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Gravity Probe B Relativity Mission

VERIFICATION OF T002 REQUIREMENT 5, Part B: GYROSCOPE READOUT NOISE

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ITAR Assessment Performed ____________
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6.17.03
ITAR Control Req'd? ☐ Yes ☑ No

1. Introduction

Requirement 5 of the Gravity Probe B Twelve Fundamental Requirements (T002) specifies the requirements on the noise and nonlinearity of the gyroscope readout system.

Requirement 5, Gyroscope Readout
The SG readout system shall have a linearity consistent with an error of less than 0.3 marcsec/year. The gyroscope readout system single-sided noise spectral density shall be less than 190 marcsec/sqrt(Hz) x sqrt(roll period/180 sec) x (130 Hz/spin speed).

This paragraph contains two requirements. The first requirement states that the nonlinearity of the gyroscope readout system shall be consistent with an error of less than 0.3 marcsec/year The second requirement specifies the readout noise. The purpose of this document is to verify the requirement on the gyroscope readout noise. Note that this requirement is substantially the same as requirement 3.2.2 of the System Design and Performance Requirements (T003), which has already been verified.

2. Measurement of SQUID Noise

The SQUID noise for all of the four flight SQUID has been measured and documented in [1] (p.11). These results are summarized in column 2 of Table 1 below for a 3 minute roll period. The relation between the SQUID noise to the noise in terms of a London moment equivalent angle has been shown [2] to be

$$v_L = \frac{1}{k_{LM}' k_S} v_S$$

where v_S is the SQUID noise, v_L is the noise expressed in terms of the London moment equivalent angle, k_{LM}' is the scale factor that determines the relation between the gyroscope misalignment (the angle between the gyroscope spin axis and the plane of the pick up loop) and the magnetic flux through the pickup loop, and k_S determines the relation between the flux in the SQUID and the flux in the pickup loop. From [2], these scale factors are

$$k_{LM}' = 7.14 \times 10^{-7} f_S \text{ in units of } \phi_{0,LOOP}/\text{mas}$$

$$k_S \approx 1/363 \text{ in units of } \phi_{0,SQUID}/\phi_{0,LOOP}$$

where f_S is the gyroscope spin speed in Hz. Using these scale factors, the contribution of the SQUID noise to the gyroscope readout noise at 130 Hz spin speed is given in column 3 of Table 1. Since the London moment is proportional to the gyroscope spin speed, it is clear that the readout noise, when expressed in terms of the London moment equivalent angle, decreases inversely as spin speed. In addition, from the measurements shown in [1], the noise decreases as the square root of the roll frequency over the range from the expected satellite roll period from 3 minutes to 1 minute [3].

Table 1. Measured SQUID Noise

Flight Gyroscope/SQUID	Measured SQUID Noise	London Moment Equivalent Noise
1	30 $\mu\Phi_0/\sqrt{Hz}$	117 mas/$\sqrt{Hz}$
2	37 $\mu\Phi_0/\sqrt{Hz}$	145 mas/$\sqrt{Hz}$
3	34 $\mu\Phi_0/\sqrt{Hz}$	133 mas/$\sqrt{Hz}$
4	31 $\mu\Phi_0/\sqrt{Hz}$	121 mas/$\sqrt{Hz}$

3. Other Contributions to Gyroscope Readout Noise

From [2], the London moment and the random miscentering of the gyroscope rotor was shown to be 0.1 mas/√Hz for the unsupported gyroscope and 0.3 mas/√Hz for the supported gyroscopes. The quantization noise of the 16-bit A/D converter is 0.03 mas/√Hz when the range and gain of the SQUID Readout Electronics are adjusted to provide a ±100 arc second full scale range. Since both of these effects are negligible compared to the SQUID noise, the overall gyroscope readout noise may be taken to be the values listed in Table 1.

Summary

The overall gyroscope readout noise for each of the four flight gyroscopes at 130 Hz spin speed and 180 second roll period is given in Table 1. When expressed in terms of the London moment equivalent angle the noise decreases with increasing spin speed. Because of the 1/f nature of the gyroscope readout noise, it decreases as the square root of the satellite roll period. Other contributions to the gyroscope readout noise are insignificant compared to the SQUID noise.

References:

1. Clark, B., *Verification of Payload Readout Requirements*, S0575, Rev. -, Hansen Laboratories, GP-B, Stanford University, 2001.
2. Keiser, G.M., J. Lockhart, and B. Muhlfelder, *Bias Variations in the Gravity Probe B Readout System*, S0352, Rev. -, GP-B, Hansen Laboratories, Stanford University, 2003.
3. Lockheed, *System Design and Documentation, Control System Error Budgets and Capability*, SCSE-04, Part 5, Rev. C, Lockheed Martin Missiles and Space, 2002.