# Background

Magnetorquers are electromagnetic magnets that utilize the magnetic field of the earth to perform 3-axis rotation in space. Its low cost and simple structure make it a perfect actuator for a 1U CubeSat. Its an important component because it plays a key role in the detumbling system of the nanosatellite once it is launched to space. It makes it so the CubeSat is stable where it has low vibration and doesn’t stray away from its orbit. It is also responsible for rotating the nanosatellite on its desired orientation in space.

# Types of Magnetorquers

There are three types of magnetorquers: embedded coil, air core torquer and torquerod magnetorquers. The following table shows some comparison of an air core torquer and a torquerod and their limitations. An embedded coil is not included because it requires large amount of power, which is not suitable for a nanosatellite.

|  |  |  |
| --- | --- | --- |
|  | Air Core Torquer | Torquerod Magnetorquer |
| 1. Volume | Takes up greater space because it would require greater number of turns and area to obtain desired dipole moment. | Takes up lower space. Adding a metal core increases the dipole moment 300 times which means less current, area, and number of turns needed. |
| 2. Mass | Requires less mass due to absence of metal rod. Can go to | More mass since a metal rod is relatively heavier than copper wire. Some products can go up to 30g for 1U CubeSat |
| 3. Power | Requires more power since there is no metal to amplify magnetic dipole. | Less power. Metal core contributes significantly to the magnetic dipole. |
| 4. Demagnetization time | Requires less time to demagnetize | Requires more time but it can be lessened depending on material. Soft ferromagnetic materials are preferable. |
| 5. Magnetization |  |  |

Importance of each characterics:

1. Volume: the cubesat has limited space so its better to have lesser volume to maximize its space.
2. Mass: a larger mass makes the cubesat more difficult to rotate so a smaller mass is preferred.
3. Power: A nanosatellite could only carry small batteries that supply a relatively small amount of power, so it’s preferred to have magnetorquers consume the least amount of power as possible while meeting mass and volume requirements.
4. Demagnetization time: longer demagnetization time could affect longer detumbling time and unstable placement of cubesat on the orbit so a shorter demagnetization time is preferred.

The table shows the difference between an air core torquer and metal core torquer in terms of volume, mass, power, and demagnetization time. An air core torquer takes up more volume and consumes more power than a torque rod while a Torquerod takes up more mass and has a longer demagnetization time than an air core torquer.

In conclusion, a torque rod would be more suitable to use because of low power and small space a Cubesat provides. However, an air core torquer could also be viable if the design has not met power and volume limitations.

# Design/Orientation & Constraints

Magnetorquer design for a 3-axis rotation

While torquerods are the ideal type of magnetorquer to use, a combination of 2 torquerods and 1 air core Torquer would be the simplest to arrange and configure in the Cubesat. Following figures show possible orientation of a 2 torquerod and 1 air core torquer combination.

|  |  |  |
| --- | --- | --- |
|  | A picture containing case  Description automatically generated |  |
| Figure 1 | Figure 2 | Figure 3 |

In designing a magnetorquer, it is important to identify the mass, volume, power, and magnetic dipole constraints. These constraints were made in the assumption that the magnetorquers are arranged like figure 2.

**Mass**: <300g

The total mass constraint for ADCS is <320g. It was assumed that the other ADCS components were <20g and so the total mass for the actuator should be no more than 300g. Based on the mass of air torquers and torque rods from various products, most products weigh <100g. This indicates that the placeholder of the magnetorquers is what takes up most of the mass.

**Volume**/Dimension: 90x90x20 mm (lxwxh)

A 1U CubeSat has a dimension of 10x10x10 cm. Inorder for the actuator to fit in the CubeSat, it’s safe to set its length and width to 90x90 mm. As for height, that depends on the height and diameter of the air core torquer and the torque rod. A height of 20mm is safe to assume because diameter of the rod is <15mm for most designs.

**Power**: 0.600W – 2W

Power consumption depends on the current delivered to the magnetorquers and the equivalent resistance of the coils. The range was based on power consumption from trade studies.

