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

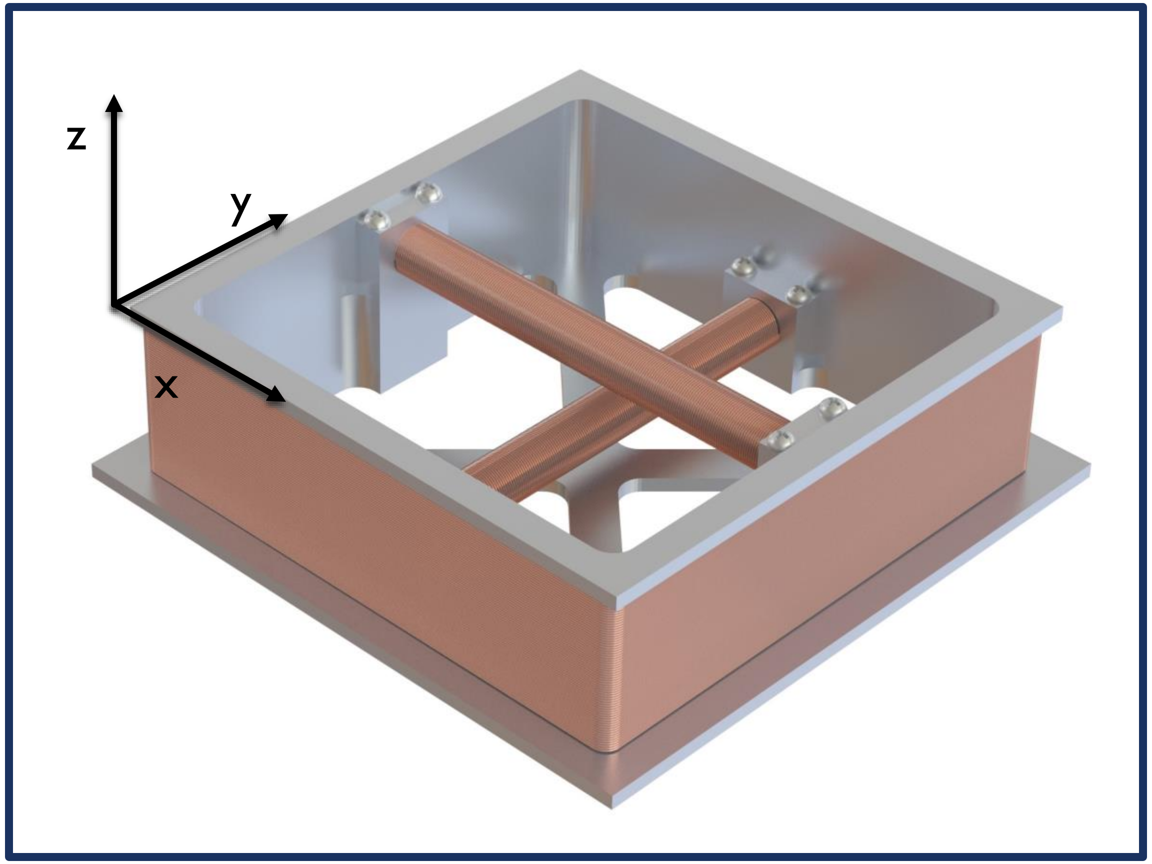
- System Requirements
- Configuration
- Optimization
- Manufacturing
- Testing

SYSTEM REQUIREMENTS

Control Requirement	Description
Minimum Magnetic Moment	0.0159 Am^2
Attitude Control Accuracy	Point CubeSat in desired direction within ±5.0 degrees
Detumbling Time	Detumble CubeSat to below 0.5 deg/sec within 72 hours
Desaturation Time	Desaturate reaction wheels within 12 hours

Constraints	Description
Dimension Constraint	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	1	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?		
Magnetic Moment	Power Consumption	Mass and Volume

What Variables can we Change		
Rod Shape	Number of Turns	Current

OPTIMIZATION EQUATIONS

Magnetic moment equation:

$$m = NIS + V_c M$$

- NIS: Electrical parameter → Affected by circuit-related parameters, such as V, AWG, length of wire, conductivity, etc.
- $V_c M$: Rod shape parameter → Affected by properties of the rod, such as length, radius, permeability, coercivity, etc.

