Search for general relativistic effects in table-top displacement metrology

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Abstract: As displacement metrology accuracy improves, general relativistic effects will become noticeable. Metrology gauges developed for the Space Interferometry Mission, were used to search for locally anisotropic space-time, with a null result at the 10^{-10} level.

OCIS codes: (120.3940) Metrology (120.3180) Interferometry (000.2780) Gravity

1. Introduction

General relativity predicts that remotely referenced displacement metrology [1] will experience an error accumulating at $(dL/L)/dh$=0.00011 pm/m^2 of altitude difference. *E.g.*, a standard at JPL (~400 m altitude) will appear 0.15 pm longer to a client at Mount Wilson (~1800 meters). Verifying effects like this and searching for exotic effects predicted by alternative theories has the potential to discover "new physics." We describe a search for anisotropy due to the gravitational field of the sun suggested by Tomozawa [2], using pre-existing apparatus.

2. Experiment

NASA/JPL's Space Interferometry Mission (SIM) [3,4] has motivated the development of interferometric heterodyne displacement metrology gauges with repeatability roughly 50 pm[5]. The gauges' linearity and thermal stability are tested [6] in a temperature stabilized vacuum tank with a dedicated laser source, a temperature stabilized 1.3 micron YAG coupled to two AOMs to produce two frequencies separated by 2 kHz. This experiment used two gauges: A oriented east-west and B north-south, monitoring the distance between corner-cube retroreflectors separated by 76 +/-.2 cm. A feedback system [7] maintained head alignment with the retroreflectors. Equal length baselines made the effect of laser frequency drift common to both gauges, making it straightforward to search for anisotropies. *E.g*, a non-isotropic metric would be observed as change in the A-B length difference.

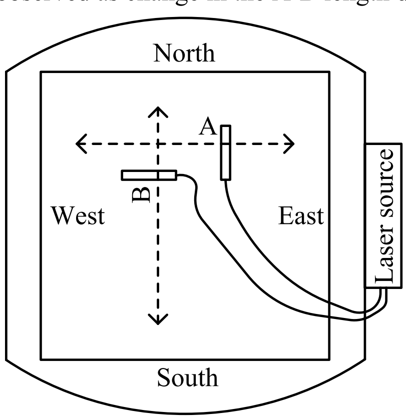

Figure 1. Laser source and optical bench in thermally isolated vacuum chamber. Metrology heads A and B were supplied by a common source via optical fibers and monitored the 76 cm E-W and N-S baselines.

3. Results

Displacement and alignment data for both gauges, and system temperatures were recorded at 6 points/hour from Dec 24, 2002 to Jan 23, 2003. Figure 2 shows the relative length difference (A-B) for this period. Features such as the initial drop, 290 pm/hour rise and dip closely follow the temperature of the aluminum optical table in the tank, indicating a slight thermal-optic asymmetry. After removing the linear trend and applying a Hanning filter, the Fourier amplitudes of the (A-B) data were computed (figure 3).

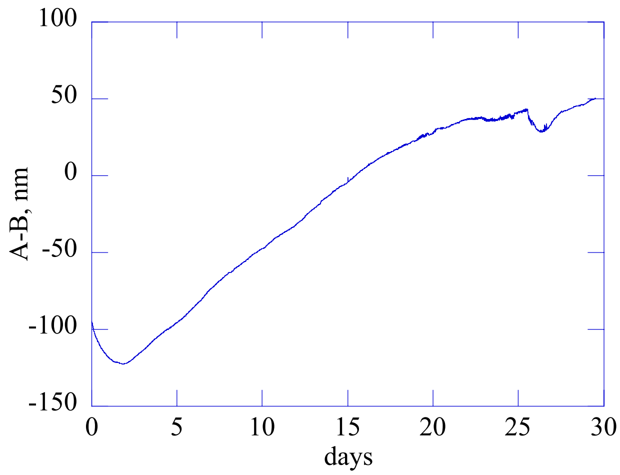

Figure 2. Length difference A-B.

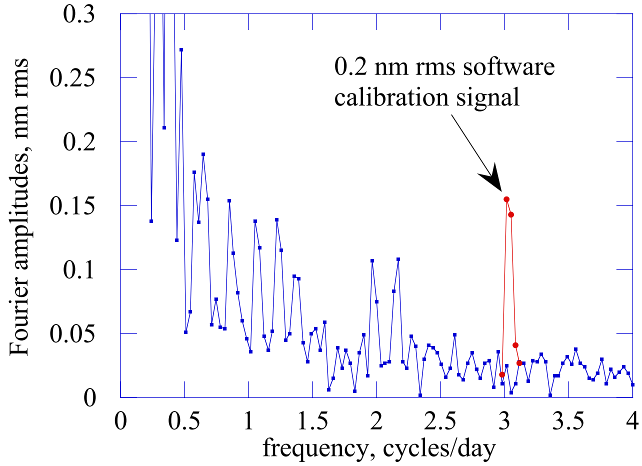

Figure 3. Frequency spectrum of A-B, normalized so peak height indicates RMS amplitude. *E.g.*, the points in the 3 cpd test signal add (in quadrature) to 0.2 nm.

4. Interpretation.

The data rule out the original motivation for this work: the possibility of an anisotropy order $M_{SUN}G/(c^2R)$, R=1 AU, correlated with sun direction. Such an effect, which would create a nm amplitude peak at 2 cpd, can be ruled out at the 0.1 nm level. Other interesting frequencies to examine are the sidereal day (1.0027 and 2.0055 cpd) and the moon's apparent position (0.966 and 1.932 cpd, the tide frequency). Testing frequencies around 1 cpd is problematic because of diurnal effects such as temperature changes. However at 2 cpd, things are more interesting. The 130 pm peak at 1.93 cpd might be tidal effects: ground tilt, movement of vacuum tank, but the peak at 2.13 cpd is not easily explained. Neither peak is in the temperature or pointing data, ruling out these obvious explanations.

5. Conclusion

A "parasitic" Michelson-Morley like experiment was conducted, ruling out local 10^{-10} anisotropies. Although this limit is not competitive with recent results [8], the experiment proved interesting and helps validate SIM metrology. A possible correlation with the lunar period hints at a local "tidal" effect.

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1 A. Hirai, H. Matsumoto, "Remote calibration of end standards using a low-coherence tandem interferometer with an optical fiber," Optics Communications **215** 1-3 pp 25-30 (2003)
2 personal communication: Y. Tomozawa, 2002
3 http://planetquest.jpl.nasa.gov/SIM/sim_index.html

4 SIM, Taking the Measure of the Universe JPL publication 400-811 3/99 (Available online at http://sim.jpl.nasa.gov/library/book.html)

5 L.L.Ames *et al.*, "SIM external metrology beam launcher (QP) development" in Interferometry in Space; Michael Shao; Ed., Proc. SPIE Vol. 4852, 347-354 (2003)

6 P.G. Halverson, L.S. Azevedo, R.T. Diaz, R.E. Spero, "Characterization of Picometer Repeatability Displacement Metrology Gauges" in ODIMAP III, 3rd Topical Meeting on Optoelectronic Distance/Displacement Measurements and Applications, Univ. of Pavia, Italy, 63-68 (2001).

7 J E Logan, P G Halverson, M W Regehr and R E Spero, "Automatic alignment of a displacement-measuring heterodyne interferometer," Appl. Opt. **41**, 4314–4317 (2002)

8 H. Muller, S. Herrmann, C. Braxmaier, S. Schiller, A. Peters, "Modern Michelson-Morley experiment using optical resonators," Phys. Rev. Lett. **91**, 020401 (2003).