

EXTENDED ABSTRACT

MODELLING A HELMHOLTZ CAGE FOR GROUND TESTING OF ADCS OF NANOSATELLITES

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Abstract

This research focuses on providing a dynamically driven ground testing equipment for the Attitude Determination and Control System (ADCS) of a nanosatellite through a Helmholtz cage that can provide a volume of a uniform magnetic field. The magnetic field components in each 3-axes can be varied independently by controlling the current supplied to each of the respective coil pairs. The orbital information was extracted from a selected Two-Line Element (TLE) by implementing an algorithm in MATLAB. To emulate these derived magnetic fields, the Helmholtz cage was calibrated by observing the generated magnetic field from the coil pairs according to the supplied current input using a driver circuit. By deriving a relationship between the pulse width and the generated magnetic field the experimental magnetic field was plotted. The experimental variation was fairly similar to the expected magnetic field variation. Therefore, this process will be able to implement as a fully functional ground testing method for ADCS of nanosatellite with some improvements.

Keywords: ADCS, Helmholtz cage, nanosatellites, TLE

1. Introduction

An artificial satellite is an object that has been placed into an orbit with a purpose. Since 1957, the first artificial object placed in orbit around the earth, thousands of various artificial satellites are sent to space for different purposes (Theoret, 2016).

When a Nanosatellite is launched into an orbit, it rotates about its centre of gravity called “tumbling” which is a 3-axis spinning around its centre caused by gravitational forces acting on the antennas and satellite body and the disturbances created by magnetic fields. Due to tumbling, satellites are unable to perform their duties effectively. To prevent this, a subsystem called Attitude Determination and Control System (ADCS) was introduced to satellites to detumble itself to perform their missions with accuracy. So, to determine the satellite’s attitude, the ADCS system consisted of sensors that gather data on the orientation of the satellite. One of those onboard sensors is a magnetometer which collects 3-axes real-time data of the Earth Magnetic Field (EMF) of a satellite’s orbit. B-Dot Algorithm is such an implementation to evaluate the satellite’s angular rate and detumble it using three orthogonal magnetic torquers which produce electromagnetic fields to stabilize the deviation of the satellite after orbital insertion by passing a current through each actuator coil (Regulinski, 1962), (Want et al, 1998).

There is no ground-testing facility in Sri Lanka to investigate the ADCS of CubeSats before it is launched into the actual orbit. Therefore, a system that is capable of simulating a uniform region of a magnetic field that the satellite will be experiencing in its orbit should be built for ground testing. The broad objective of this is to build up a fully functional ground testing system called Helmholtz cage which generates a uniform magnetic field within a volume large enough for CubeSats to test the ADCS of Cube Satellites. The specific objectives are to generate a real-time on-orbit magnetic field for any CubeSat anywhere at any time using MATLAB coding and Simulink as well as to power up the cage and supply the current as a Pulse Width Module (PWM) to the X-coil of the Helmholtz cage through the driver circuit and compare the theoretical values and experimentally implemented values.

This research was carried out for a RAAVANA – 1, which was launch to space by Sri Lanka in 2019. It's a 1U CubeSat which has a 10 cm length on each side. The Biot-Savart law implies that not only the radius of the coils but also the distance between the coils are proportional to the volume of the magnetic field that should be produced. Therefore, a cubic contact magnetic field of 20 cm on each side of the volume was necessary to be generated to cover the whole volume of the CubeSat and more.

When there is a pair of identical circular magnetic coils parallel to each on the same axis, the setup of these coils is called the Helmholtz coil pair proposed by the German physicist Hermann von Helmholtz (1821-1894).

