Mitigation of Frequency Shifts in a Cold-Atom Coherent Population Trapping Clock

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A compact cold-atom clock based on lin || lin coherent population trapping[1] (CPT) has been developed in which 2×10^5 ^{87}Rb atoms are interrogated via Ramsey spectroscopy[2] with phase-locked DFB/DBR lasers. Unlike conventional Ramsey spectroscopy, $\pi/2$ pulses are not employed. Rather, the first CPT pulse pumps the atoms into a dark quantum superposition state, and the much shorter second pulse probes the phase of that dark state[3]. The clock demonstrates a fractional frequency stability of $4\times10^{-11}/\sqrt{\tau}$, limited by frequency noise on the interrogation lasers, and integrates down as $\tau^{-1/2}$ out to $\tau = 5000$ s. Beyond this, the long-term stability is affected by the light shift and the Doppler shift.

Light-shift measurements are qualitatively explained by adding contributions from resonant CPT generating couplings[2], resonant non-CPT generating couplings, and far detuned couplings. With current operating parameters, light shift effects in the clock depend heavily on the noise spectrum of the slave laser. Suppressing this noise by optimizing the intensity ratio of the two CPT frequency components and improving the fraction of beat-note power in the coherent carrier has decreased the measured light shift sensitivity. This is an area of continued improvement. Under conditions that minimize the light shift, the clock sensitivity to laser frequency drift is currently 0.45 Hz/MHz. The laser frequencies are stable at the few kHz level over 5 h, thus clock drift arising from laser frequency instability is estimated at $< 3\times10^{-13}$ out to 5 h.

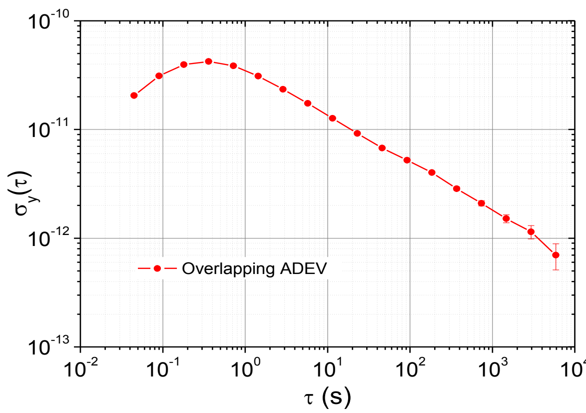

Fig. 1: Fractional frequency stability vs. integration time.

Doppler shifts in the clock can be as large as 1×10^{-10} when interrogating with travelling waves along the direction of gravity, but the shift is significantly reduced by probing the atoms with balanced, counter-propagating CPT beams[4]. Under horizontal interrogation, Doppler shifts can arise if the phases and/or intensities of the counter-propagating CPT beams are not uniform and well overlapped. Currently, drift from Doppler effects limits the long-term fractional frequency stability to the high 10^{-13} range. Improvements are planned that should reduce the clock's sensitivity to residual Doppler shifts.

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[2] P. R. Hemmer et al., *J. Opt. Soc. Am. B* **6**, 1519, 1989.
[3] T. Zanon-Willette et al., *Phys. Rev. A* **84**, 062502, 2011.
[4] F.-X. Esnault et al., *Phys. Rev. A* **88**, 042120, 2013.