PROGRESS IN THE MEASUREMENT OF THE GRAVITATIONAL CONSTANT USING A CRYOGENIC TORSION PENDULUM

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Abstract

Continuing measurements of G are being made using a cryogenic torsion pendulum in the "dynamic" (time-of-swing) mode. The total metrology contribution to the G error budget is about 7 ppm. Data runs are being conducted using both CuBe and Al5056 torsion fibers to test for systematic fiber-dependent effects.

Method

We determine G by measuring the change in oscillation frequency of a thin-plate torsion pendulum due to a pair of ring-shaped source masses positioned alternately as indicated in Figure 1. The pendulum is in an evacuated chamber within a dewar filled with liquid helium; the source mass rings are suspended outside the dewar at room temperature. The pendulum's suspension point is maintained at ~ 2.7 K, normally controlled within 0.2 mK. Advantages of low temperature operation include reduced thermal noise, increased frequency stability, and superconducting magnetic shielding.

The high Q afforded by low temperature operation minimizes bias due to fiber anelasticity [1]. Details of the apparatus are reported elsewhere[2,3].

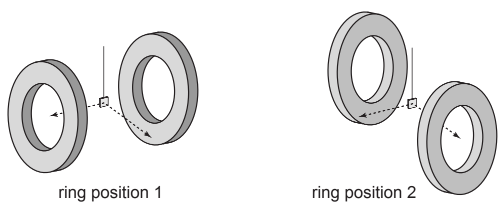

Figure 1: The pendulum and source mass rings. The pendulum is an 11 gram fused silica square plate 40x40x3 mm, suspend by a copper-beryllium fiber 20 μm diameter and 24 cm long. Each copper ring is 59 kg with dimensions: 52 cm OD, 32 cm ID, 5 cm width.

The frequency shift due to the source mass rings may be expressed as: $\omega_1^2 - \omega_2^2 \cong KG\ J_1(2A)/A$, where ω_1 and ω_2 are the pendulum's frequencies for the ring positions as indicated in Figure 1, K is a geometric factor determined by the mass and dimensions of the pendulum and rings, G is the gravitational constant, J_1 is a Bessel function, and A is the oscillation amplitude of the pendulum. Thus by measuring the frequencies and amplitude of the pendulum, KG may be determined. We operate the pendulum at an oscillation amplitude near an extremum of $J_1(2A)/A$: 2.57, 4.21, 7.40 radians. The oscillation period is about 135 seconds. At 2.57 radian oscillation amplitude the period shift due to the source mass rings is 1.7 milliseconds. Data runs of 12 to 48 hour length are made by setting the pendulum's amplitude to about 50 mrad above one of the extrema, then allowing the pendulum to "ring down" while alternately moving the source mass rings every 20 pendulum cycles. By restricting our knowledge of K as we analyze our data, we are able to conduct a "blind" experiment minimizing the danger of bias.

Data runs, 2000 and 2002

Data runs totaling $\sim$690 hours were made in the Fall of 2000, yielding "KG" values (Figure 2) which proved to be compromised by a timing glitch. It was possible to identify and filter out the glitches quite effectively, yielding a KG value with about 10 ppm uncertainty based on data taken with 2.7 radian oscillation amplitude. We returned to take an additional $\sim$660 hours of data in the Spring of 2002 with the glitch problem corrected. These runs suffered however from much worse temperature control than the earlier runs, and yielded far noisier data (Figure 3). Selecting data taken at 2.57 radian amplitude with relatively good temperature control yielded a KG value with 18 ppm uncertainty, differing from the earlier value by 24 ± 21 ppm. Most disturbing however is an indication in the 2002 data, less evident in the 2000 data, of a dependence of apparent KG on oscillation amplitude. This suggests that, contrary to the conclusion of our analysis in reference [2], there may be significant systematic error from fiber anelastic properties. The temperature control problem has been traced to electronic noise coupling to the temperature control servo systems. We have also found a helium leak into the pendulum's vacuum chamber, which we suspect was a major cause of the increased noise.

Planned runs, 2004

Additional data runs will be made in the Spring of 2004, after rectifying the problems which afflicted runs in 2000 and 2002. The pendulum will use an Al5056 torsion fiber with higher Q than that of the CuBe fibers used previously. Comparison of results using this fiber with earlier results using both heat-treated and non-treated CuBe fibers will provide checks for systematic bias associated with anelasticity. Several apparatus improvements will be implemented for these runs. The magnetic eddy current system that damps pendulum swing modes has been modified so that it also damps "bounce" modes associated with stretching of the fiber, which we expect will reduce noise levels. Improvements to the optical readout system are being made which will stabilize and minimize the optical power absorbed by the pendulum's mirror, reducing noise associated with variations in fiber temperature. Results of these runs will be presented at CPEM2004.

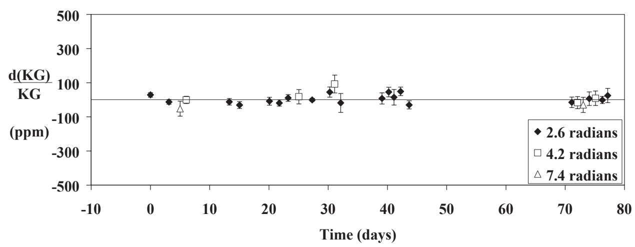

Figure 2: Determined KG values for data runs from October to December 2000, expressed as their ppm deviation from a value hidden from the experimenter. For each run, the pendulum's oscillation amplitude was one of three nominal values: 2.57-solid diamond, 4.21-open square, and 7.40-open triangle. After day 45 the as-drawn fiber ($Q \sim 80,000$) was replaced with a heat treated fiber of the same material ($Q \sim 120,000$). Outliers, about 2% of the data, were excluded in the determination of KG values.

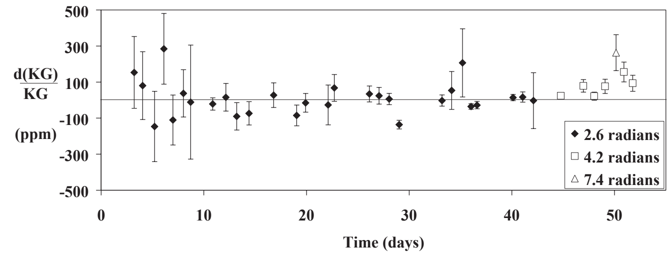

Figure 3: Determined KG values for data runs in 2002, expressed as their ppm deviation from the same hidden value used in 2000.

Acknowledgments

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