Ohm's Law:

$$V = IR$$

Power equation:

$$P = I^2 R$$

Variable Key:

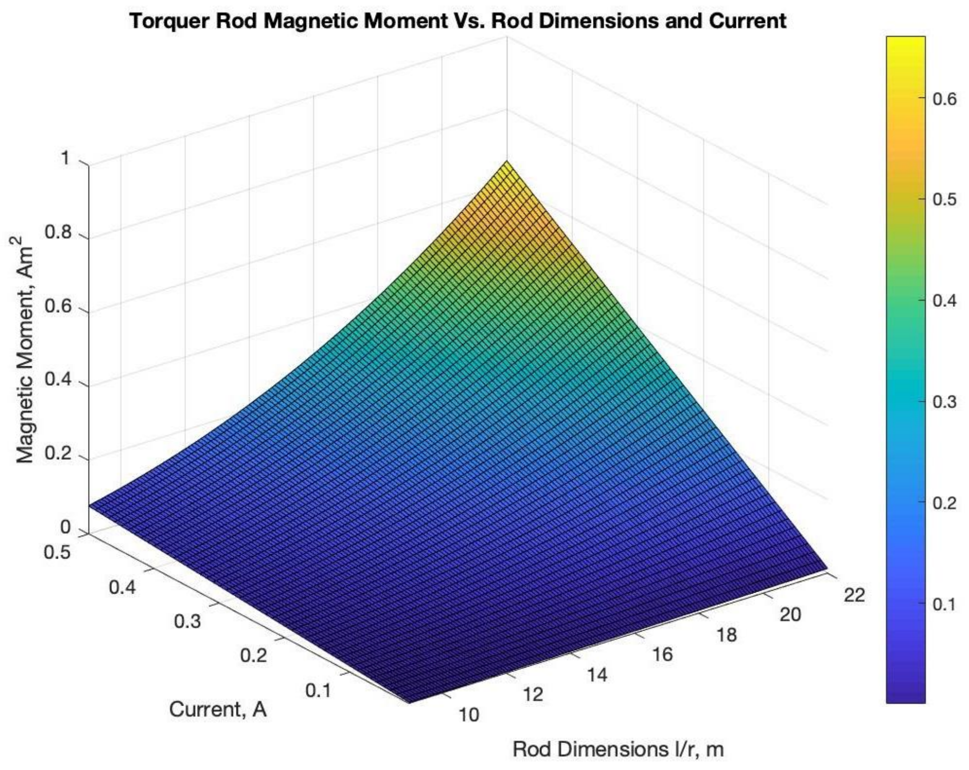
- m = Mag. Mom. [Am^2]
- I = Current [A]
- S = Rod C.S. Area [m^2]
- N = # of Turns [N/A]
- V_C = Rod Vol. [m^3]
- M = Mag. Factor [A/m]
- l/r = Rod Shape [N/A]
- V = Voltage [V]
- P = Power [W]
- AWG = Wire Diam. [m]

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



Core Shape	• Affects Magnetic Dipole
Number of Turns	• Affects Power Consumption
Wire Gauge	• Limits Current