**Magnetic Moment:** 0.140 – 0.25 Am2

The minimum magnetic dipole from studies shows a value of 0.12Am2. setting the maximum to 0.25Am2 was based on other designs from trade studies. Other designs show that magnetic dipole for each magnetorquer could go up to 0.25 Am2

For the procedure, its suggested that the dimension remain as a fixed variable.

# Air Core Torquer Design



An air core torquer relies on the number of turns the magnet has and current being delivered to the coil. Using a rectangular coil is suggested than a circular coil because it presents “ higher ratio S/C where S if the surface and C the length of the coil: these two parameters directly are connected to the efficiency of magnetorquer”[MANAC]. Magnetic field formula for rectangular coil shown below:

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n – number of turns

I – current

µo – permeability constant

l1 x l2 – cross-sectional area of coil

Another important equation is the magnetic moment because it determines the amount of torque the actuator exerts on the CubeSat.



S – Surface Area

In addition to the dimension being fixed, we can also assume that the voltage supplied to the torquer is fixed. This is assumed inorder to define the mass, magnetic dipole, and power consumed by the air core torquer. The mass(M), magnetic dipole(m), and Power(P) formulas are the following:

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**Sample Calculations:**

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Timeline

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**Design:**

Used MatLab and excel to perform magnetic dipole, power, and mass calculations. The voltage and dimensions were set to be constant. For **Table 1**, below, shows sample designs for an air core magnetorquer made of copper wire. The design was made in dependence of wire diameter and number of coil turns. Parameter assumption are the following: V=3.3V, sigma=17.24 nΩm, ρ = 8960 kg/m3, S = 90mmx90mm

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Area(mm) | dw(mm) | N | P(mW) | M(g) | m(Am2) | AWG |
| 8100 | 0.32 | 350 | 403 | 90.79 | 0.3464 | 28 |
| 8100 | 0.32 | 200 | 706 | 51.88 | 0.3464 | 28 |
| 8100 | 0.32 | 100 | 1411 | 25.94 | 0.3464 | 28 |
|  |  |  |  |  |  |  |
| 8100 | 0.18 | 350 | 128 | 28.73 | 0.1096 | 33 |
|  |  |  |  |  |  |  |
| 8100 | 0.254 | 350 | 254 | 57.21 | 0.2182 | 30 |
| 8100 | 0.254 | 200 | 445 | 32.69 | 0.2182 | 30 |
| 8100 | 0.254 | 100 | 889 | 16.34 | 0.2182 | 30 |

**Table 1**

The highlighted row follows close to the desired constraints. This could change after figuring the Torquerod’s design.

# Torquerod Magnetorquer Design

**Terms**:

**Susceptibility**-refers to how much a material can become magnetized in the presence of an external magnetic field.

**Permeability**- refers to how easily a material can be magnetized.

**Saturation**- refers to the maximum magnetic strength of the material.

**Coercivity**- refers to the resistance of a magnetic material to becoming demagnetized in the absence of external magnetic field. (in A/m)

**Difference between H field and B field:**

Information gathered from ChatGPT

In electromagnetism, the H field and the B field are two different but related concepts.

The H field, also known as the magnetic field intensity or magnetic field strength, is defined as the magnetic field created by the flow of electric current. It is measured in amperes per meter (A/m). The H field is related to the current flowing through a conductor and the number of turns in a coil, and it is used to calculate the magnetic force that acts on a magnetic material.

The B field, also known as the magnetic flux density or magnetic induction, is a measure of the magnetic field that exists in a space, regardless of the presence of a current. It is measured in tesla (T) or gauss (G). The B field is related to the strength and orientation of a magnet or magnetic material, and it is used to calculate the magnetic force that acts on a charged particle moving through a magnetic field.

The relationship between the H field and the B field is given by the magnetic permeability of the medium, which relates the magnetic flux density to the magnetic field intensity. The magnetic permeability of a vacuum is constant and is defined as 4π x 10^-7 henries per meter (H/m). In a medium with a different permeability, the H field and the B field are related by the medium's magnetic permeability.

In summary, the H field is the magnetic field produced by the flow of electric current, while the B field is the magnetic field that exists in a space, regardless of the presence of a current. The two fields are related by the magnetic permeability of the medium.

