel with an inlet and outlet for the helium gas, raised spinup lands to reduce leakage of the gas into the gyro during spinup, and an auxiliary channel for differential pumping of the leakage gas through the exhaust holes.

The GP-B experiment requires that the Newtonian drift rate of the gyroscopes be less than 0.3 milli-arc-sec/year. Based on analysis of various Newtonian torques

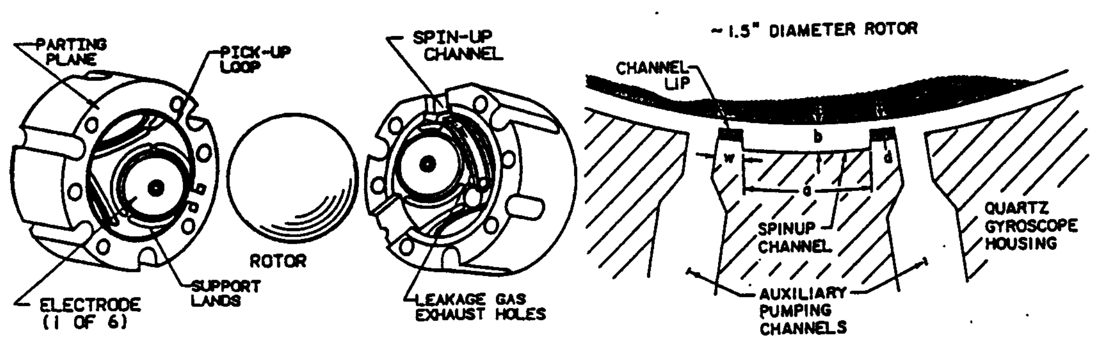

Figure 1: Exploded view of the gyroscope and the cross section of the spinup channel.

on the gyroscopes, specific requirements concerning the gyroscopes can be derived[2]. The current requirements are: 1) rotor mass unbalance less than 50 nm; 2) rotor asphericity less than 50 nm; 3) charge on the rotor less than 50 pC; 4) gyro spin speed between 140-180 Hz; 5) initial alignment within 10 arc-sec of the telescope axis; 6) housing electrode coating non-uniformity less than 0.63 μm; 7) electrode area variation less than four percent; 8) electrode locations within 15 arc-min of its designed locations; In the following sections, we report progress towards meeting these requirements.

2. Mass Unbalance and Asphericity

Mass unbalance is the distance between the center of mass and the center of geometry. Asphericity is defined as the peak-to-valley value of the deviation from an ideal sphere. Two methods are used in measuring the mass unbalance and the asphericity: 1) In the manufacturing process, quartz density variations[3], uncoated quartz rotor asphericity and the coating thickness uniformity are measured. These data allow us to directly calculate mass unbalance and asphericity; 2) Mass unbalance and asphericity affect precession and polhode motion of the gyroscope. By observing gyro precession and polhode motion at low frequencies (1-20 Hz) in the earth's gravity field, both the mass unbalance and the asphericity can be derived[4]. This method provides a good end-to-end check on the entire manufacturing process.

The two methods agree well. To date, the typical vales are: mass unbalance 30–80nm, asphericity 15–90 nm. Further improvements are expected in the near future as we update the coating facilities.

3. Charge Control

Cosmic radiation is the expected principal source of gyroscope charging during the GP-B experiment. The expected charging rate is about 10^{-10} C/Y[5]. Techniques have been developed to monitor and control the charge on the rotor[5]. In laboratory experiments, we demonstrated that the charge on the rotor can be controlled to below 50 pC, see Fig. 2 and note that one volt potential difference between the rotor and the electrodes is equivalent to 500 pC charge on the rotor since the capacitance between the rotor and the electrodes is 500 pF. The current limitation on the control is due to the measurement accuracy. The measurement accuracy will be improved by a factor of ten when the same technique is applied to the flight experiment, we therefore expect that the charge on the rotor be controlled at levels below 5 pC during the GP-B experiment.

