

Design and Manufacturing of Electromagnetic Torque Rods for Hawaii Space Flight Lab

Code Smith, Morgan Roman, and Devin Kamita | University of Hawaii at Manoa | Advisor: A Zachary Trimble

Abstract

Satellites are an essential part of modern society. From global communications to advanced research and everything in between satellites have a huge impact on how we live today. However, a satellite would be useless if it could not be properly oriented while it is in orbit and that can be difficult to do in the frictionless environment of space. Of the three commonly used methods to control a satellite's orientation while it is in orbit (thrusters, reaction wheels, and torque rods) this research developed a cost effective torque rod for smaller satellites.

Project Objectives

❖ Design and manufacture a torque rod meeting the following specifications:

Item	Specification
❖ Cost	<\$1500
❖ Mass	<1 kg
❖ Operating Range	-20°C to +65°C
❖ Length	<400 mm
❖ Diameter	<50 mm
❖ Voltage	24V
❖ Resistance	Approximately 300 Ohms
❖ Maximum Current	<150mA
❖ Magnetic Moment	30 Am ² at 150mA
❖ Linearity	<10% at 20 Am ²

Physics

A torque rod is essentially a solenoid. The torque, T , generated by a torque rod in a magnetic field is given by the cross product of the magnetic moment, M , of the rod with the magnetic field vector, B ; $T = M \times B$. The magnitude of the magnetic moment, M , of an electromagnet similar to a torque rod is:

$$M = NI \left(1 + \frac{\mu_r - 1}{1 + (\mu_r - 1)N_d} \right) \frac{\pi}{4} \sum_{k=1}^n (d_{core} + 2k * d_{wire})^2$$

Mehjardi, Mohamad F. et al. "Design and Manufacturing of a Research Magnetic Torquer Rod." Contemporary Science and Engineering, Dept. of Aerospace Engineering, K.N. Toosi of Technology University, 2010.

Where n is the number of layers, N is the number of turns per layer, d_{core} is the diameter of the core, and d_{wire} is the diameter of the wire, μ_r is the relative permeability of the core material and N_d is the demagnetization factor. The wire's diameter must be added twice for each additional layer. This is the fundamental equation used to model the magnetic moment of the device.

Assuming that the core is much longer than it is wide the demagnetization factor becomes:

$$N_d = \frac{4[\ln(l_{core}/r_{core}) - 1]}{(l_{core}/r_{core})^2 - 4\ln(l_{core}/r_{core})}$$

where l_{core} is the length of the core and r_{core} is the radius of the core.

Design

To meet the specifications the prototype was designed to be made from a 14" long 1/4" diameter nickel-iron alloy core wrapped with a little over 20,000 wraps of 32 AWG wire which would allow for a resistance of approximately 280 ohms. To prevent out gassing and to protect the rod an anodized aluminum case was filled with resin using a vacuum potting procedure. The finished prototype is approximately 500 grams in total. Figure 1 is a pictorial representation of the design.

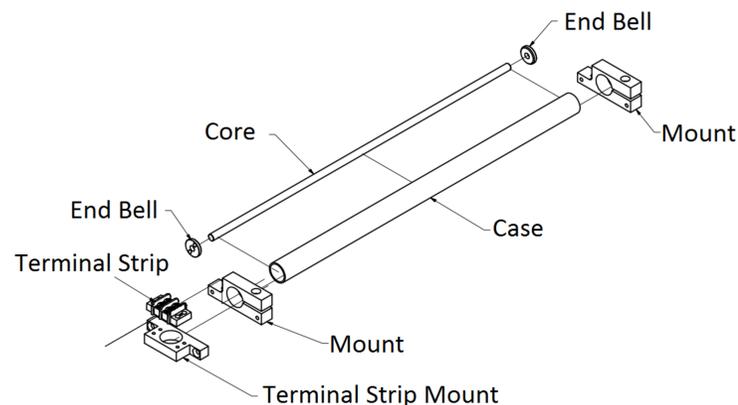


Figure 1: Exploded Assembly

Manufacturing

A torque rod is an electromagnet therefore the manufacturing process consists of creating a coil around a metal core. To make it possible to wrap that immense length of wire a lathe and its built in power feed were used. A custom tool was made that both holds the spool of wire and tensions the wire as it feeds onto the coil. Figure 2 shows the rod being wrapped on the lathe using the tensioning device.

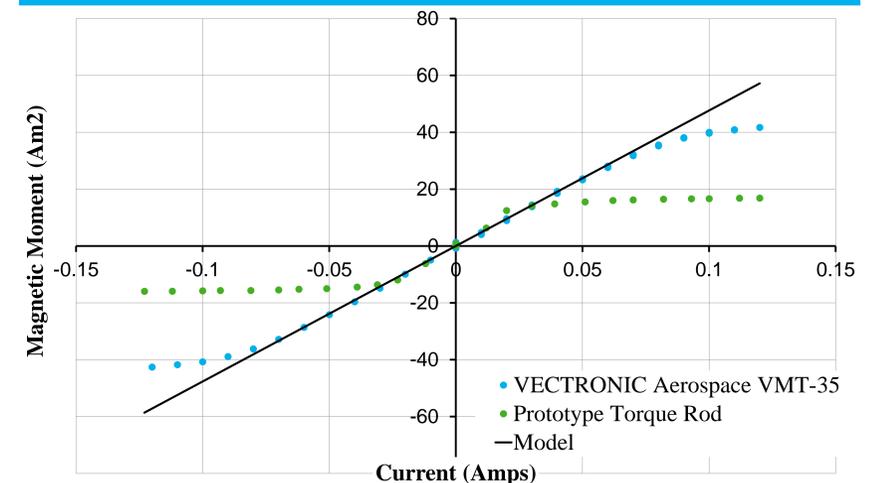


Figure 2: Rod Being Wrapped on a Lathe

Testing

To experimentally determine the strength of the magnetic moment generated by our torque rod the rod was secured to an aluminum test bed with magnetometers placed 45 mm away at zero, 45 and 90 degree angles to the rod. The rod was then supplied a current which ranged from 0.01 A to 1.0 A and the corresponding values of magnetic field strength were recorded. This data was then converted into magnetic moment. This measured magnetic moment was then compared to the predicted values from the model. Additionally, the same measurement process was repeated using the VECTRONIC Aerospace VMT-35 provided by HSFL for this test for comparison.

Results



- ❖ Prototype torque rod matches predicted magnetic moment in the linear region, but fails to reach the target magnetic moment of at least 30 Am² due to saturation.
- ❖ Prototype does meet weight, size, and resistance requirements
- ❖ Testing method and manufacturing process both validated

Conclusion

Due to a poor core material selection the rod did not reach the target magnetic moment of at least 30Am², however the design tools and manufacturing process required to produce a torque rod using existing machinery and a simple wire tensioning device for the lathe was successfully designed and tested. The testing method and modeling equations were successfully verified. Based on the data gathered it would be possible to reach the target specifications by either selecting a higher permeability core material which does not saturate in the operating area, or to increase the core diameter and adjust the number of wraps, thus decreasing the magnetic flux density while increasing the magnetic moment generated. Ultimately this shows that it is possible to produce inexpensive torque rods which are comparable to commercially available products provided low volume vendors can be found for the appropriate core material.