Sensitive, stable, finite-field atomic cesium vector magnetometer

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Introduction

The magnetometer uses optically pumped cesium vapor in a cell at room temperature and magnetic resonance to measure the magnetic field and its vector components. The laser beam creates net vector magnetization in the medium, which precesses around the magnetic field and creates measurable modulation signals that are analyzed to extract the magnetic field vector.

High sensitivity!

The Vector Cesium Magnetometer (VCsM), was tested in a proof of principle experiment, and has shown a sensitivity of \( \delta B = 7.5 \times 10^{-13} \) T and with a flat Allan Standard Deviation up to 1000 seconds. The sensitivity of the magnetometer is very close to the theoretical limit, which is calculated through the Cramér-Rao Lower Bound \([1, 2]\).

How is the magnetic field information extracted?

The amplitude and phase of different FIDs from different directions is an indication of the direction of the magnetic field through a geometrical decomposition using the in-phase and quadrature components of the modulation, as the figure shows.

What kind of signals are recorded?

According to Bloch equations, the combined effect of a pumping laser beam and a magnetic field orients the magnetization along the magnetic field. A \( \pi/2 \) pulse is applied to tilt the magnetization and create transverse magnetization. The magnetization then, precesses freely while orienting along the magnetic field. Each laser beam probes the projection of the magnetization on its \( k \)-vector, creating a decaying modulation that is called a Free Induction Decay (FID).

How does it operate?

A circularly polarized laser beam is applied on the cesium atoms. According to conservation of angular momentum, a net magnetization is created in the atomic medium.

<table>
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<tr>
<th>Classical picture</th>
<th>Quantum picture</th>
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<td>( n ) light</td>
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<td>Unpolarized, isotropic</td>
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According to Bloch equations, a vector magnetization will precess around the direction of an applied magnetic field with a frequency \( \omega = \gamma B \). This precession can be probed by the applied laser beam. The intensity of the transmitted laser beam is proportional to the projection of the vector magnetization on the \( k \)-vector of the laser beam. If multiple laser beams are used, the dynamics of the vector magnetization can be recorded from multiple directions.

Setup of the VCsM

A laser beam that is in resonance with the \( D_2 \) transition of \( ^{133} \)Cs is guided through a single mode fiber to the beam splitter, which splits the laser beam into four branches that go into four multimode fibers. The light proceeds to the magnetometer module, where it leaves a fiber and is collimated with a lens. It goes through two linear polarizers with a cross-angle that can be changed, in order to modify the intensity of the light that goes through the cell. A quarter wave-plate converts the linear polarization of light to circularly polarized light. The circularly polarized light goes into the cesium cell \([1]\), and interacts with the atoms, and then falls onto a photodiode. The photodiode measures the power of the light and creates an analog signal that is amplified by preamps. The analog signal is digitized with an Analog to Digital Converter (ADC) system, and sent to a computer for analysis.

Where was it tested?

The magnetometer was tested on a moving robot inside the magnetic shield of the nEDM experiment \([4]\) called mapper. The mapper measures the spatial distribution of the magnetic field in the shield. A measurement was done to test the stability of the sensor, as well.

Where can it be used in the future?

The Vector Cesium Magnetometer is planned to be used inside the vacuum chamber of the nEDM experiment \([8]\). Cesium magnetometers are important to measure gradients of the magnetic field at the precession chamber.

References


