Magnetic field stabilization in ultracold atom experiments using partial transfer absorption imaging

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We present a non-destructive method for measuring and stabilizing magnetic fields in ultracold atom experiments using partial transfer absorption imaging.

This is the introduction

Proposal

The population transfered by the microwave pulse is

$$P_e(\Omega, \delta, t) = \frac{\Omega^2}{\Omega^2+\delta^2}\sin^2\left(\frac{\sqrt{\Omega^2+\delta^2}}{2}t\right) \tag{1}$$

The full width half maximum is $1/t$. Set Ω and t such that $P_e < 0.05$

Each pulse

$$n_\pm = n_0 P_e(\Omega, \delta_+, \tau) \tag{2}$$

with $\delta_+ = \delta_0 + 1/(2\tau)$

Second pulse:

$$n_- = (n_0 - n_+)P_e(\Omega, \delta_-, \tau) \approx n_0 P_e(\Omega, \delta_-, \tau) \tag{3}$$

The transfer function is

$$g(\Omega, \delta_0, \tau) \tag{4}$$

Main contributions are shot noise and technical noise of the detector. *Signal to noise ratio* SNR for absorption imaging according to Erin's paper is

$$SNR_{\rm model} = \frac{OD}{\Delta_0}\left(\frac{2}{1+e^{OD}}\right)^{1/2} \tag{5}$$

where Δ_0 is the noise in the absence of atoms.

Write transfer function, propagate uncertainties in n transferred to get the real transfer function.

Dick effect

Dick effect due to non-continuous probing

Implementation

Most experiments are performed in the $F = 1$ ground hyperfine manifold with some bias field $B_0\mathbf{e}_z$ that shifts the energies of the different $|m_F\rangle$ states. Due to the linear dependence of the energies of the $|m_F = \pm1\rangle$ and the constant changes in the ambient magnetic field we use microwave assisted partial transfer absorption imaging (PTAI) to monitor and stabilize the magnetic field.

The method relies on transferring a small fraction of atoms into the $5^2S_{1/2}$ $F = 2$ manifold using an oscillating magnetic field with frequency close to the 6.8 GHz ground hyperfine splitting. The atoms in $F = 2$ can be imaged without the use of repump light and therefore minimally disturbing the remaining atoms in $F = 1$. We apply two microwave pulses for a total time τ with frequency $\omega_0 - \delta_\pm$ where $\delta_\pm = \pm 1/(2\tau)$. We typically set ω_0 equal to the Zeeman splitting between the $|F = 1, m_f = -1\rangle$ and $|F = 2, m_f = -2\rangle$ states at a target magnetic field and we set the coupling strength $\Omega_0 \ll 1/\tau$ such that only about 5% of the atoms are transferred by each pulse. We image the transferred atoms following each pulse using absorption imaging and from the measured densities we calculate the imbalance or error

$$n_{\rm imb} = \frac{n(\delta_+) - n(\delta_-)}{n(\delta_+) + n(\delta_-)} \tag{6}$$

signal that is both insensitive to fluctuations in the number of atoms and linearly sensitive to changes in magnetic field[1] . We use this error signal both to monitor the magnetic field before performing experiments and to cancel long term drifts in the field. In most cases, we chose the states $|F = 1, m_F = -1\rangle$ and $|F = 2, mf = -2\rangle$ as their relative energies are the most sensitive to changes in magnetic field. Figure 1a shows the number of atoms

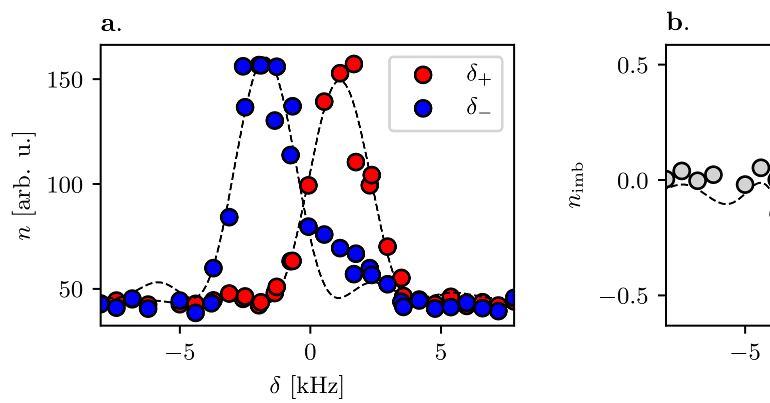

FIG. 1. Magnetic field stabilization using microwave assisted PTAI. **a.** Population transfered into $|F = 2, m_F = -1\rangle$ from $|F = 1, m_F = -1\rangle$ as a function of bias magnetic field (global detuning δ). Each microwave pulse was $\tau = 250\,\mu$s and detuned by $\delta_\pm = \pm 1/(2\tau)$ transfer a small fraction of atoms from $|F = 1, m_F = -1\rangle$ into $|F = 2, m_F = -1\rangle$. **b.** Error signal calculated using the transfered atoms by each pulse. We lock the magnetic field to the $\sim 5\,$kHz ($\sim 7\,$mG) wide linear portion of the signal.

transferred by each microwave pulse for different values of bias magnetic field and Figure 1b shows the imbalance. The microwave frequency ω_0 is on resonance with the $|F=1, m_F=-1\rangle \rightarrow |F=2, m_F=-2\rangle$ transition when both pulses transfer the same number of atoms.

In [2] we studied partial transfer absorption imaging as a minimally destructive technique for imaging ultracold atoms.

Results

More results maybe

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[1] A single pulse on resonance is quadratically sensitive to detuning.

[2] E. M. Seroka, A. V. Curiel, D. Trypogeorgos, N. Lundblad, and I. B. Spielman, Optics Express **27**, 36611 (2019).