OPTIMIZATION PROCESS

Maximize Core Shape

- Increases Magnetic Dipole
- Decreases Demagnetization time

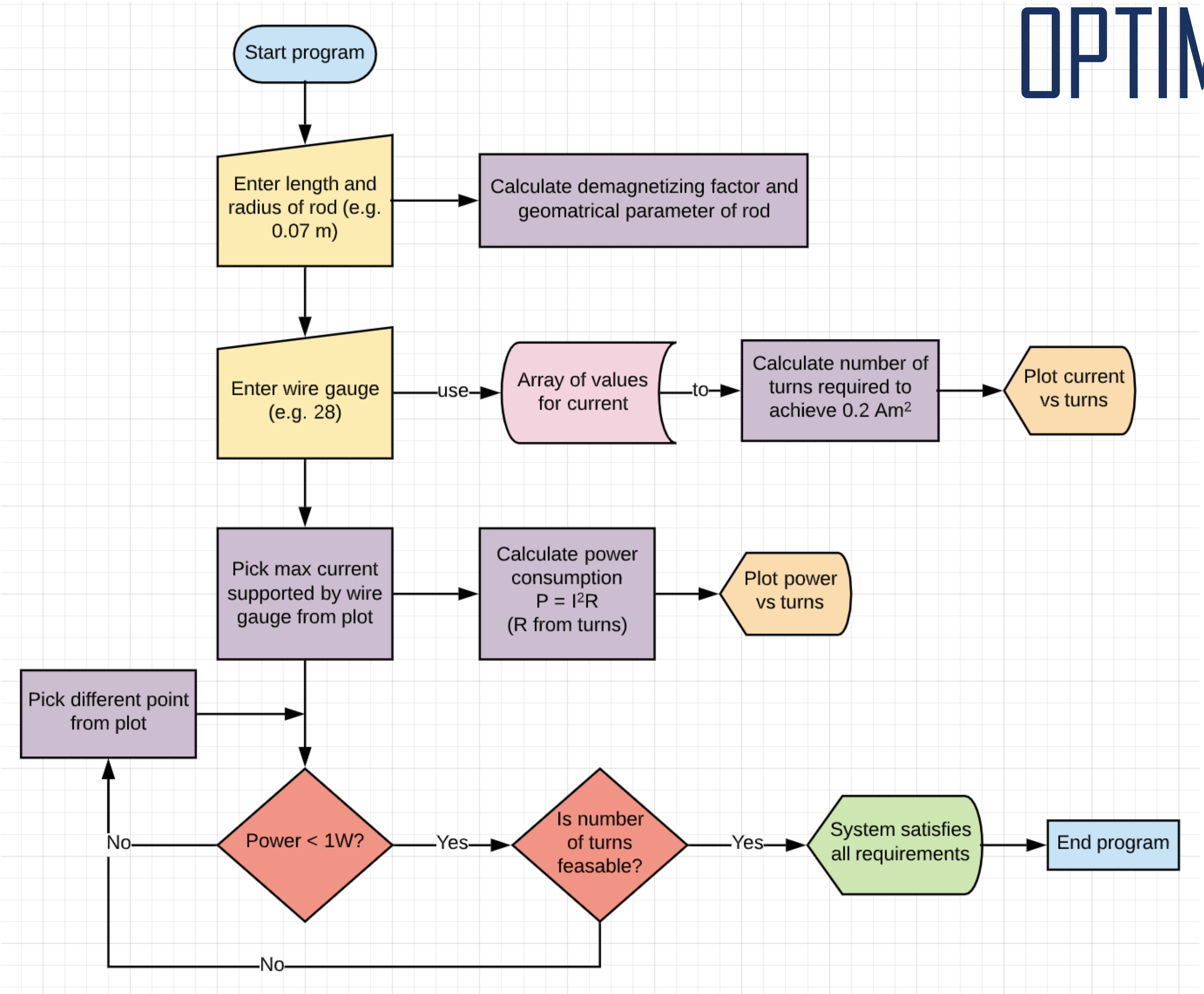
Fix Wire Gauge.
Chosen by seeing which:

- Provides more flexibility in terms of operative region
  - Larger current ranges to work with

Choose number of wire turns and current consumption required to reach minimum dipole requirements

Check if power and space requirements are met. Repeat until a reasonable configuration is acquired.

