Research on Homogenous Analysis of Magnetic Field through Helmholtz-coil Mechanism for Ground-based Attitude Determination and Control Testing Platform †

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Abstract: A desired orientation in outer space, with a specified level of precision, is a mission requirement for every spacecraft based-on payload condition. Technically, Attitude Determination and Control Sub-system (ADCS) is responsible for satisfying this requirement which primary focused on Low-Earth Orbit micro-satellite missions. To make the analysis realistic, ground-based ADCS simulation and testing platform was established under Thai Space Consortium (TSC) program at National Astronomical Research Institute of Thailand, Chiang-Mai, Thailand. Normally, the Helmholtz coil is a primary equipment to simulate the Earth's magnetic field that is a part of ADCS. In this research, the Biot-Savart's law was applied to describe the magnetic distribution through the mechanism of Helmholtz coil (circular and square) based on International Geomagnetic Reference Field model in three-axis. The facility's objective is testing and verification of the TSC's micro-satellite research and developing program. Therefore, in this paper, we introduce hardware-in-the-loop test bench with specific devices, their performances, and future extensions in progress.

Keywords: Attitude Determination and Control Sub-system; Biot Sarvart' s Law; Helmholtz coil; Hardware in the loop.

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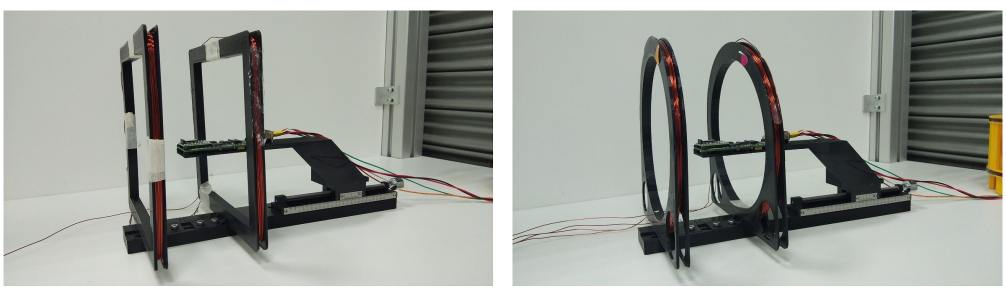
1. Introduction

Thai Space Consortium (TSC) is a cooperative research-based program to develop a micro-satellite in Thailand that has primarily proposed to observe the Earth-natural resourced by capture multispectral images via a passive optical instrument [1]. Typically, the micro-satellite consisted of many significant sub-systems that support the satellite to success mission. One of the significant sub-systems is the Attitude Determination and Control Subsystem (ADCS), which defines a spacecraft's orientation and rotation in outer space through multi-sensors data fusion. Moreover, the development of satellite orientation control algorithm is a classic problem in Earth-natural resourced observation via applying external and internal forces or torques as a function in magneto or mechanical actuators [2]. This study set out with the aim of assessing the importance of testing mechanisms in ADCS to validate both determination and control algorithms [3] before launching to outer space. Knowledge of this platform has great importance for demonstrating the operation of a satellite control system with an actual device. Practically speaking, this platform is associated with the immediate physical effects of the space environment related to zero gravity, the Earth's magnetic field, and the Sun's light. In this research, we focus on the Earth's magnetic field simulation through the mechanism of the Helmholtz coil. Very little was found in the literature on the question of homogenous analysis that is a strong relationship between two general geometry are square and circular. Therefore, this paper was undertaken to design the comparative of the magnetic distribution and homogenous magnetic field by Helmholtz coil both square and circular geometries through Biot-Sarvart's law based mathematical modeling and experiment results.

2. Methodology

2.1. Mathematics Modeling

Helmholtz coil is equipment for generating the Earth's magnetic field that using the Biot-Savart law [4]. The Helmholtz coil is a pair of square and circular coil, and it arranges co-axially and parallel to one another. Each coil consists of a turn-number (N), a_{sq} is the half side length of square coil, a_{cr} is the radius length of circular coil . h is the distance between square coils and circular coils are 0.5445*2a_{sq} and a_{cr} [5], respectively. z is the distance between the center point of separation and evaluation. μ_0 is the magnetic permeability of free space. The coils are connected in series and including an electrical current (I) and are related as follows:



(a) Square helmholtz coil

(b) Circular helmholtz coil

Figure 1. The Helmholtz coil testing bench.

The distribution of magnetic field in $\hat{z}$-axis (B_z) shown as an equation:

- The circular Helmholtz coil:

$$B_z(z) = \frac{\mu_0 N I a_{cr}^2}{2}[(a_{cr}^2 + (z + \frac{h}{2})^2)^{-3/2} + (a_{cr}^2 + (z - \frac{h}{2})^2)^{-3/2}]. \quad (1)$$

- The square Helmholtz coil:

$$B_z(z) = \frac{2\mu_0 N I a_{sq}^2}{\pi}[(a_{sq}^2 + ((z + \frac{h}{2})^2)^{-1}(2a_{sq}^2 + (z + \frac{h}{2})^2)^{-1/2} + (a_{sq}^2 + (z - \frac{h}{2})^2)^{-1}(2a_{sq}^2 + (z - \frac{h}{2})^2)^{-1/2}]. \quad (2)$$

- Specification of the magnetic field:

A measure of fluctuation of the magnetic field in a selected area is called the homogeneous of the magnetic field. It can be defined by H which normally show in the percentage difference of the central field (B_0) as follows:

