In-orbit Alignment Analysis of the Magnetometer Sensor on the Arase (ERG) Satellite

Ayako MATSUOKA[*1], Mariko TERAMOTO[*2], Reiko NOMURA[*3]

ABSTRACT

Precise magnetic field measurement is aimed in the Arase project to investigate the growth and decline of the earth radiation belt. The sensing directions of the magnetometer sensor elements in the spacecraft reference frame are calculated by the analysis of the in-orbit magnetic field data. They are determined with good accuracies, within 0.05° and 0.2° for the ±8000 nT and ±60000 nT measurement ranges, respectively. The misalignment angles are continuously varying with the time, and the variation is supposed to be caused by the mechanical deformation of the extendable MAST on which the magnetometer sensor is mounted.

Keywords: Arase, ERG, MGF, magnetometer, calibration, alignment

1. INTRODUCTION

Many magnetometers have boarded on the spacecraft and measured the magnetic fields in the space. The accurate measurement of the magnetic field direction is essential for several scientific objectives, i.e., pitch angle determination of the charged particles and examination of the high-order components in the planetary magnetic moment.

To precisely measure the magnetic field direction, we need to accurately determine the sensing directions of the sensor elements in the spacecraft reference frame as well as the spacecraft attitude in the inertia coordinate. When the spacecraft is spinning, knowledge of the sensor alignment in the spacecraft reference frame is also necessary for accurate determination of the measurement offset.

When the sensor is mounted on a deployment boom, the sensor alignment may change over time due to the deformation of the boom. Therefore the sensor alignment in the spacecraft reference frame is difficult to determine in advance in the ground experiments. Meanwhile, in the case of spinning spacecraft, the inclination angles of the sensor can be calculated from the amplitude and phase of the sinusoidal wave forms in the in-orbit data, if the sensitivity of the sensor elements are precisely calibrated and the magnetic field is sufficiently stable during the spin period.

Arase (also known as Energization and Radiation in Geospace, ERG) is a satellite orbiting around the earth to study the generation and loss mechanism of relativistic electrons in the radiation belts (Miyoshi et al., 2018). A magnetometer, Magnetic Field Experiment (MGF), is installed in the Arase satellite for the precise measurement of the magnetic field. The design and characteristics of MGF are described in Matsuoka et al. (2018). We evaluated the MGF sensor alignment in the spacecraft reference frame.

2. ANALYSIS METHOD

Figure 1 shows the photo of the MGF sensor unit. Three sensor elements, X, Y and Z are mounted on the sensor base to measure the three orthogonal components of the magnetic field. The angles between the sensing directions of the three sensor elements are very close to 90° and determined in the ground experiment (Teramoto et al., 2018). The sensor Z is nearly parelle to the spacecraft spin axis.

doi: 10.20637/JAXA-RR-18-005E/0003
[*] Received October 8, 2018
[*1] Department of Solar System Science, Institute of Space and Astronautical Science
[*2] Institute for Space-Earth Environmental Research, Nagoya University
[*3] Research of Interior Structure and Evolution of solar system bodies, National Astronomical Observatory of Japan

Figure 2 (a) shows the definition of an intermediate coordinate O_1 to determine the sensor alignment angles in the spacecraft reference frame. O_1 is defined as an orthogonal coordinate that has the same X-direction and coplanar X–Y with the sensor. Figure 2 (b) shows the relationship between O_1 and the spin coordinate which has the Z direction along the spacecraft spin axis and coplanar X–Z with the sensor. Sensor misalignment is expressed by inclination angles α and β of O_1 in the spin coordinate.

