Quantum optimal control for sensitive atomic gravimetry

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Inertial sensors based on atom interferometry provide exceptional accuracy and long-term stability levels, which is crucial for precision tests in fundamental physics, inertial guidance and demanding geophysics applications. The sensitivity of these sensors can be further improved by several orders of magnitude using a large momentum transfer (LMT) atom-optics that boost the atomic wave-packet separation, and thus an interferometric area[1]. The application of LMT (n^{th} diffraction order) in the state-of-the-art devices is, however, challenged by the atomic source dispersion and excitation of parasitic diffraction orders. Such systematic effects compromising the interferometric contrast and the extraction of inertial phase should be carefully understood and eliminated[2].

In this work, we use the methods of quantum optimal control (OC) to enhance the fidelity of the LMT atom-optics, employed in a 3-pulse Mach-Zehnder-like gravimeter using cold atoms at ~ 1 μK temperature. Our OC-based algorithm optimizes (simulation) atom-optics fidelity by varying a phase and an amplitude of the Bragg laser field. The obtained optimal patterns (Fig. 1a, left) are then applied to modulate the phase (EOM, about $\pm\pi$ range) and the amplitude (AOM, full range) of interrogating light pulses (Fig. 1a, right). The OC provides a net gain of 20% in the contrast of n = 3 (6 ħk) LMT interferometer, minimizing the contrast drop with respect to the conventional 2 ħk (no OC) case to about factor of 2 (Fig. 1b). Accounting for a three-fold increment in the wave-packet separation, we thus observe up to 50% potential gain in gravimetric sensitivity. Our findings quantitatively differ from the similar recent results[3], while both works underline a great potential of quantum OC methods for cold-atom interferometry. Our results can readily be extended to the dual atomic source configuration, for an enhanced sensitivity in gravity gradient measurements.

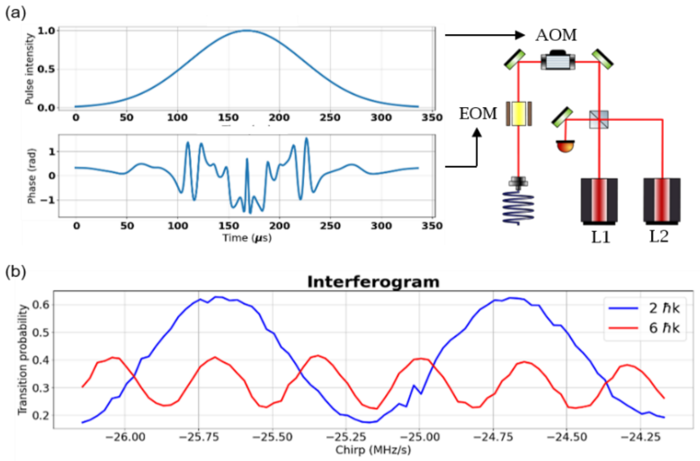

Figure 1: Application of the quantum OC to cold-atom gravimetry. (a) Example of optimized phase profile for Gaussian intensity envelope of the beam-splitter pulse; (b) Recorded fringes for 6ħk OC-enhanced LMT and conventional 2ħk interferometers as a function of laser chirp rate.

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