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.

DEFINE VARIABLES

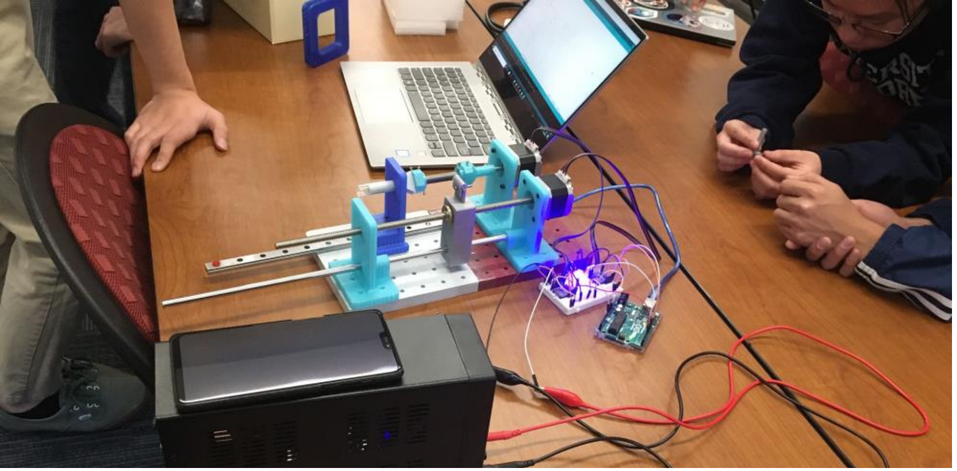
- Air core structure..
  - Maximum outer side length
  - Thickness
  - Total height
  - Clearance between edge of PCB and coil structure

