Error estimate for calibrated fluxgate magnetometer data in space plasma

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Fluxgate magnetometers are widely used in in-situ space plasma observations such as near-Earth space, planetary magnetospheres, and solar wind. Use of the fluxgate magnetometers is advantageous for many reasons: (1) the magnetometers are operationally less demanding to the limited spacecraft resources (mass, electric power cosumption, telemetry data limit), (2) the magnetometer data incude both the large-scale DC (direct current) magnetic field and the lower frequency part of AC (alternate current) field ranging up to about 10 or 100 Hz on the sampling rate.

The fluxgate magnetometers operate with a set of coils (typically with an excitation coil and a pick-up coil wound around a soft ferromagnetic core, and a compensating feedback coil per axis). The coil system is often amounted on a boom extending (over several meters) from the spacecraft body to minimize the interference from the spacecraft-generated field (both in the DC and AC senses). Like most of the other scientific instruments, the fluxgate magnetometers need to be calibrated against the standard. There are uncertainties in the magnetometer (in-flight) calibration associated with the coil property (offset levels) and the angular deviation of sensor directions from the ideal (e.g., orthogonal) set-up. It is beneficial in the space plasma observational studies to know the systematic error behavior in the (in-flight) calibrated magnetometer data.

The uncertainties of calibrated data are derived analytically for a spinning spacecraft by perturbing the calibration parameters, and are simplified into the first-order expression including the (constant) offset errors and the coupling of calibration parameter errors with the ambient magnetic field. The error study shows how the uncertainty sources combine through the calibration process.

The final error depends on (1) the magnitude of the magnetic field with respect to the offset error and (2) the angle of the magnetic field to the spacecraft spin axis. The offset uncertainties are the major factor in a low-field environment, while the angle uncertainties (rotation angle in the spin plane, sensor non-orthogonality, and sensor misalignment to the spacecraft reference directions) become more important in a high-field environment in a proportional way to the magnetic field.

The error formula reads in a simplified fashion as

$$|\Delta B_{x'}| \leq 0.1\,[\mathrm{nT}] + (B_\mathrm{p} + B_\mathrm{a}) \times 10^{-2},$$
$$|\Delta B_{y'}| \leq 0.1\,[\mathrm{nT}] + (10B_\mathrm{p} + B_\mathrm{a}) \times 10^{-3},$$
$$|\Delta B_{z'}| \leq 0.2\,[\mathrm{nT}] + (B_\mathrm{p} + B_\mathrm{a}) \times 10^{-3}.$$

where x' is in the projection calibrated (or reconstructed) magnetic field onto the spin-plane component (spin-plane primary), y' is the spin-plane residual component, and z' is the spin-axis of the calibrated field. B_p and B_a are the spin-plane and the spin-axis component of the ambient field, respectively (see derivations in Ref. [1]).

The error formula above serves as a useful tool in designing higher-precision magnetometers in the future spacecraft missions as well as in developing novel data analysis methods in geophysical and solar system science as constraint.

Reference

[1] Narita et al., Geosci. Instrum. Method. Data Syst., **10**, 13 (2021)

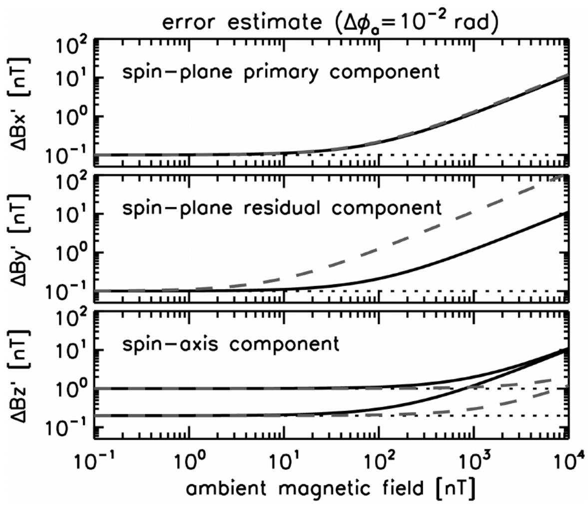

Figure 1. Example of in-flight calibrated magnetometer error applied to the BepiColombo Mio magnetometer (Ref. [1]). Solid curves are for the axial ambient field. Dashed curves are for the spin-plane ambient field.