

MAGNETIC FIELD SIMULATOR DEVELOPMENT FOR CUBESAT TESTING

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Abstract

This work strived to develop a device which could recreate the magnetic fields seen in space. The fundamental piece of hardware was a cubic cage that spans 1.5 meters in length. The cage was encased with three sets of coils, each orthogonal to the other. In the center of the cage a 30-centimeter cube of constant magnetic field strength and direction should be obtained, once the coils are excited by current. Rewiring of the surrounding coils and modification of the controls circuitry was performed. A new user interface was developed to allow the user to generate the desired fields from a designated orbit. The magnetic fields within the cage were mapped to determine the region of uniformity. The uniformity measured was acceptable: the z-axis coils yielded less than 1% fluctuation in the region of interest. The result is a functional magnetic field simulator that can be integrated with other tools developed in the Virginia Tech Space Simulations Laboratory to facilitate full CubeSat subsystem verification.

1. Introduction

CubeSats, a classification of nanosatellites, are small-scale research satellites.¹ Their popularity continues to increase as they transition from proof-of-concept implementations of space technologies to now also performing scientific investigations.² As the number of CubeSat missions continues to climb, the success of each mission is still non-trivial.

Attitude determination and control systems are critical for successful mission completion. The Magnetic Field Simulator (shown in Figure 1) in the CubeSat Attitude Determination and Control Testing apparatus at the Virginia Tech Space Systems Simulations Laboratory can be used to accurately simulate the magnetic field around a satellite in orbit. The developed simulator can provide better testing of satellite controls systems prior to

launch. The work performed falls under three main categories: Fidelity Improvements, Software Development and Field Mapping. This document features information adapted from previous proposals and presentations.^{3,4}

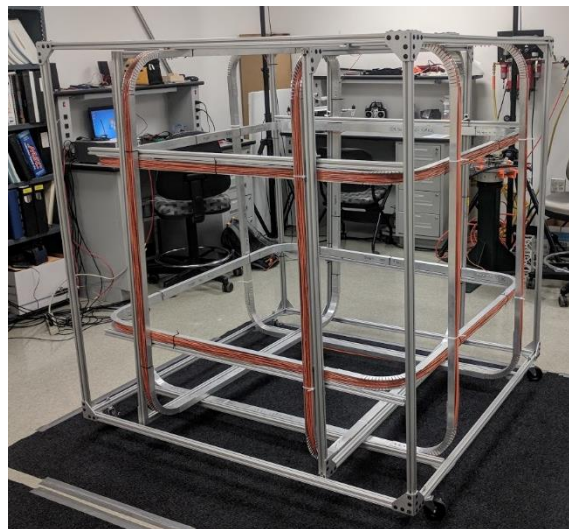


Figure 1. Helmholtz Cage at Virginia Tech

2. Fidelity Improvements

The overall quality of the apparatus needed improvements as work began. The cage was initially not in running condition. First, a dedicated hardware rack was designed and built to mount the necessary power-supplies as well as relays and external controls circuitry that is necessary for the cage to run. The frame of the rack was constructed using extruded aluminum, with wheels on the bottom and shelves that allowed for mounting the power supplies and acrylic shelves for mounting the electronics. Additionally, the physical wiring of the peripheral circuitry was redone as to alleviate unnecessary shock risks.

The cage itself was moderately unstable and the coils were displaced. The coils were reinstalled properly, and all the necessary hardware was secured. Then, the validity of the coils was inspected. It was found that only two of the three axes were functioning properly. Upon further investigation of the fields produced within the cage as a function of the current going through them, the non-functioning axis was behaving poorly as the two sets of coils were wound opposite each other. The coils were in series and positioned such that the resulting magnetic field vector from each coil completely cancelled out the other. Reversing the polarity of one of the coils allowed for all axes to be functioning.

3. Software Development

The entire system required multiple developments regarding software. The overall interface algorithm was modified. Additionally, integration with AGI's System Tool Kit (STK) was developed.