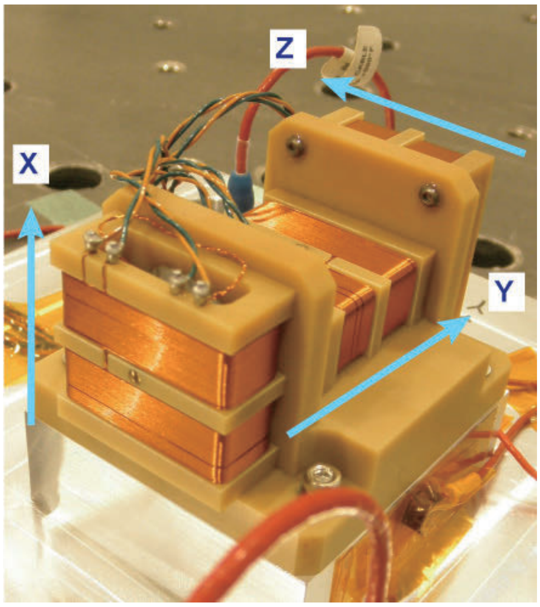


Fig. 1 Photo of the MGF sensor unit. Three sensor elements, X, Y and Z are mounted on the sensor base.

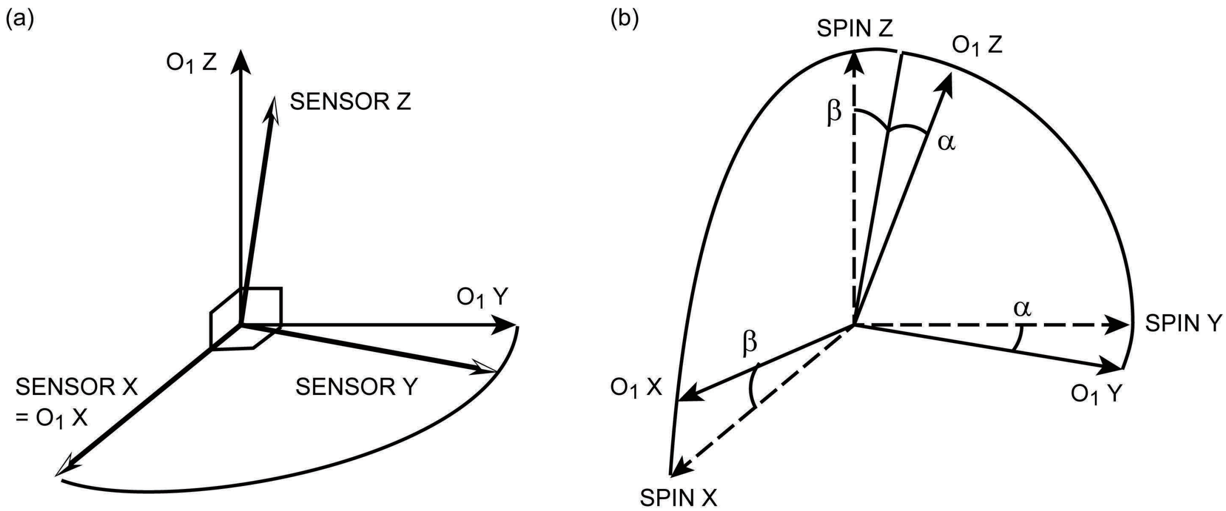
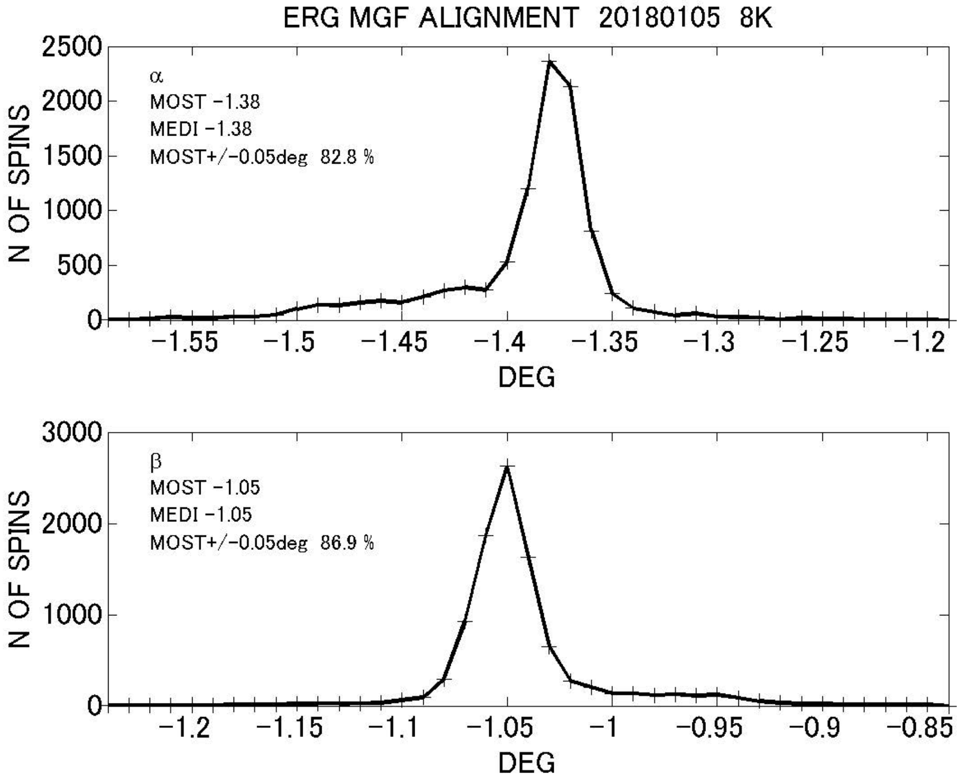


