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Quantum magnetometry as an enabling technology in the NewSpace domain

Stephan Busch[1], Peter A. Koss[2], Martin Rother[3], Monika Korte[3]

[1] Fraunhofer EMI, Ernst-Zermelo-Str. 4, 79104 Freiburg, Germany
[2] Fraunhofer IPM, Georges-Koehler-Allee 301, 79110 Freiburg, Germany
[3] Helmholz-Zentrum Potsdam GFZ, Albert-Einstein-Straße 42-46, 14473 Potsdam, Germany
stephan.busch@emi.fraunhofer.de

Summary: Quantum magnetometry advances rapidly, leading to compact sensors with high sensitivity and absolute accuracy without the need for cryogenic cooling which makes them a promising technology for the NewSpace domain. Small satellite technology provides economic access to space, and when launched in large constellations, they open new possibilities for global applications with high temporal and spatial resolution. This contribution shows benefits of emerging technologies for magnetic cleanliness verification and spaceborne geomagnetic observation.

Keywords: small satellites, geomagnetism, magnetic cleanliness

Introduction

Quantum magnetometry uses the connection between light and atomic systems to measure magnetic fields [1]. Specifically, optically pumped magnetometers (OPM), have seen significant advancements in terms of sensitivity and compactness, as cryogenic cooling is not required. Due to the atomic origin of their signals, OPM have an extremely high magnetic sensitivity and they can operate calibration-free. Thus, OPM are likely to become an enabling technology, in particular for small satellite applications in the NewSpace domain.

Small satellites are currently revolutionizing the space sector as they are significantly cheaper and easier to launch than traditional large satellites. Thus, they are popular for a variety of applications such as Earth observation, satellite communication, and scientific research. When launched in large constellations, they open new possibilities, with the potential to offer worldwide coverage with high temporal and spatial resolution.

The benefits of OPM technology might be exploited for two relevant applications:

1. Magnetic Cleanliness Verification
2. Spaceborne Geomagnetic Observation

Magnetic Cleanliness of Small Satellites

The use of small satellites in scientific and commercial applications presents new and unique challenges, particularly for the pointing requirements where small disturbance torques from residual magnetic dipoles interact with the magnetic field in low Earth orbits. The verification of magnetic cleanliness requirements is particularly challenging for small satellite systems, due to increased utilization of commercial-off-the-shelf (COTS) technology, as well as scaling and signal-to-noise ratio issues. Spatially distributed high accuracy magnetic field measurements can precisely characterize the spacecrafts magnetic properties which allows to compensate their effects on attitude control. For example, the qualification of the Fraunhofer small satellite ERNST [2], lead to the development of a cutting-edge test setup for precise characterization of small residual dipole moments [3].

Geomagnetic Observation on Constellations of Small Satellites

The use of OPM onboard resource-limited small satellites has several advantages as they can be extremely small and lightweight with comparably low power requirements, while the technology allows extremely sensitive measurements without the need for calibration. Considering emerging capabilities of commercial devices to measure also magnetic field vector components, economic small satellite constellations have the potential to provide high-resolution measurements of the Earth's magnetic field simultaneously at many locations and local times. This is particularly useful for studying the Earth's magnetic field in regions where it

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is particularly complex, such as the polar regions or at very low orbital altitudes. This enables studies of geomagnetic field variations to infer about Earth's interior dynamics or space weather [4].

Meeting Scientific Requirements

In order to assess the potential of the current capabilities regarding small satellite technology and OPM sensors, scientific observation requirements were estimated in *Tab. 1*, which are based on observations described in [5] and [6]. All requirements for magnetic flux and attitude knowledge are given as goal specification and corresponding threshold values, describing minimal requirements to ensure valuable observations.

Tab. 1: Scientific observation requirements

Parameter	Goal	Threshold
B, Dyn. Range	±65000 nT	±65000 nT
B, Accuracy	1 nT	5 nT
B, Precision	0.1 nT	1 nT
|B|, Cadence	16 Hz	0.25 Hz
$B_{i=x,y,z}$, Cadence	128 Hz	0.25 Hz
Attitude Accuracy	1 arcsec	30 arcsec

A first analysis on current capabilities of OPM technology shows promising results. Scalar sensors with less than 100 fT/Hz$^{1/2}$ noise floor were built recently [6] and the extraction of vector information with an angular resolution better than 2 arcsec is also possible [7]. It is assumed, that miniaturized OPM which meet the scientific requirements will become commercially available within the next years. Especially mass, size, and power consumptions of commercially available devices qualify them as potential scientific instrument for miniature spacecrafts.

The power requirement of such a payload could likely be met by an efficient 1-2U cubesat platform as described in [8], optimized for the instrument operation such that any electrical currents would be minimized during measurements. Attitude knowledge better than 6 arcsec could be achieved by two orthogonal star trackers on a shared optical bench, mounted as close as possible to the OPM. This instrument assembly could easily be deployed from the satellite with a flexible boom as shown in Fig. 1.

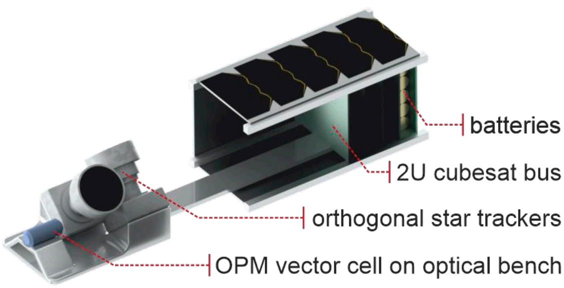

Fig. 1. A satellite concept with an OPM onboard.

Sufficient attitude stabilization to allow for acquisition of the star trackers could be realized by efficient magnetic attitude control [9], operated between the sampling periods. This way, the satellite would create minimal magnetic noise during measurements to meet the challenging magnetic cleanliness requirements.

Conclusions

Recent advances in the development of OPM provides great potential for future small satellite applications. On small satellites, they can be used for high quality platform magnetometer missions, covering many local times to support dedicated science missions [10], and they might be developed into full high-quality magnetic science missions in the future.

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