Feasibility Study for a Novel Type of Optical Vector Magnetometer

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In the frame of a feasibility study for a novel type of vector magnetometer first test measurements were performed at the double Merritt coil system of the Conrad Observatory. The proposed magnetometer is based on the Coupled Dark State Magnetometer (CDSM).

Since 2008, a scalar omni-directional magnetometer has been developed in a cooperation between the Institute of Experimental Physics (Graz, University of Technology) and the Space Research Institute of the Austrian Academy of Sciences in Graz. The magnetometer is especially designed for scientific satellite missions[1,3]. The measurement principle is based on the coherent population trapping (CPT) effect, which is a quantum mechanical interference effect. The magnetometer couples several of the CPT resonances in the atomic vapour of rubidium by multiple laser light fields to measure the magnetic field strength. The CPT resonances are often referred to as dark states, therefore the instrument was named Coupled Dark State Magnetometer (CDSM)[2]. Two sets of different CPT resonances (set A and B) are utilised to cover the entire 360° angular range between the sensor axis and the magnetic field vector (sensor angle β). Figure 1 shows the atomic transition scheme used for the CDSM. The blue resonances form set A and the purple resonances form set B. The resonance amplitude of the set A has a sensor angular behaviour which is proportional to $\cos^2(\beta)$, while the amplitude of set B is proportional to $\sin^2(\beta)$. These angular behaviours have a broad angular range where both sets can be measured simultaneously.

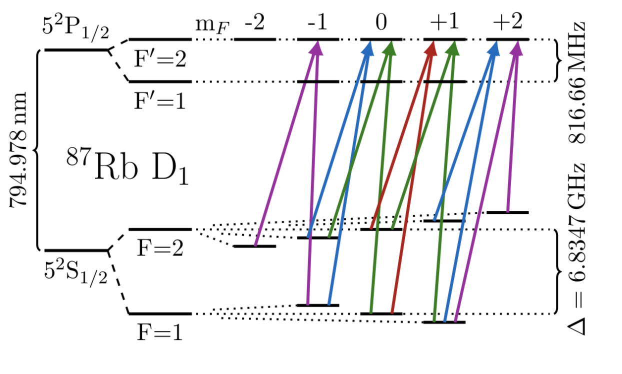

Figure 1: Hyperfine structure of the 87Rb D1 line. Seven different CPT resonances are depicted by their Λ-shaped (two arrows with the same colors) excitation schemes. The degeneracy of the ground states (F= 1,2) is lifted and thus split due to an external magnetic field according to their m_F quantum number (Zeeman effect), as indicated by the dotted lines. The CPT resonance set A is formed by the two blue Λ-shaped resonances and the CPT resonance set B is formed by the two purple Λ-shaped resonances.

Based on the successful CDSM, a novel vector magnetometer is proposed which utilises the CPT resonance amplitude strengths of set A and B to determine the sensor angle. The sensor angle is determined by the amplitude ratio of both sets. First measurements to study the feasibility of this novel concept were performed at the double Merritt coil system of the COBS. Figure 2 displays the first results of the amplitude ratio (orange dots) as a function of the sensor angle. The measured ratio is compared to the amplitude ratio for ideal $\cos^2(\beta)$ and $\sin^2(\beta)$ functions. The amplitude maximum of set A is not equal to the amplitude maximum of set B, thus, their ratio differs from the ideal functions and an angular calibration will be needed for accurate measurements of the sensor angle. The findings confirm the feasibility of the new concept and encourage its further development to a three-laser beam setup. This setup will eliminate angular dead zones around multiples of 90° and it will allow to determine the entire magnetic field vector information. Currently, investigations are performed to evaluate the impact of external parameters like vapour temperature and laser light intensity on the amplitude ratio.

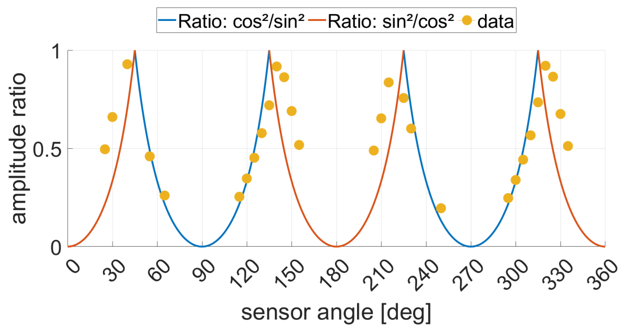

Figure 2: The measured amplitude ratio (orange dots) is compared to the ideal ratio of the amplitude for sets A and B. For each sensor angle, the smaller amplitude is divided by the larger amplitude. At multiples of 90° angular dead zones appear which will be eliminated by a three-laser beam setup.

References:
[1] Pollinger et al., https://doi:10.1088/1361-6501/aacde4 (2018)
[2] Lammegger, R., pat. WO/2008/15134
[3] Pollinger et al., Instrum. Method. Data Syst., 9, 275–291, https://doi.org/10.5194/gi-9-275-2020 (2020)

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