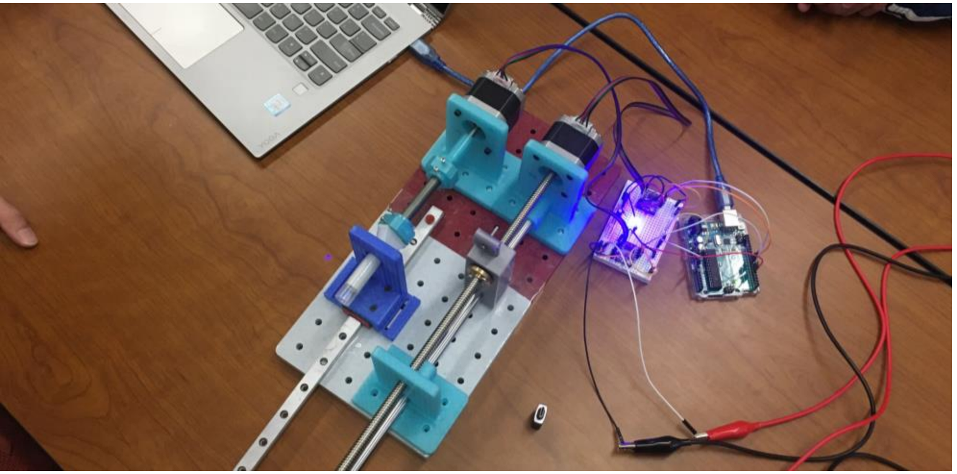
INPUTS

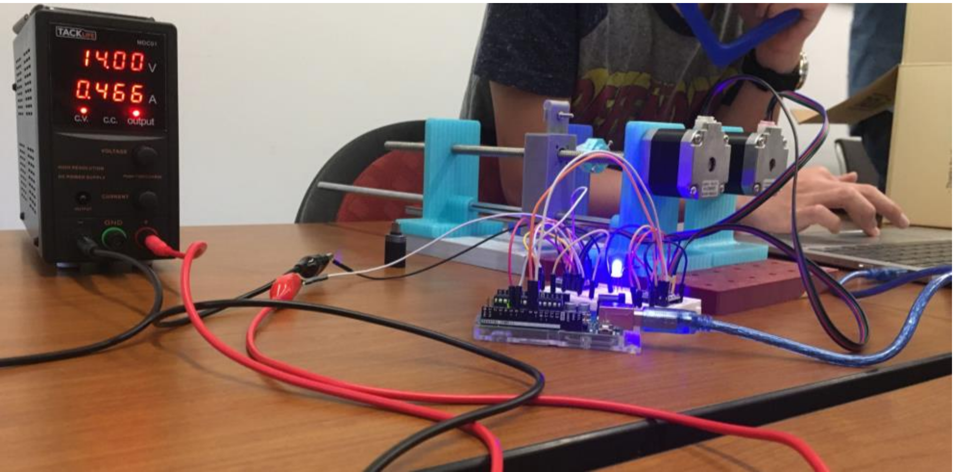
- Power Consumption
- Voltage
- Wire gauge
- Inner Side Length

OUTPUTS

- Magnetic Moment
- Number of Layers
- Number of turns per layer
- Current







MANUFACTURING- COIL WINDER

<u>Why?</u>

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.

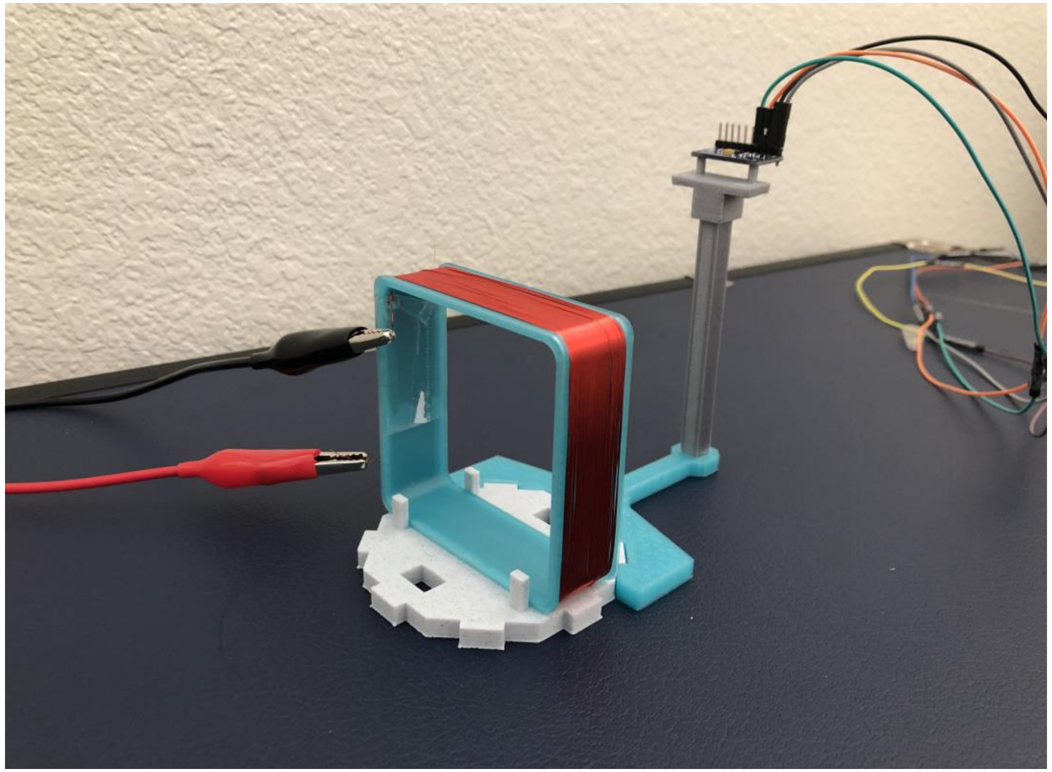
<u>How?</u>

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

<u>What?</u>

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