# Design of a Novel 300W Thruster: The Vectorable Cross-Field (VeX) Thruster

**Rainer Küüsvek,** ***Imperial College London***

***Abstract*— Reducing the need for mechanical gimbals for thrust vectoring can greatly reduce the cost and complexityof satellites utilizing Electric Propulsion (EP), particularly for small GEO satellites. The VectorableCross-Field (VeX) Thruster allows nonmechanical thrust vectoring to be achieved via the use of two setsof concentric arc-segment magnets. This configuration magnetically isolates four anode quadrants in the discharge channel, allowing the thrust angle of each quadrant to be modified electrically. The 300W thruster has a channel diameter and length of 46mm and a maximum magnetic field strength of 400 Gauss. Models for the 3-dimensional magnetostatic field are provided.**

## I. INTRODUCTION

The primary aim of this project is to facilitate a method to alter the ion beam trajectory in order to achieve thrust control without the need for a mechanical gimbal system. This will greatly reduce the cost and complexity of the thruster, introducing a new option into the low power, low cost propulsion market. Vectorability is of critical importance for Geosynchronous satellites whose attitude and orientation must be maintained during maneuvers. Thrust must always be directed through the craft's centre of gravity to prevent rotation of the craft which is difficult to halt. Vectoring ensures that this is the case, especially as the location of this centre can change during operation.

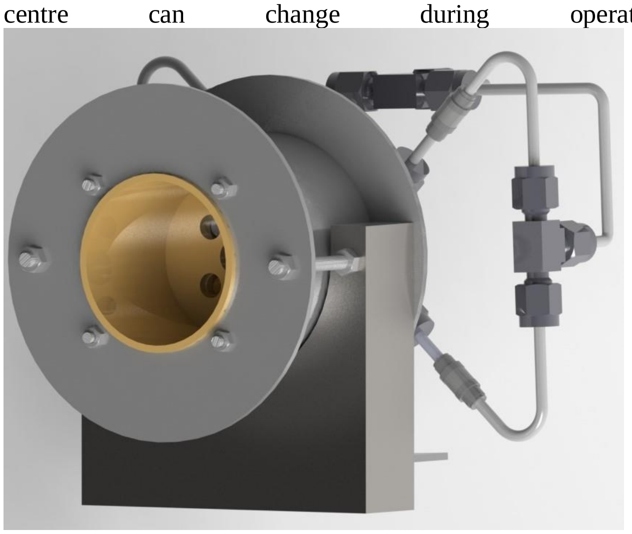

*Figure 1. Solidworks model of the VeX Thruster, including discharge channel, fuel feed system, and anodes*

The configuration investigated in this paper has many similarities to the CHTs and Halo thrusters that have come before it. It retains the annular concentric magnets, but rather than two continuous rings, the magnets on the VeX Thruster are each divided into four arcs. The reasoning behind this is to isolate the four anodes which lie between the inner magnets, 45 degrees out of phase. It is theorized that this will divide the plasma channel into isolated quadrants which can be individually excited in order to achieve thrust vectoring without the need for mechanical gimbals. This is dependent on a degree of beam divergence as well as the anodes' distance to the centre of thrust, to maximize the leverage that a single anode quadrant can exert on the spacecraft.

## II. DESIGN METHODOLOGY

Due to the complexity of the magnetic field, the EMWorks simulation was initially compared to magnetic and thermal results from FEMM to validate axisymmetric models, and which convergence studies were completed to determine ideal mesh sizes. Only then was the final VeX Thruster magnetic topology modelled.

In order to estimate thermal loads within the thruster, two extreme cases were examined. The first assumed all of the power passed into the thruster (300W) was dissipated on the anodes, and the second assumed dissipation on the channel walls. These two load cases are shown in *Figure 2.*

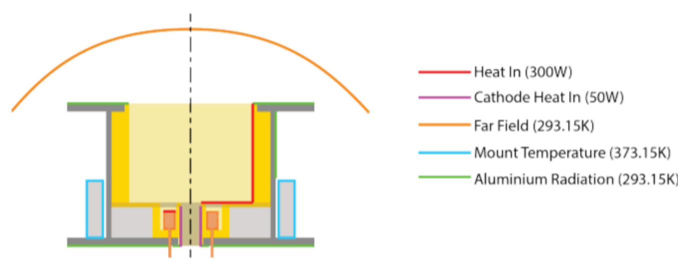


*Figure 2: Thermal Load Cases. Left: All power dissipated on anode. Right: All power dissipated on channel walls*

## III. SIMULATION RESULTS

*Table 1*is a summary of the materials used in the simulation.

| Component | Remane-nce [mT] | Conductivity [Mho/m] | Relative permeab-ility |
|---|---|---|---|
| Y10T Magnets | 200-235 | 0.029 | 5000 |
| Boron Nitride Channel | - | 700 | 1 |

| | | | |
|---|---|---|---|
| Copper Anode | - | 401 | 1 |
| Aluminum Frame | - | 237 | 1 |
| Vacuum | - | ~0 | 1 |

***Table 1. Materials in Simulation***

EMWorks was used to simulate the magnetic topology of this system, which could then be used to accurately size the thruster, as well as determine electron behavior within the ion plume. The field is shown in Figure 3a, and the downstream magnetic field strength at various radii is shown in Figure 3b. The maximum field strength was used to size the thruster, by comparing it to the field strength in existing thrusters of similar scales. Figure 4 represents the field lines in a single quadrant of the thruster. Note that the field in each quadrant is isolated from those in other quadrants.