Fig. 2 Relationship between the sensor non-orthogonal coordinate and the spacecraft reference frame, as well as the definitions of the misalignment angles, α and β. (a) An intermediate orthogonal coordinate O_1 is defined to have the same X-direction and coplanar X–Y with the sensor. (b) The sensor misalignment is expressed by inclination angles α and β of O_1 in the reference coordinate with respect to the spacecraft spin axis.

(a)



(b)

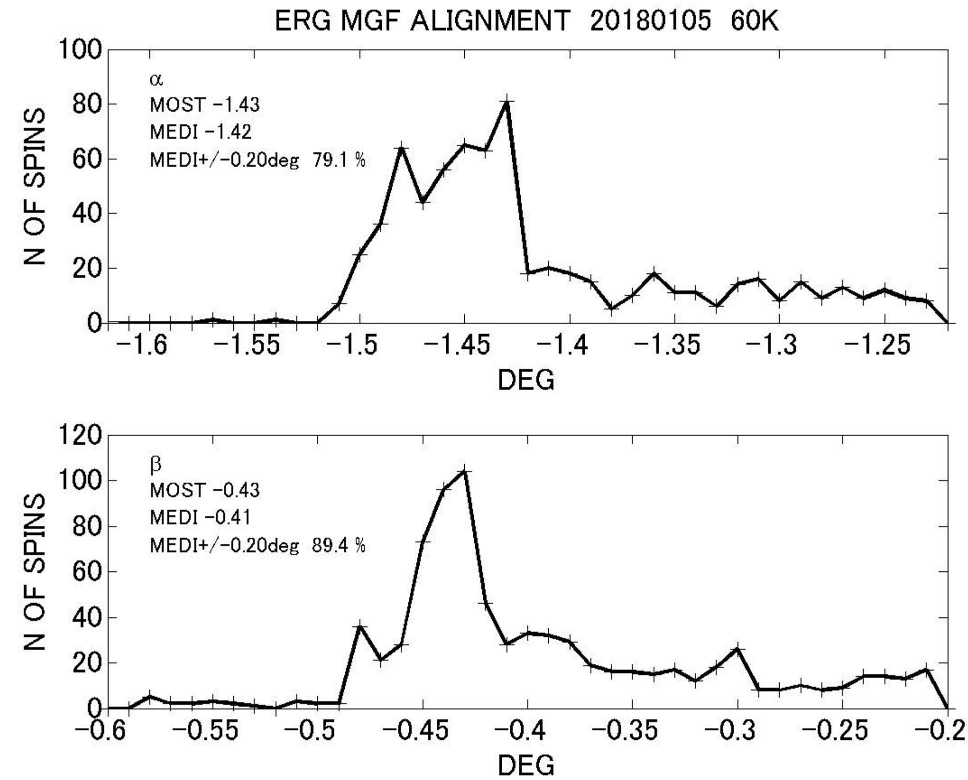


Fig. 3 Statistical results for the sensor misalignment angles α and β on January 5, 2018 for the measurement ranges (a) ±8000 nT and (b) ±60000 nT.

