Chapter 3
Magnetic Dipole Modeling for DC and Low Frequency AC Magnetic Fields in Space Missions

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ABSTRACT

In this chapter, modeling methods of static and slowly varying magnetic field emissions that are generated by spacecraft equipment are analyzed and discussed. In particular, specific issues on the established methods for multiple magnetic dipole modeling (MDM) are investigated and validated via near field measurements of well-behaved magnetic sources. Moreover, a software-based calibration technique for measuring facilities, dedicated to magnetic characterization of spacecraft units, is described and implemented on a configuration consisting of 12 sensors. Due to increasingly strict magnetic cleanliness demands, the modeling of units’ induced DC magnetic behavior has become a necessary requirement for various space missions. Therefore, a baseline methodology regarding the measurements and modeling of induced magnetic fields is presented. Finally, DC methods are complemented to cover AC magnetic cleanliness requirements for on-ground verification of low-frequency magnetic fields, including AC induced magnetization effects.

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INTRODUCTION

In most space missions, dedicated sensitive instruments are mounted on the spacecraft in order to perform in situ measurements of interplanetary magnetic fields (Acuna, 2002). Fluxgate and Search Coil Magnetometers are commonly placed on a long boom that extends beyond the main structure of the spacecraft. The sensitivity (resolution) of these magnetometers is very high for purposes of measuring very weak variations of magnetic flux density (Musmann, 2010). Due to their high sensitivity, however, these sensors are susceptible to magnetic field emissions generated by the spacecraft. Units and equipment on-board, as well as components of the spacecraft itself produce a combined magnetic field at the location of the magnetometers, thus interfering with the output of the instruments. Unquestionably, one of the critical requirements for these instruments is to operate in a magnetically “clean” environment; typical requirements on the total DC magnetic field generated by the spacecraft at the location of the magnetometers are in the order of 0.1-1 nT (Primdahl, 1989; Mehlem, 1987). Moreover, current and upcoming space missions (Solar Orbiter, PLATO, JUICE), have even more stringent requirements on magnetic cleanliness of slowly time varying AC magnetic fields.

The “magnetic cleanliness” of the spacecraft, which is targeted during the development phase, is realized by application of “best engineering practices”, i.e. careful design and construction of the spacecraft by using non-magnetic materials, magnetic shielding, etc. Therefore, the spacecraft residual magnetism is usually kept below the requirements determined by the scientific application and commensurate with the sensitivity of the on-board magnetometers. In most cases, however, magnetic fields emitted by subsystems and components of the spacecraft are still present at the location of the magnetometers. To overcome the magnetic fields’ measurements contamination, it has been a standard practice to perform on-ground electromagnetic compatibility (EMC) test campaigns at unit and system level (Junge & Marliani, 2011). At early stages of the space missions, the main target is to capture the magnetic signature of individual units and/or subsystems that will actually be mounted on the spacecraft and characterize them. The magnetic cleanliness test campaign is finalized at system level, with magnetic measurements and characterization of the entire spacecraft.

The unit level measurements are performed on-ground in dedicated facilities, namely Magnetic Coil Facilities (MCF). These facilities usually employ a pair of Helmholtz coils in order to compensate Earth’s magnetic field (ECSS, 2012). The Equipment under Test (EUT), is placed on a turntable that makes a full rotation of 360° while several magnetometers measure its (remanent) magnetic field at various angles (most commonly at 0°, 10°, …), ensuring that the unit’s magnetic signature is well covered. Although the location of the sensors is in close proximity to the EUT
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