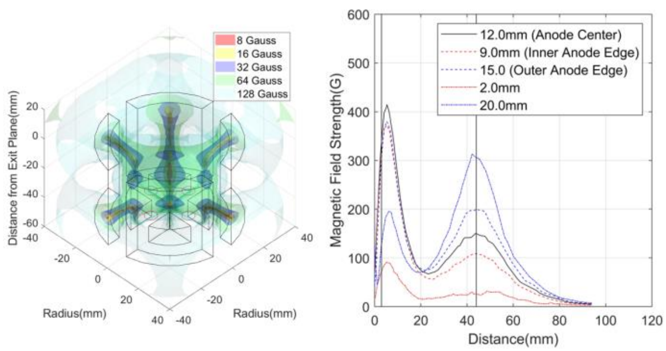


*Figure 3: Magnetic field strength topology (a) and downstream field strength at various radii (b)*

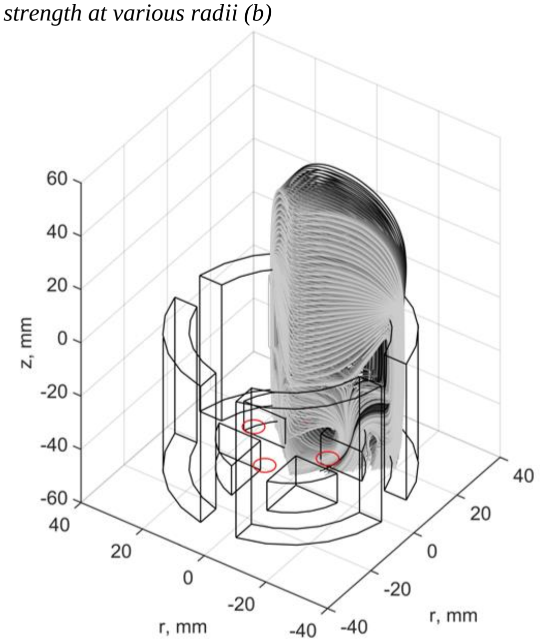


*Figure 4: Field lines in thruster quadrant, above anode depicted in red. Note that field lines are isolated from other quadrants*

FEMM and EMWorks simulations resulted in maximum temperatures which were within 8-14% of each other in either case. The latter is shown in *Figure 5*. Being conservative and assuming the higher temperature, the Ferrite magnets retain their magnetism even in the worst case scenarios, ensuring the safety and robustness of the thruster.

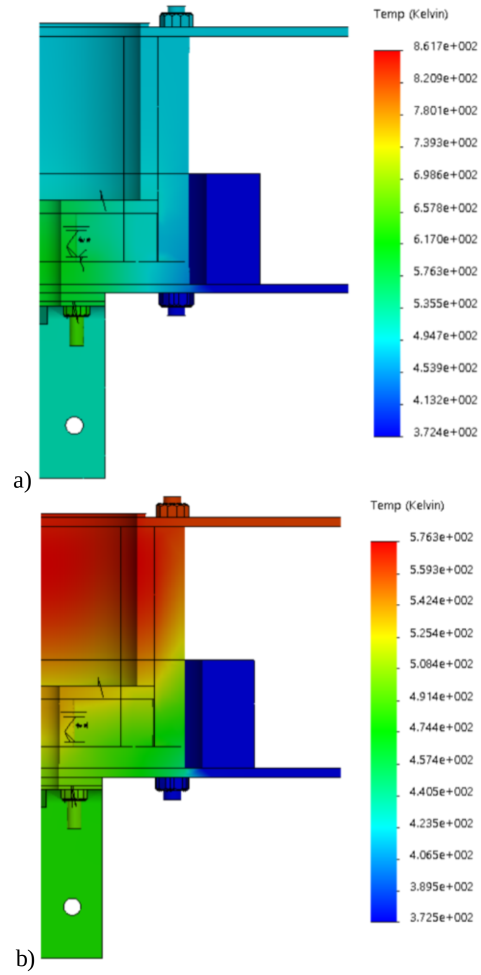


*Figure 5: Temperature distribution in two thermal load cases.*

## *IV. CONCLUSION*

This project has confirmed that thrust vectoring is possible via segmentation of the anode into four quadrants and isolating them via the use of a magnetic field. The design presented above achieves this via the use of concentrically placed permanent magnets, and vectoring thrust through control of the anode quadrant voltage and current, without the need for mechanical gimballing. The 3D EMWorks will prove invaluable in the design process, as well as future analysis of the internal electron behavior of the thruster.

In this report as part of the design process, it was assumed that the VeX Thruster would experience equal vectoring forces for each of its quadrants, whereas in reality more complicated effects will likely arise. In particular, there could be a potential dampening of this effect due to increased electron loss arising from higher Hall mobility in the excited quadrant.

Primary experimentation of the thrust, thrust vectoring, and anode efficiency must be undertaken as the next stage of the design. Secondary experimentations would also provide a better understanding of the internal physics within the thruster – these include channel erosion, charge accumulation, and plasma plume characteristics.