In the frame of a rotating spacecraft, the magnetic field in the spin plane varies simusoidally with the same period as the rotation, while the magnetic field along the spin axis is static. The output signals from the three sensor elements are the projections of the magnetic field to the sensing directions in the spacecraft frame. The amplitude and phase of the simusoidal waves in the output signal reflect the inclination and azimth angles of the sensing directions in the spacecraft frame. Namely, α and β in Figure 2 (b) can be expressed by the amplitude and phase of the output sinusoidal signal from the three sensor elements. Details about the computation method are described in a separated report (Matsuoka et al., 2019).

3. RESULTS

3.1. Daily Statistics of the Misalignment Angles

We calculated the misalignment angles α and β for every spacecraft rotations and took the daily statistics. Matsuoka et al. (2018) showed an example of the statistics on March 19, 2017. Here we show another example on January 5, 2018. Figure 3 shows the distributions of the sensor misalignment angles. For the ±8000 nT measurement range, the distribution of α (β) exhibited a clear peak at −1.38° (−1.05°) (Figure 3 (a)), and 83% (87%) of the α (β) samples were within ±0.05° of the peak. For the ±60000 nT measurement range, the distribution was broader (Figure 3 (b)), and 79% (89%) of the α (β) samples were within ±0.20° of the median value of −1.42° (−0.41°). We note that the field intensity changes rapidly near the perigees, where the measurement range is nominally ±60000 nT. Time variation of the field intensity during a spin period could cause errors and broadening of the distribution of the calculated misalignment angle.

The misalignment angles are difference between two ranges, ±8000 nT and ±60000 nT. The difference is 0.16° for α and 0.64° for β. The difference is meaningful even we consider the large statistical errors for the ±60000 nT. There would be several possible reasons which cause the difference. The major one is the difference of the inter-axes alignment angles we derived in the ground experiment. The sensor alignment angles in the reference frame defined by the cubic mirror are different between the two ranges, ±8000 nT and ±60000 nT (Teramoto et al., 2018). The difference is about 0.6° and very similar to the difference shown here.

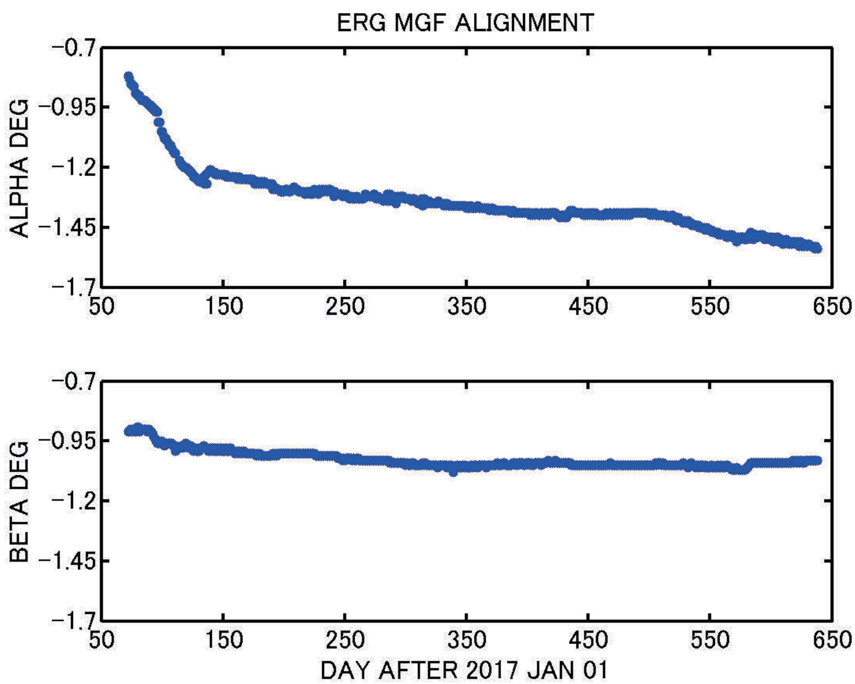


Fig. 4 Time variation of misalignment angles α (upper panel) and β (lower panel) for the ±8000 nT measurement range from March 13 2017 to September 30 2018.

