Gravity Gradiometer based on Atom Interference

G.T. Foster, J.M. McGuirk, J.B. Fixler, and M.A. Kasevich

Physics Department, Yale University
217 Prospect Street, 06520-8120, New Haven, CT USA
Tel (203)432-3834, Fax (203)432-9710
E-mail: greg@amo.physics.yale.edu, Website: http://amo.physics.yale.edu

Atom interference techniques allow for highly sensitive and accurate measurements of accelerations [1]. We measure gravity gradients by performing simultaneous acceleration measurements on two cold Cs samples separated vertically by $\approx$ 1 m [2]. The gravity gradiometer has important applications to inertial navigation and remote sensing as well as for tests of general relativity and precision measurements of the gravitional constant G.

We report progress towards increasing the sensitivity of our gravity gradiometer. An improved sensitivity of ≈ 2 E/Hz$^{1/2}$ (for a 10 m device) has been demonstrated (1 E = 10^{-9} s^{-2}) which is better than current state of the art commercial instruments. This enhancement is the result of improvements to our detection technique and atomic state preparation.

The device operation is based on light pulse atom interference. A cold sample of Cs atoms is prepared in a magneto-optical trap (MOT) and launched on a vertical ballistic trajectory. We apply a $\pi/2$ - π - $\pi/2$ sequence of doppler sensitive two-photon Raman transitions between the Cs $6S_{1/2}$ F = 3 and F = 4 ground states. This sequence directly maps the atomic motional state to the atomic internal state. The acceleration of gravity $\vec{g}$(r) causes a gravitional phase shift $\Delta\phi = (\vec{k}_1 - \vec{k}_2) \cdot \vec{g}(r)T^2$ to accrue over the course of the interferometer with pulses separated by time T for counterprogating Raman beams with propagation vectors $\vec{k}_1$ and $\vec{k}_2$. We detect the phase shift as a change in the F = 4 population following the interferometer. The gravitational acceleration is simultaneously measured in both chambers since the interferometer beams are aligned vertically to pass through the two cold samples. The subtracted signal divided by the separation yields the gravity gradient in the direction of the Raman beams. This approach exhibits immunity to platform vibrations which couple through the mirror for retroreflecting the Raman beam. Vibrations appear as common phase noise in both samples, which can be directly cancelled out.

We have implemented an improved detection system which cancels out noise from thermal background atoms as well as atom number fluctuations. The atoms are detected using a modulation transfer technique. We first detect the F = 4 ground state population, and then repump and detect the total number of atoms. This allows the removal of amplitude fluctuations from atom number fluctuations associated with the MOT loading. A balanced detector is used with two probe beams, one which detects the cold atoms and one which measures background vapor. The resulting subtracted signal cancels out background atom noise. We have measured signals with a signal to noise in excess of 2000:1.

Changes have also been made to the state preparation sequence to increase signal. In partic-

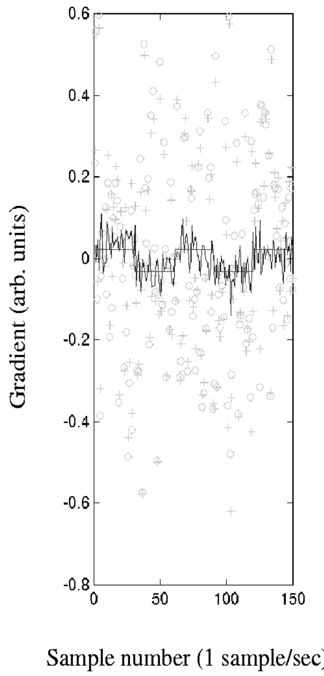

Figure 1: Data showing gravitational phase shift due to $\approx$ 100 kg of Pb bricks stacked 0.2 m above lower chamber. The circles/pluses are the accelerometer output of the upper/lower chambers. The noisy trace shows the gradiometer output with a fit to guide the eye. The brick in/out data is interleaved.

ular, an optical pumping scheme is used to increase the number of atoms that are interrogated in the atom interferometer. We have also employed composite pulse techniques from the field of NMR to improve the effectiveness of our microwave state preparation pulses. These improvements allow detection of small gradients from test masses placed near one chamber, as shown in Fig. 1.

Further improvements are expected by employing more elaborate interferometer sequences which compensate for an inhomogeneous Rabi frequency across the expanding atom ensembles. Improved sensitivity opens up new prospects for measurement. We are currently working towards a measurement of the gravitational constant G.

[1] B. Young, M. Kasevich and S. Chu, *in Atom Interferometry edited by P. Berman* (Academic Press, New York, 1997).

[2] M. J. Snadden, J. M. McGuirk, P. Bouyer, K. G. Haritos, and M. A. Kasevich, *Phys. Rev. Lett.* **81** 971 (1998).