**CORE MATERIAL TYPE**

There are three types of magnetic material: Diamagnetic, Paramagnetic, Ferromagnetic. A soft ferromagnetic material is preferrable for a magnetorquer because of its typically **low coercivity, high permeability and saturation.**

Table

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**Important relations**

### Magnetic dipole increases with current but effect of core’s shape is not negligible: a high l/r ratio improves the performance of the rod reducing the demagnetization factor.

### Typical values of permeability for these material are in order of 1000 to 10000

### Magnetix flux saturation is typically under 0.6T

**Trade Studies for Metal Core**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Price cite** | **Data** | **Price/Qty** | **Dimension(dxl)** |
| **EFI Alloy 50** | https://www.edfagan.com/soft-magnetic-alloys/alloy-50/alloy-50-rod/ | https://www.edfagan.com/soft-magnetic-alloys/alloy-50/alloy-50-properties/ | $75 | 0.500”x2.3622”  12.7mmx60mm |
| **EFI Alloy 79** | https://www.edfagan.com/soft-magnetic-alloys/magnifer-7904-hymu-80-hipernom-moly-permalloy-80-rod-sheet-coil-square-bar/efi-alloy-79-rod/ | https://www.edfagan.com/soft-magnetic-alloys/magnifer-7904-hymu-80-hipernom-moly-permalloy-80-rod-sheet-coil-square-bar/alloy-79-properties/ | $50 | 0.500”x2.3622”  12.7mmx60mm |
| **Hiperco 50** | https://www.edfagan.com/soft-magnetic-alloys/hiperco-50/hiperco-50a-round-bar-rod/ | <https://f.hubspotusercontent20>.  net/hubfs/7407327/  carpenter\_electrification  /Resources/Datasheets  /Hiperco\_50A\_Alloy\_(E199).pdf | $50 | 0.510”x2.3622”  12.954mmx60mm |
|  |  |  |  |  |
|  |  |  |  |  |

**Table 2:** List of preferred soft-ferromagnetic materials for the metal core. The price the links for data and their dimensions in inches and mm are given.

Diagram, text, letter

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Figure 2: Sample calculation for the magnetic dipole of a torque rod given a DC source. (MANAC)

# Next Steps/Conclusion

Build the torque rod and air core torquer. For the air core torquer, you may use the design I made for its support on the “Air Core Torquer support” folder. Follow the formula highlighted in **Table 1**. For the torque rod, purchase EFI Alloy 79, follow listed size on **Table 2**. I’m still figuring out how many turns we need for the torque rod. Although I provided sample calculations from previous page for calculating magnetic dipole. Experiment with different values for the number of turns (N) while keeping current(I) and G fixed. The magnetic moment has to be at least 0.14 Am^2 (the higher the better). But first find out the relative permeability of the metal core before any calculations (I’ve been struggling with this, according to ChatGPT, you may find it through given data or experimentation). You will need this to find N\_d. Also the wires needs to be glued together. Research an adhesive that is suitable in space.

Coiling up the wires can be tedious since you have to coil it up hundreds of times and has to be as precise as possible. I have made a design for a coil winder (look it up in the “coil winder” folder). Although please find other ways to coil up the wire because building the coil winder may take a lot of time to finish. A team from UC Davis for example, used a drill to manually do it (A coil winder is not necessary).

<http://mstl.atl.calpoly.edu/~workshop/archive/2010/Summer/10%20-%20Barrington-Brown%20-%20Air%20Cored%20vs.%20Rod%20Magnetorquer.pdf>

* 2010 short presentation of advantages and disadvantages of magnetorquers. Also mention briefly about air vs metal core torquers.

<https://www.youtube.com/watch?v=EpQ_xIyCSXk&ab_channel=SpaceandSatelliteSystemsatUCDavis>

* A 2020 presentation about ADCS magnetorquers from UC Davis
* Includes information about their configuration, manufacturing, testing experiences
* They use a coil winder

<https://ssdl2.gatech.edu/sites/default/files/ssdl-files/papers/mastersProjects/AminJ-8900.pdf>

* 2019 article about metal torquer design and testing from Georgia Tech

Magnetic Actuators for Nanosatellite Attitude Control (MANAC)

* I usually refer to this document