An accurate free spin precession cesium magnetometer

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An ongoing search [1] for a permanent neutron electric dipole moment (nEDM) at the Paul Scherrer Institute (Switzerland) calls for an utmost control of the applied $\approx 1\ \mu$T magnetic field B_0. The nEDM experiment consists in searching for a change of the spin precession frequency of ultracold neutrons (UCN) induced by a static electric field applied either parallel or anti-parallel to the magnetic field. The precession frequency is measured using Ramsey's method of (time-)separated $\pi/2$-pulses with a free spin precession time of $\sim$100 s. Within the multinational nEDM collaboration our team is responsible for monitoring spatial and temporal variations of the magnetic field and its gradient around the UCN precession chamber mounted inside of a 5 layer μ-metal shield. For this we currently operate an array of 16 Cs magnetometers mounted both above the high-voltage electrode and below the ground electrode used to apply the electric field to the neutrons. Although extremely sensitive ($\approx$ 10 fT/Hz$^{1/2}$), the M_x-mode of operation of our magnetometers has an accuracy in the upper pT range due to unavoidable phase setting errors in the deployed phase-feedback method of the M_x method. While a high magnetometric sensitivity is key to achieving a high nEDM sensitivity, high accuracy is a *sine qua non* prerequisite for inferring gradient values from the readings of distinct sensors.

In view of improving the accuracy of Cs magnetometry we have investigated the free-spin-precession (FSP) in antirelaxation-coated [2] vapor cells using an all-optical mode of operation. Atomic spin orientation is produced by a circularly-polarized amplitude-modulated pump beam with $\vec{k} \perp \vec{B}_0$ that is resonant with 4→3 transition of the Cs D_1 line. After 20 ms of pumping with a large light intensity, the FSP is recorded with a lower intensity probe beam for 80 ms, the pump-probe process being repeated periodically. The recorded FSP data is bandpass filtered and the Larmor frequency is extracted by fitting a decaying sine wave to the filtered data. The sine wave's oscillation frequency (Larmor frequency) ω_L is a measure of the magnetic field's modulus according to $B_0{=}\omega_L/\gamma_F$, where $\gamma_{F=3}$ is the gyromagnetic ratio of the Cs $F{=}4$ ground state that is known with an accuracy of 10^{-7}. We have experimentally optimized all parameters of the pump and read-out process and estimated a sensitivity below 100 fT/$\sqrt{\text{Hz}}$ in the (light) shotnoise limit. In small fields the accuracy should be on par with the sensitivity. The quadratic Zeeman effect (QZE) resulting from the Breit-Rabi interaction was expected to affect the accuracy at the level of a few pT in a 1 μT field when the readout laser beam is not perpendicular to $\vec{B}_0$. We have measured the anticipated systematic shift $\delta B{=}\beta_{\text{QZE}}\, B_0^2$ due to the QZE, by comparing the FSP frequencies of two readout lasers, one perpendicular to and a second propagating at an angle of 52° with respect to $\vec{B}_0$. To our surprise we found that the experimental difference frequencies are rather described by $\delta B{=}b_{\text{offset}} + \beta_{\text{QZE}}\, B_0^2$. While β_{QZE} agrees well with model calculations, the offset field $b_{\text{offset}}{\approx}50$ pT, derived from the $B_0{\to}0$ limit of $(\omega_L^{90^\circ} - \omega_L^{52^\circ})/\gamma_F$ poses a serious problem. Experimental and theoretical efforts towards a better understanding of this 'offset problem' are in progress.

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References

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