3.2. Time Variation of the Misalignment Angles

Figure 4 shows the time variation of the misalignment angles α and β for the ±8000 nT measurement range from March 13 2017 to September 30 2018. Both show a general tendency to decrease with the time. The changing speed of α, roughly $-6.5°\times10^{-4}$/day, is faster than that of β, $-1.0°\times10^{-4}$/day. It may be interpreted that the time vation of the misalignment angles would be caused by the mechanical relaxation of the extendable 5-m MAST on which the MGF sensor is mounted. Figure 5 shows the Arase spacecraft configuration after the deployment of the MAST and correspondence with α and β. α is defined as the rotation of the MAST around the deployment direction while β corresponds to the inclination from the spacecraft spin plane. The MAST deployment operation was performed on January 17, 2017. During the deployment the tip of the MAST rotated counterclockwise when viewing from the spacecraft −y (deployment direction). The long-term negative vatiation of α seen in Figure 4 indicates that the MAST is slowly rotating in the same direction.

Figure 4 shows that the changes of α and β are not very monotonic and the changing speeds are not uniform. The irregular variation of α on the days 130−140 especially draws our attension. It is not easy to interprete such irregular variations because the long-period stability of the MAST shape is not examined in the ground experiment.

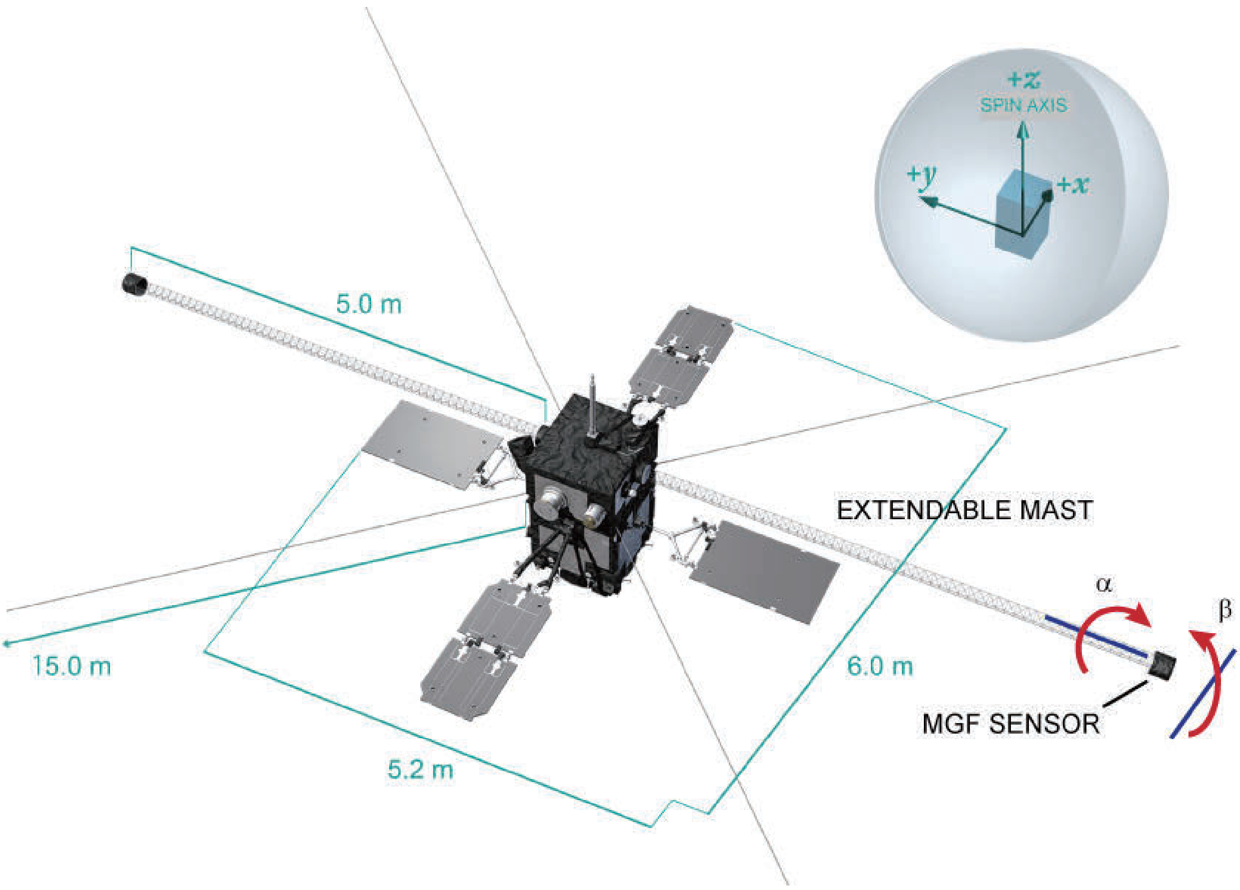


Fig. 5 Arase spacecraft configuration after the deployment of MAST and correspondence with the α and β.

4. SUMMARY

We analyzed the in-orbit Arase MGF data and calcurated the sensing directions of the.three sensor elements in the reference frame defined by the spacecraft spin axis. The alignment angles are determined with better accuracy than 0.05° and 0.2° for the ±8000 nT and ±60000 nT measurement ranges, respectively. These angular accuracies are enoght to calibrate the in-orbit MGF data with the finally aimed acuracy.