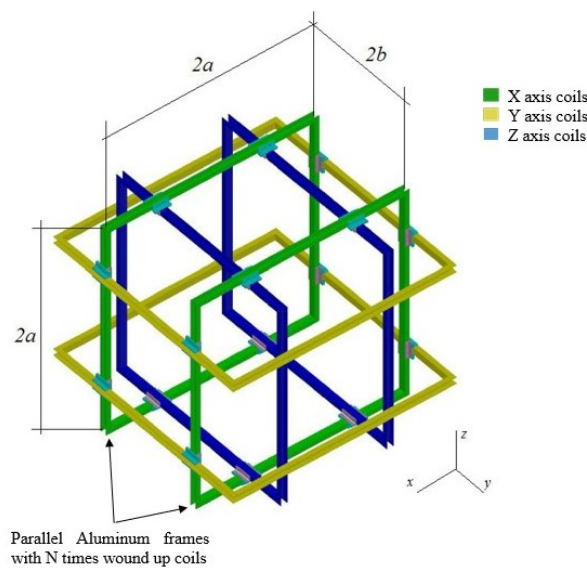


Figure 1. The Helmholtz cage design (Cayo et al.,2019)

Instead of a plane magnetic field, they generate a uniform volume magnetic field along the axis (Theoret, 2016). A wider uniform field can be generated by utilizing square coils instead of circular coils ((Regulinski, 1962), (Want et al, 1998)). And it got greater central accessibility and the computations of the field are easier than circular coil pairs (Want et al, 1998). By using the traditional form of the Biot-Savart law, the scale of applicability was broadened up while implementing it to the Helmholtz Cage. So, a Helmholtz cage can be designed to create such a dynamic and uniform magnetic field using three pairs of orthogonally connected Helmholtz coils (Theoret, 2016), (Pastena et al.,2002).

The inputs of the algorithm are based on the Two-Line Element (TLE) dataset which describes the location of a satellite using Keplerian Elements that a set of 8 parameters which describe the orbit. Based on three reference frames the position and the orientation of a satellite can be expressed. They are Perifocal Coordinate System, Earth-Centered Inertial (ECI) frame and Earth-Centered Earth Fixed (ECEF) frame.

2. Methodology

2.1 Materials

Software and Hardware

To full fill the objectives, three software were used for different purposes. MATLAB (2018b), Arduino - 1.8 and Realterm - 2.0.0.70 were the software utilized. The algorithms were implemented using MATLAB (2018b). The magnetic field in a certain orbit can be modeled using the World Magnetic Model (WMM) in the MATLAB Aerospace Toolbox when the orbit information is given. Mainly four hardware were used in case of emulating the on-orbit magnetic field into the Helmholtz cage. To measure magnetic fields and communicate with a computer HMR2300 Smart Digital Magnetometer was used. A BTS7960 High Current H-Bridge module was applied for taking a PWM signal as input and making a current output according to the duty cycle of the PWM signal. A Driver circuit was made for supplying the current to the cage. Finally, the Helmholtz Cage was the test subject.