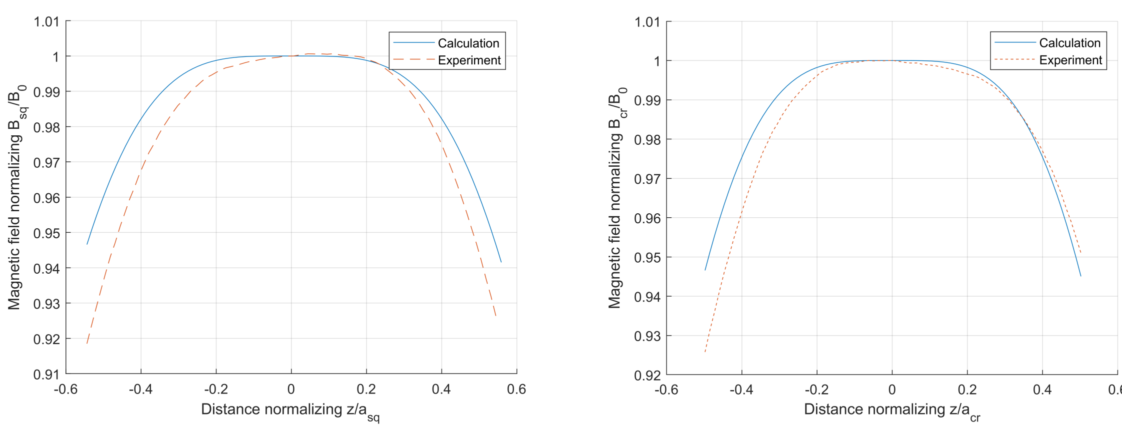
$$H[\%] = \frac{B_z(z) - B_0}{B_0} \times 100. \tag{3}$$

2.2. *Evaluation platform*

Figure 1. presented the comparison of Helmholtz coil's mechanism both square and circular coil pairs via a 3D printer consisting of a wire winding core with a haft-side length or radius of 78 mm., a base for fastening the core and rail, and a magnetometer holder. The rail uses to move the magnetometer along the z-axis. The copper wire, AWG 22, use to wind around the core with 60 turns for each core. The specification of magnetometer was refered to [6].

3. Experimental results

The result of this study indicates that the intensity of magnetic field related to the position in range between -43 mm to 43 mm and -39 mm to 39 mm with a pair of square coils and circular coils, respectively, while having a measuring resolution at 1 mm. A positive correlation was found between the distribution B(z)/B_0 and measuring distance z/a_{sq} or z/a_{cr}. Figure 2. presented the similarity of the result from measuring and calculating the equation (1) and (2). Turning now to the experimental evidence on the distribution of magnetic field from both geometries. Further statistical tests revealed the percent difference of homogenous magnetic field distribution between the center and surrounding square/circular coil pairs. Considering the proportion range of z/a_{sq} and z/a_{cr} that the homogenous magnetic field as shown in Figure 3. is not greater than or equal to 0.1%, 0.5% and 1%. The proportional z/a_{sq} of the square coils are arounds 0.225, 0.275, and 0.32. The circular coils are arounds 0.15, 0.23, and 0.26. Comparing the two results, it can be seen that the proportional range z/a_{sq} of the square coils is greater than the circular coils at 50%, 20%, and 23% ,respectively.



(a) Square helmholtz coil

(b) Circular Helmholtz coil

Figure 2. Normalized magnetic field distribution based on mechanical geometries.

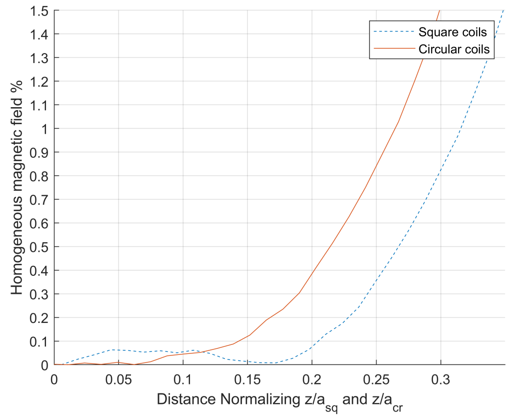


Figure 3. Homogenous analysis of magnetic field.

4. Conclusions

To conclude, the magnetic field from distinction geometry coils gives the difference of magnetic distribution according to Biot Savart's law. The changing of magnetic distribution of square coils is lease than the circular coils at the same position. Therefore, the homogenous of square coils is greater than the circular coils. This can prove that the geometry of the Helmholtz coil is an essential point that effect to the magnetic distribution. Thus, the result of square coils has considered as a noncomplex shape to assemble and install for ground-based testing platform in the future for TSC program.

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1. Sreesawet, S.; Jaturat, S.; Channamsin, S. Orbit Design for Thai Space Consortium Satellite. Multidisciplinary Digital Publishing Institute Proceedings, 2019, Vol. 39, p. 1.
2. Bohlouri, V.; Hosseini-Onari, H.; Meibody, M.N.; Seyedzamani, S. An Online Hardware-in-the-Loop Testbed for Spacecraft Attitude Control. 2019 27th Iranian Conference on Electrical Engineering (ICEE). IEEE, 2019, pp. 1002–1006.
3. Kato, T.; Heidecker, A.; Dumke, M.; Theil, S. Three-axis disturbance-free attitude control experiment platform: FACE. *Transactions of the Japan Society for Aeronautical and Space Sciences, Aerospace Technology Japan* **2014**, *12*, Td_1–Td_6.
4. Bell, G.B.; Marino, A.A. Exposure system for production of uniform magnetic fields. *Journal of Bioelectricity* **1989**, *8*, 147–158.
5. Alvarez, A.F.R.; Franco-Mejia, E.; Pinedo-Jaramillo, C.R. Study and analysis of magnetic field homogeneity of square and circular Helmholtz coil pairs: A Taylor series approximation. 2012 VI Andean Region International Conference. IEEE, 2012, pp. 77–80.
6. Honeywell, H. Smart Digital Magnetometer. *Sensor Products*.