The alignment angles have continuously varied with time for one year and seven months after starting of the regular measurement. The variation is consistent with the rotation of the sensor accompanied by the mechanical relaxation of the MAST.

ACKNOWLEDGEMENTS

The authors wish to express their sincere thanks to all of the ERG (Arase) project team members. We are also grateful for the manufacturers of MGF, Sumitomo Heavy Industries, Ltd., and Tierra Tecnica Corporation, as well as the manufacturer of the extendable MAST, NIPPI Corporation. The MGF calibration test was supported by the Environment Test Technology Unit of JAXA. Ayako Matsuoka gratefully acknowledges valuable comments from Dr. Tateo Goka and Prof. Susumu Kokubun at MGF review meetings.

REFERENCES

Ayako Matsuoka, Mariko Teramoto, Reiko Nomura, Masahito Nosé, Akiko Fujimoto, Yoshimasa Tanaka, Manabu Shinohara, Tsutomu Nagatsuma, Kazuo Shiokawa, Yuki Obana, Yoshizumi Miyoshi, Makoto Mita, Takeshi Takashima and Iku Shinohara, The ARASE (ERG) magnetic field investigation, Earth, Planets and Space, 70:43, 10.1186/s40623-018-0800-1, 2018

Ayako Matsuoka, Mariko Teramoto and Reiko Nomura, Method to Determine the In-orbit Sensor Alignment of the Magnetometer Onboard a Spin-stabilized Satellite(Japanese), JAXA Research and Development Memorandum, JAXA-RM-18-008, 10.20637/JAXA-RM-18-008/0001, 2019

Miyoshi, Y., I. Shinohara,, T. Takashima, K. Asamura, N. Higashio, T. Mitani, S. Kasahara, S. Yokota, Y. Kazama, S.-Y. Wang, S. W. Tam, P. T. P Ho, Y. Kasahara, Y. Kasaba, S. Yagitani, A. Matsuoka, H. Kojima, H. Katoh, K. Shiokawa, and K. Seki, Geospace Exploration Project ERG, Earth Planets Space, 2018a

Mariko Teramoto , Ayako Matsuoka and Reiko Nomura, Re-evaluation of the ground calibration for the Arase Magnetic Field Experiment, JAXA Research and Development Report, JAXA-RR-18-005E, 10.20637/JAXA-RR-18-005E/0001, 2019