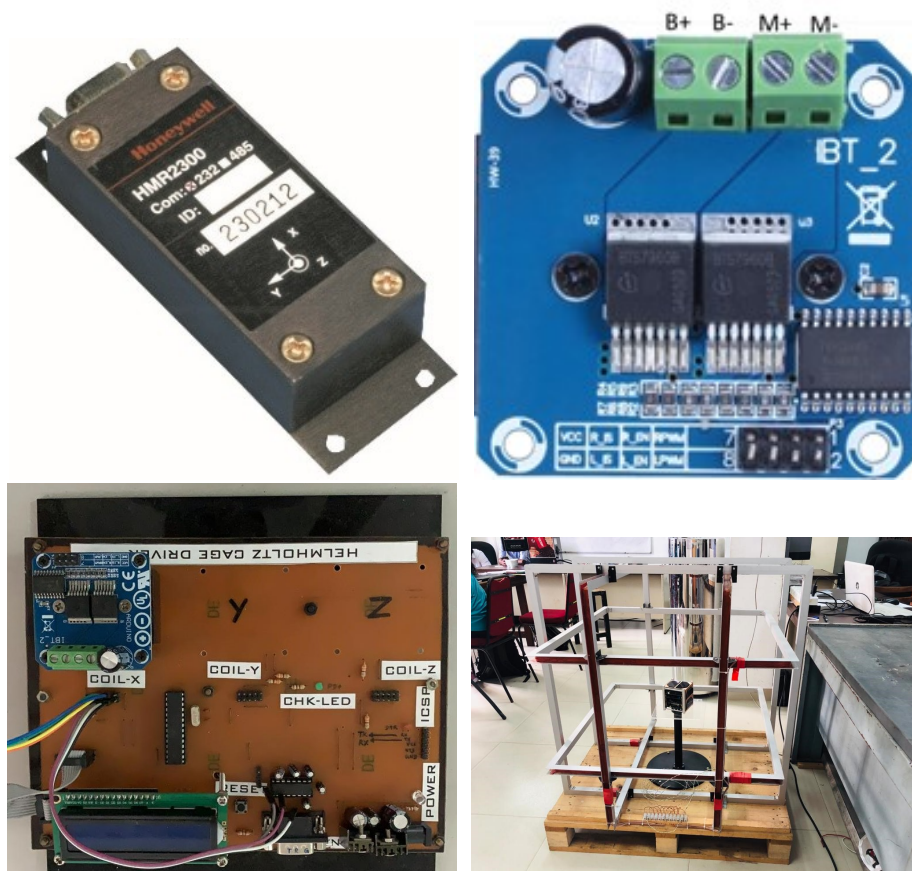


Figure 2. (a) HMR2300 Smart Digital Magnetometer (b) BTS7960 High Current H-Bridge module (c) The Driver Circuit (d) The Helmholtz cage design built at Arthur C. Clarke Institute for Modern Technologies.

2.2 Procedure

Calculation of the orbital coordinates in Longitude, Latitude and Altitude (LLA) form using a Two-Line Element (TLE) set. All the results and observations are based on the following TLE.

First of all, a TLE of RAAVANA-1 was downloaded as a text file. To Extract the necessary Keplerian Elements, the downloaded TLE file was read using the Common TLE format. Then those extracted six elements were given as the inputs for the further coding procedure. Then the Epoch and the Greenwich sidereal time were calculated. Then Two frame transformations were done to calculate the inputs for WMM. First from Perifocal to ECI was performed to determine the

0 Raavana-1
1 44330U 98067QF 19345.06705768 .00006175 00000-0 99589-4 0 9998
2 44330 51.6387 201.0952 0006480 22.9331 337.1948 15.54365198 27497

eccentric and true anomaly using Newton’s Raphson method and then from ECI to ECEF frame transformation was done. Then an algorithm was created to evaluate the three inputs (LLA) which express the position of the satellite at any point of the orbit using the ECEF coordinate system. Finally, the LLA coordinates were set into the WMM as inputs and derive the orbital magnetic fields experienced in one period of the orbit.

All the hardware was connected like the below experimental setup. Here only one coil was focused. The driver circuit was connected with the cage and the magnetometer. Then the whole setup was connected to a power supply and a Cathode Ray Oscilloscope to supply the power to the cage and take the real-time readings of the centre of the cage using the Magnetometer. For the driver circuit, 12 V and 6 A were given. The selected coil was supplied with 10 V and 0.15 A of a current through the Arduino-based driver which can vary the provided current according to the pulse width of a rectangular pulse. By getting the PWM scale 0 to 255, the resulting magnetic field at the center of the coil was measured by the magnetometer by increasing pulse width 5 by 5. The magnetic fields created by the coil were measured and plotted against the pulse widths. Using that, a relationship between the pulse width and the created magnetic field was obtained.

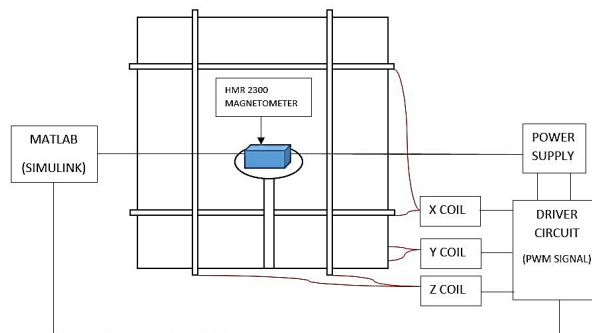


Figure 3. The fully-equipped experimental setup.

Emulation of the X-coil magnetic field inside the Helmholtz cage.

After deriving the relationship between the pulse width given to the current driver and the generated magnetic field, the pulse widths required to create the orbital magnetic field generated by the algorithm using the TLE data set were calculated. Next, those pulse widths were supplied to the current driver to generate the orbital magnetic field inside the Helmholtz cage. Finally, the generated X-axis magnetic field was measured and recorded. Then the graph of experimentally generated X-axis magnetic field was plotted throughout one period of the Nanosatellite. Finally, the experimental and theoretical graphs were compared.