3.1. Algorithmic Progress

The state of the software was also non-functioning when work restarted on the cage. The old code was written in Python 2.7. It was upgraded to Python 3.7. The code utilizes Microsoft Excel formatted with columns representing each component of the magnetic field vector. Then, for each component, the current that should go through each coil was

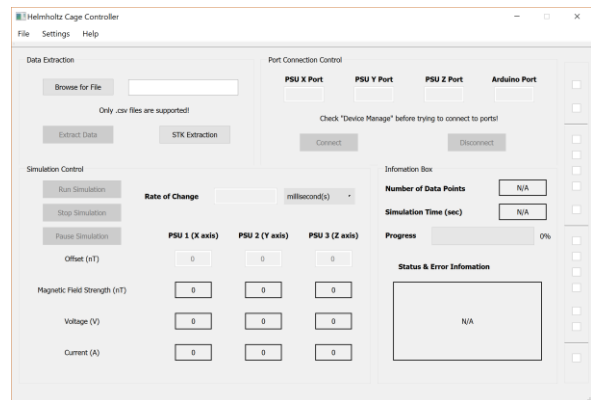


Figure 2. Helmholtz Cage Controller User Interface

calculated. The expression for the current required was derived from the cage's geometry. The three currents are then prescribed to each of the power supplies with a PyVISA, a Python package to support National Instrument's Virtual Instrument Software Architecture. In the instance of accidental open-circuits, cross cable short-circuits, or hardware disconnections, the power-supplies are equipped with over-voltage protection and maximum power protection. The entire logic is wrapped up in a graphical user interface as shown in Figure 2.

3.2. STK Integration

The logical development of CubeSat programs typically yield a desired or predicted orbit for the mission. Orbits can be modelled both mathematically and

graphically using AGI's STK. STK can model most aspects of spacecraft missions and that is leveraged to make this system even more powerful.

Code was created that extracts the magnetic field data from any orbit designed in STK. The only thing necessary is to have STK open, and to enter the name of the satellite into the software block. The code then extracts all the magnetic field vector components for the specified timestep. This allows for magnetic fields to be generated in "real-time." The fields produced would be modified at the same rate of change that the satellite would experience while traversing through its orbit. With timestep modification the system can recreate a full orbit in expedited time as well.

4. Field Mapping

While the cage is running, there is no visual feedback for the user to recognize whether the cage is operating properly. As such, mapping the fields within the cage can provide beneficial insight as to the performance of the cage. The two logical methods for performance validation are mapping the cage in along one, two and three dimensions.

4.1 One-Dimensional

Mapping the cage along lines that go through the center of each face of the cage while only exciting the coil that generates fields along the axis being measured yields the coil response. From the curve, the region of uniform field along the axis can be determined.

To perform the measurements, a non-ferromagnetic beam was placed inside the cage, spanning the entire length. It was

placed through the center. The beam was marked with even spacings. One coil was excited, and a magnetometer was used to make measurements along the entire beam. The magnetometer's coordinate system was aligned with the cage's such that the component of interest. Data from the magnetometer was obtained by communicating with an Arduino (reprogrammable microcontroller) using a standard communication interface. The data was obtained from the microcontroller utilizing a serial connection with a computer.

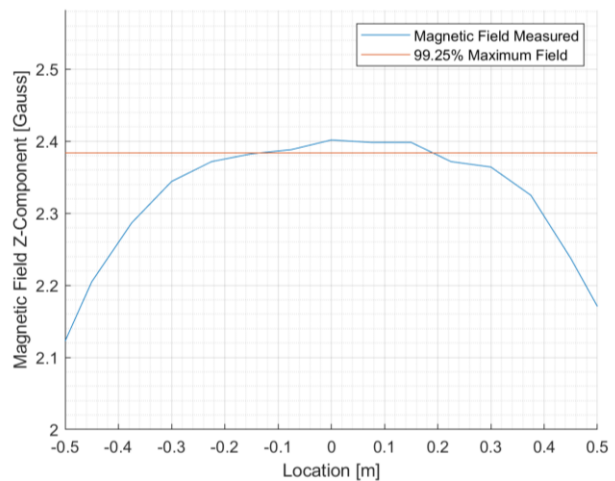


Figure 3. Plot of Z-Component of Magnetic Field with Constant Excitation

The results of measuring the z-axis coils is shown in Figure 3. The curve is highly similar to the theoretical curve derived for the geometry of the cage. The goal of the cage was to have a uniform magnetic field for 30 centimeters along each axis. Percentage lines of the maximum magnetic field measured were drawn and the line which intersected the magnetic field curve at the proper bounds was selected. From this process it was observed that in the central region of the cage, along the z-axis, the field will vary by less than 1%.

