

Mathematical Modeling, Prototyping, and Verification Testing of Low Cost Magnetorquers for 3 Axis Control with Designed and Assembled Coil Winder for UC Davis CubeSat Mission

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## **OVERVIEW**

System Requirements
 Configuration
 Optimization
 Manufacturing

Testing



## SYSTEM REQUIREMENTS

<b>Control Requirement</b>	Description
Minimum Magnetic Moment	0.0159 Am^2
Attitude Control Accuracy	Point CubeSat in desired direction within $\pm 5.0$ degrees
DetumblingTime	Detumble CubeSat to below 0.5 deg/sec within 72 hours
<b>Desaturation Time</b>	Desaturate reaction wheels within 12 hours

Constraints	Description		
<b>Dimension Constraint</b>	80mm x 80mm x 25mm		
Power Constraint	≤ 2W		
Mass Constraint	≤ 320 g		

## CONFIGURATION



	Air Core	Rod (x2)	
Dimensions	78mm(l) x 78mm(w) x 25mm(h)	71mm(l) x 6mm(d)	
Layers	I	3	
Turns per layer	66	134	
Current	0.6 Amps	0.4 Amps	
Axis Control	z-axis	x-, y- axis	

### OPTIMIZATION-RODS

What are we trying to optimize?		What Variables can we Change			
Magnetic Moment	Power Consumption	Mass and Volume	Rod Shape	Number of Turns	Current

### OPTIMIZATION EQUATIONS

#### Magnetic moment equation:



#### <u>Ohm's Law:</u>

$$V = IR$$

#### Power equation:

$$P = I^2 R$$

$$m = Mag. Mom. [Am2]$$

$$I = Current [A]$$

$$S = Rod C.S. Area [m2]$$

$$N = \# of Turns [N/A]$$

$$V_{C} = Rod Vol. [m3]$$

$$M = Mag. Factor [A/m]$$

$$I/r = Rod Shape [N/A]$$

$$V = Voltage [V]$$

$$P = Power [W]$$

$$AWG = Wire Diam. [m]$$

### OPTIMIZATION EQUATIONS

Things to keep in mind during optimization:

- Voltage is fixed because it depends on external conditions;
- The current is controlled by PWM, and it can be capped off at a certain value;
- For a given value of magnetic moment, a larger current requires less turns on the coil;
- Extremely high number of layers and small radius for the core can both make manufacturing more challenging.



#### IMPORTANT RELATIONSHIPS

### OPTIMIZATION PROCESS



**Check** if power and space requirements are met. Repeat until a reasonable configuration is acquired. **Choose** number of wire turns and current consumption required to reach minimum dipole requirements



# OPTIMIZATION PROCESS -MATLAB CODE

- Tests various combinations of variables;
- Approves all combinations that produce desired results;
- Can be used by any CubeSat developer
- Potential to become interactive.

## OPTIMIZATION- AIR CORE

MATLAB code defines complete layers to wind the air core structure for easier manufacturing.









### MANUFACTURING- COIL WINDER

#### Why?

Faced multiple problems while trying to hand wind the coils.

- Varying number of turns
- Wire intertwining
- <u>Solution:</u> Build a coil winder that could wind both the torque rods and the air core coils.
  - Can define the number of turns and avoid the wire from getting intertwined.

#### How?

All parts for the winder are 3-D printed out of PLA plastic on our campus 3D printing shop.

#### What?

The coil winder includes two stepper motors and two drivers, one controlling the wire and the other for spinning coil.

### TESTING



#### Goal:

Test if magnetorquer design produced desired magnetic moment

#### **Data Collected**

Magnetic field readings from magnetorquer at various points using a magnetometer.

#### **MATLAB Calculations:**

- Input: Earth's magnetic field and magnetorquer's magnetic field readings
- **Output:** Magnetic moment produced by magnetorquer

#### Test Setup:

- Octagon base holds coils and rotates to allow measurement of magnetic field from various angles
- Rotating base maintains the magnetometer stable without effecting our values

## FUTURE WORKS

- Controls testing: Current prototypes will be handed off to the electrical system to test with PCB for the controls and software system for B-Dot controls.
- Manufacturing flight test configuration: Producing the complete magnetorquer design of one air coil and 2 rods using the selected space grade material for flight testing.
- Create a guide for universities to follow using our methods (publishing)

### REFERENCES

- N. Bellini, "Magnetic Actuators for Nanosatellite Attitude Control," Universita di Bologna, Tesi di Laurea, 2013/2014.
- Larson, Wiley J., et al. SMAD III: Space Mission Analysis and Design, 3rd Edition: Workbook. Microcosm Press, 2005.

Thank You