3. Results and Discussion

This graph shows the real-time on-orbit x-axis magnetic field (B_x) of RAAVANA – 1 satellite for the chosen TLE over a period along the orbit. It was found that the X components of the EMF (B_x) of this orbit ranges from 1.014×10^4 to 3.228×10^4 nanotesla.

According to the experiment, variation of B_x with the increment of PWM value was observed to be linear as shown below. So, the following linear relationship between PWM and B_x was obtained.

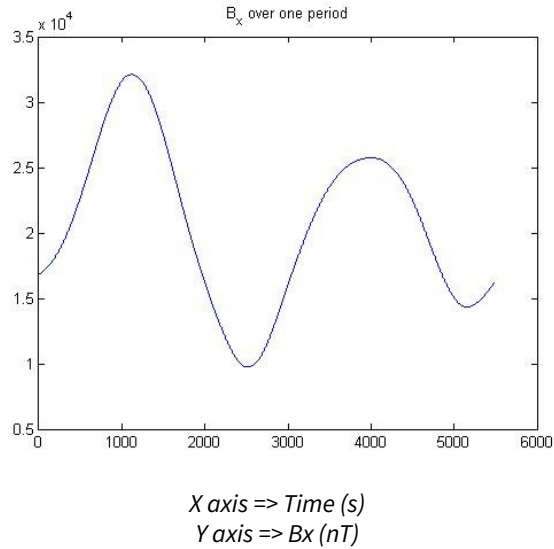


Figure 4. The graphs of the real-time on-orbit x-axis magnetic field (Bx).

$$PWM = (0.0026)B_x - 43.4330$$

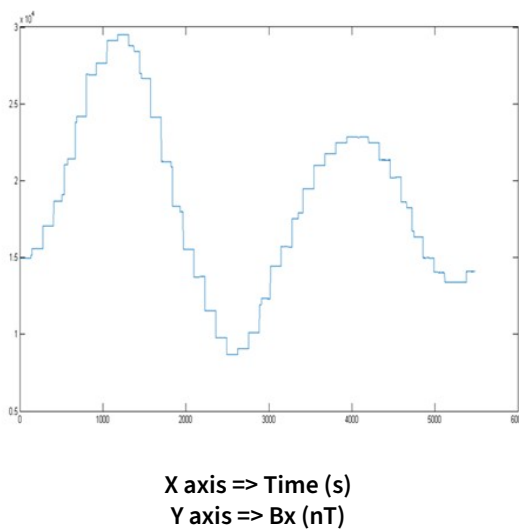


Figure 5. The experimental graph of x-axis magnetic field (Bx) for a period.

Using this relationship, by giving the calculated Bx values using the implemented algorithm by reading the TLE, the pulse widths were obtained. Then the experimental graph was plotted for the Bx values given for the newly generated pulse width values using the above relationship for one period of the CubeSat.

4. Conclusion

This research focuses on emulating the magnetic fields experienced by CubeSats in their orbits utilizing a Helmholtz cage for ground testing of the ADCS of Nanosatellites. By implementing the algorithms using MATLAB (2018b) to analyze the required magnetic fields inside the cage for one of the three coils is successful since the plot of the expected magnetic field variation and the experimentally implemented magnetic field variation of the selected coil (X-coil) were found to be similar. So, it concludes the relationship between the pulse width and the created magnetic field was obtained is correct. Since the graphs of the orbit of the RAAVANA – 1 satellite are presenting accurate

information, this method can be used to calculate the Longitude, the Latitude and the Altitude for any TLE of any CubeSats. It was found that the total EMF of this orbit ranges from 2.103×10^4 to 4.419×10^4 nanotesla. The previous studies on EMF show it varies from average 2.5×10^4 to 6.5×10^4 nanotesla (Chulliat et al., 2019). So, the resultant magnetic field is almost exactly within the limits. By calculating the magnetic field experienced by a CubeSat in the orbit using the implemented algorithm by reading a TLE dataset can be concluded as a suitable modelling method for the Helmholtz cage. Therefore, this whole process will be able to implement as a fully functional ground testing method for ADCS of CubeSats with some more improvements.

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