4. Gyro Spinup

To ensure that the London moment can be developed properly, the spinup has to be carried out at temperatures below the transition temperature of the superconducting film[6]. The transition temperature is about 9K for niobium film. Within the available flow conductance allocated for the spinup system, the maximum gyro

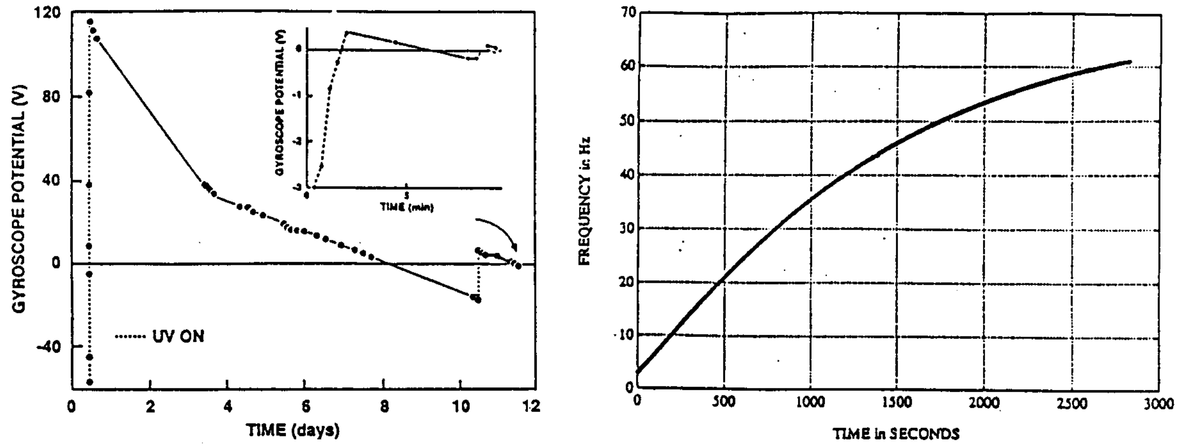

Figure 2: Left: Charge Control. One volt potential is equivalent to 300 pC; Right: Spinup at 8K with a flow of 1.5 mg/s.

spin speed is determined by the ratio of the frictional force produced by gas flow in the spinup channel and the drag force produced by gas flow over the spinup lip (the raised spinup lands). The flow over the lip happens to be in the transitional flow region where little data is available. In a recent experiment, we measured the drag force and demonstrated the feasibility of the spinup system. The results, shown in Fig. 2, agree well to our design model[7] which predicts that the rotor can be spun to 170 Hz in 180 minutes with a flow of 2.5 mg/s.

5. Conclusion

We have reported the progress towards producing precision gyroscopes for the GP-B experiment. All results are at or near the requirements for the GP-B experiment which is expected to be launched in 1998.

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1. Bardas et al., "The Gravity Probe-B Relativity Gyroscope Experiment: Progress on Development of the Flight Instrument", this conference.

2. G. M. Keiser, GP-B Tech. Report, S0019.

3. G. Dunbar, Measurement of optical homogeity of fused silica, M. SC. Thesis, University of Aberdeen, Scotland, U.K. (1981)

4. S. Feteih, G. M. Keiser, J. V. Breakwell, and Y. Xiao, "Results of Dynamic Testing of GP-B Spherical Gyroscopes", Proceedings of the AIAA Guidance, Navigation, and Control Conference, Boston, MA, August, 1989;

5. S. Buchman, G. M. Keiser, D. Gill, and R. A. Van Patten, "Charge Measurement and Control for the GP-B Experiment", to be published.

6. J. M. Lockhart, "SQUID Readout and Ultra-low Magnetic Fields for GP-B", SPIE Vol. 619 Cryogenic Optical Systems and Instruments II (1986).

7. Y. M. Xiao, A Low Pressure Gas Spinup System, GP-B Tech. Report, S0136.