

Magnetometer calibration technique for the ground-based stage of spacecraft system diagnostics

© I.O. Akimov^{1,2}, S.N. Ilyukhin², N.A. Ivlev¹, G.E. Kolosov²

¹Sputnix JSC, Moscow, 121059, Russia

²Bauman Moscow State Technical University, Moscow, 105005, Russia

The article lists empirical techniques for thermal calibration and accounting for intrinsic error in magnetometers used in onboard measurement equipment of modern spacecraft. We developed a mathematical model of magnetometer readings that takes into account current measurement errors and provided a geometrical interpretation of errors. We present the relationship between readings of typical magnetic sensors and ambient temperature. We formulated a thermal calibration technique for instrument readings that ensures instrument accuracy at different temperatures. We introduce an approach to determining a transformation matrix connecting magnetometer coordinate systems that makes it possible to eliminate component positioning errors occurring during magnetometer assembly; we also describe development testing algorithms approved by the core enterprise for gathering data required for implementing the techniques under consideration. We provide the results of calibrating a magnetometer using the techniques developed.

Keywords: magnetometer, thermal calibration, measurement processing, magnetic field

REFERENCES

- [1] Lysenko L.N., Betanov V.V., Zvyagin F.V. *Teoreticheskie osnovy ballistiko-navigatsionnogo obespecheniya kosmicheskikh poletov* [Theoretical foundations of ballistics and navigation support of space missions]. Moscow, BMSTU Publ., 2014.
- [2] Tyulin A.E., Betanov V.V. *Letnye ispytaniya kosmicheskikh obektov. Opredelenie i analiz dvizheniya po eksperimentalnym dannym* [Flight testing of spacecraft. Motion assessment and analysis based on experimental data]. Moscow, Radiotekhnika Publ., 2016, 336 p.
- [3] Beletskiy V.V., Khentov A.A. *Vrashchatelnoe dvizhenie namagnichennogo sputnika* [Rotary motion of a magnetised satellite]. Moscow, Nauka Publ., 1985, 288 p.
- [4] Solovev V.A., Lysenko L.N., Lyubinskiy V.E. *Upravlenie kosmicheskimi poletami* [Space flight control]. In 2 vols. Moscow, BMSTU Publ., 2009 (vol. 1), 2010 (vol. 2).
- [5] Fraden J. *Handbook of Modern Sensors. Physics, Designs, and Applications*. New York, Springer-Verlag, 2004, 608 p. [In Russ.: Fraden J. *Sovremennye datchiki. Spravochnik*. Moscow, Tekhnosfera Publ., 2005, 587 p.].
- [6] Kruzhkov D.M. *Sovremennye i perspektivnye integrirovannye sistemy vysokotochnoy navigatsii KA na geostatsionarnoy i vysokikh ellipticheskikh orbitakh na osnove ispolzovaniya GNSS-tehnologiy*. Diss. ... kand. tekhn. nauk [Modern and promising integrated systems of precision spacecraft navigation at geostationary and highly elliptical orbits based on GNSS technology. Cand. eng. sci. diss.]. Moscow, MAI Publ., 2014.
- [7] Ivanov D.S., Tkachev S.S., Karpenko S.O., Ovchinnikov M.Yu. Kalibrovka datchikov dlya opredeleniya orientatsii malogo kosmicheskogo apparata [Sensor calibration for determining attitude of a small spacecraft]. *Preprinty IPM RAN* [Keldysh Institute Preprints], 2010, no. 28, p. 30.

- [8] Aleynikov A.F., Gridchin V.A., Tsapenko M.P. *Datchiki. Perspektivnye napravleniya razvitiya* [Sensors. Promising development directions]. Novosibirsk, Novosibirsk State Technical University Publ., 2001, 176 p.
- [9] Mascarenhas W.F. On the divergence of line search methods. *Comput. Appl. Math.* 2007, vol. 26 (1), pp. 129–169.
- [10] Vasconcelos J.F., Elkaim G., Silvester C., Oliveira P., Cardeira B. A Geometric Approach to Strapdown Magnetometer Calibration in Sensor Frame. *IFAC Workshop on Navigation, Guidance and Control of Underwater Vehicles*, Killaloe, Ireland, April 2008, p. 12.
- [11] Van Loan C.F. *Journal of Computational and Applied Mathematics*, 2000, vol. 123, pp. 85–100.

Akimov I.O. (b. 1994) 6th year student, Bauman Moscow State Technical University. Engineer, Sputnix JSC. e-mail: akimov-94@mail.ru

Ilyukhin S.N. (b. 1990) graduated from Bauman Moscow State Technical University in 2013. Assistant Lecturer, Department of Dynamics and Flight Control of Rockets and Spacecraft, Bauman Moscow State Technical University. Author of over 20 scientific and popular science publications in the fields of ballistics, flight dynamics, aircraft motion guidance and armament history. e-mail: iljuchin.stepan@bmstu.ru

Ivlev N.A. (b. 1988) graduated from Bauman Moscow State Technical University in 2010. Research Fellow, Head of Precise Orientation Systems Lab, MIPT; Head of Branch, Sputnix JSC; post-graduate student, Space Research Institute of the Russian Academy of Sciences. e-mail: nikitavlev@mail.ru

Kolosov G.E. (b. 1936) graduated from Lomonosov Moscow State University in 1959. Professor, Department of Dynamics and Flight Control of Rockets and Spacecraft, Bauman Moscow State Technical University. Author of over 100 scientific and popular science publications in the fields of flight dynamics, aircraft motion guidance and control in engineering systems. e-mail: prof_g_kolosov@mail.ru