Sources of heading error of atomic magnetometers operated in Earth magnetic field

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In the context of atomic magnetometers the term "heading error" summarizes any falsification of the measured magnetic-field strength in dependence on the orientation of the pump beam direction with respect to the magnetic field B_0 to be measured. Thus, the heading error is a great challenge in the use of such detectors concerning geomagnetism. Special operational modes offering in principle tens of fT per root Hz resolution in Earth magnetic field strengths have been recently introduced [1,2]. These Light Narrowing (LN) and Light-Shift Dispersed M_z (LSD-Mz) modes require large off-resonant pumping and thus exploit large light shifts. Therefore, in our investigations of the heading error we focused on two main contributions, namely the non-linear Zeeman splitting in Earth magnetic field and the light shift.

Our experimental investigation is thus aimed for an independent estimation of both effects. The measurements were performed with setups of cesium vapour atomic magnetometers cleaned from any magnetic pollution that are rotated in a stable and uniform artificial magnetic field well shielded from the outside.

Using a glass-blown vacuum cell [3] the sole action of the non-linear Zeeman effect in the conventional M_x mode at B_0=50μT is investigated. The measured Larmor frequencies as a function of the angle between the pump laser beam direction and the magnetic field are shown in Fig. 1 for both circular polarizations. In the Light Narrowing (LN) [1] and the Light-Shift Dispersed M_z (LSD-Mz) mode [2] strong detuned pumping of a micro-fabricated Cs cell with high buffer-gas pressure is used. The orientation dependence shown in Fig. 2 is a superposition of scalar, vector and tensor light shift.

We support our experimental findings with a theoretical analysis and demonstrate that both dependencies result from the scalar product of the electric field vector of the pump laser and the dipole moment of the atoms in the magnetic field B_0. Our description is based on the modification of the transition dipole moment for different optical transitions when the orientation of the laser beam to the magnetic field is changed. In that frame, the population of the cesium atoms' ground-state levels is calculated following rate equations. This allows a qualitatively description of the measured heading error due to the non-linear Zeeman effect. The light shift of the ground state levels is modified when the atomic magnetometer is rotated in the B_0 field due to the modification of interaction strengths between a single ground and different excited state levels. For parameters consistent to the experiment we achieve good quantitative agreement of the theoretical curves. Our analysis suggest that by the use of both circular polarizations the heading error caused by both, the non-linear Zeeman effect and the light shift, can be compensated when both, amplitude and grade of polarization, are accurately balanced between the two channels.

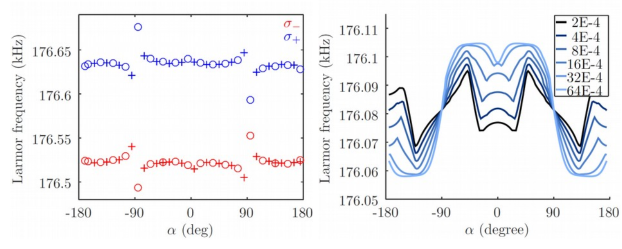

Figure 1: Measured Larmor frequencies for both circular polarizations in dependence of the orientation angle (left) and calculated Larmor frequency for σ+ light.

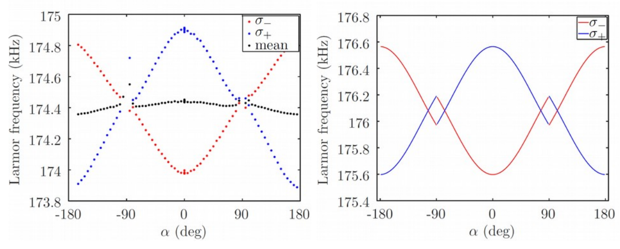

Figure 2: Measured (left) and calculated (right) heading error caused by light shift in the LSD-Mz operational mode for both circular polarizations.

References

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