4.2 Two- and Three-Dimensional

Upon completion of the one-dimensional mapping, the natural extension was to perform the mapping in two and three dimensions. The procedure was developed using the same methodology but expanded along two more dimensions. The Helmholtz Cage was gridded off yielding 125 vertices to perform measurements at.

All three coils were given uniform, constant currents. The magnetic field at every single vertex was measured. This resulted in a three-dimensional mapping of the magnetic field in and around the cage. A visualization of this data is shown in Figure 4, where the arrows demonstrate the direction of the magnetic field at each particular point, and the color represents the magnitude.

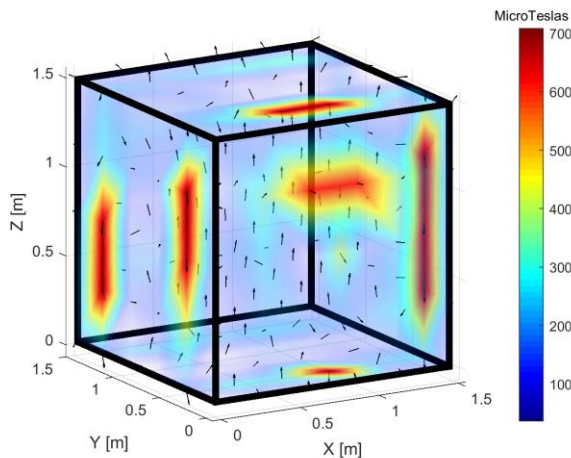


Figure 4. Three-Dimensional Mapping of the Helmholtz Cage with Uniform Excitation

The results from the three-dimensional measurement experiment yields extremely intuitive results regarding electromagnetics. The fields of strongest magnitude are located nearest the coils. In fact, the geometry of the coils can be observed in the field magnitude plot. This,

however, poses a bit of a problem. Because the field is so strong, the region of uniformity at the center of the cage cannot be observed. Modifying the bounds of the color scale, and looking at only a two-dimensional cut of the cage map yields a plot that clearly demonstrates the geometry of region of uniformity. The results of that procedure are shown in Figure 5.

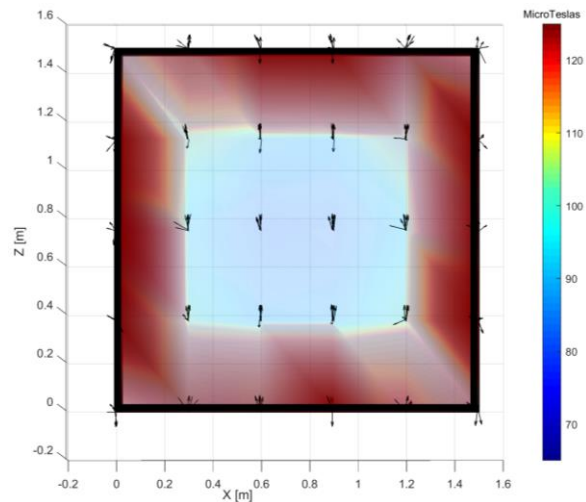


Figure 5. Two-Dimensional Mapping of the Region of Uniformity

The two-dimensional mapping shows similar results to the one-dimensional mapping, but with less resolution.

5. Future Work

There is a multitude of directions that this research can progress. The first is to continue the mapping of the cage. This would be accomplished by using a motion-capture system such as OptiTrack. A magnetometer would be affixed to a wand-type apparatus that provides several nodes for the motion capture system to provide sufficient orientation information about the magnetometer. Relatively simple mathematics can be used to back out the relative coordinate systems such that the

magnetic field components are obtained. The system would also require a method of sampling that ensures sampling of magnetic field and positioning at the same time.

The other sensible direction to take this research is to integrate it with other tools currently in development. One example is the air-bearing table that is under development. The air-bearing table will provide a little over two degrees of freedom. Combining the two will allow for effective attitude determination system testing for CubeSats.

6. Acknowledgements

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⁴Gaeron Friedrichs. Helmholtz Cage Development for CubeSat Testing. *ACC Meeting of the Minds Conference*, 2019.