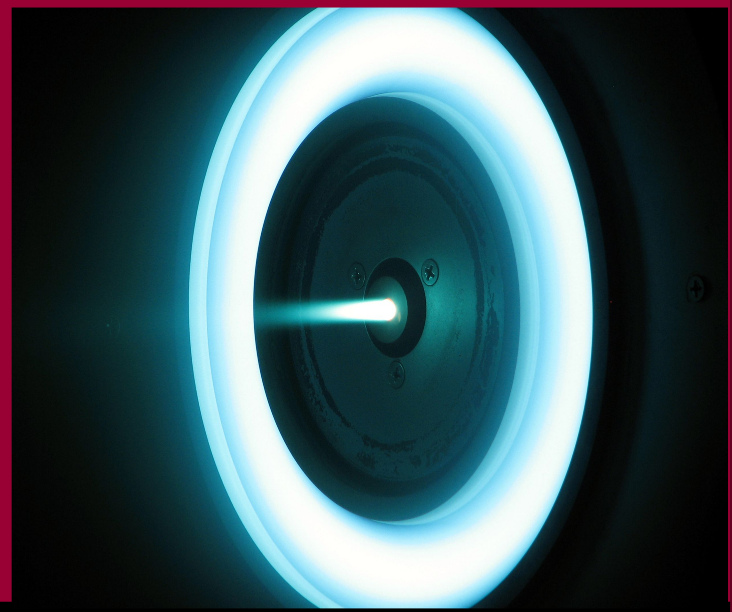
The Effect of Magnetic Shielding on H6 Hall Thruster Performance and Erosion Rates

Thousand Oaks High School's AP Research
Kernan Lee



ABSTRACT

An issue with high power Hall Thrusters (HT) has been their limited service lives due to ion to wall abrasion. In a 2010 wear test by the BPT-4000 Hall, virtually abrasion less performances measures were recorded due to changes in electric field configuration. Current magnetic shielding (MS) methods in Hall Thrusters aim to follow the same electrostatic principles in regards to the ever so desire for extended service life.

Purpose

Since Hall Effect Thrusters were designed to address the lack of reusability of combustion type rockets, it is absolutely imperative to eliminate factors that unnecessarily reduce the lifespans of HTs. In the past few years, the H6 and H9 Hall Thrusters have shown improved operation levels with the implementation of magnetic shielding. However, continuing to maintain adequate thruster efficiency is crucial in evaluating the applicability of Hall Thrusters. Furthermore, as internal erosion continues to be a prevalent issue for HT's, increased service lifetime will greatly bolster their candidacy in field missions. Considering its core performance metrics, this study aims to investigate magnetic shielding's effect on both HT channel erosion and operation levels.

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INTRODUCTION

Today's state of the art Hall Thrusters are known to reach minimum specific impulses of 3000s and net efficiencies of at least 60% at 800V (Cusson et al, 2017 (a)). Compared to conventional chemical rockets that operate at average specific impulses of 300s at 40% net efficiency, Hall Thrusters show statistically higher performance standards (Goebel & Katz, 2008). However, critical wear processes exist in a HT's fuel channel which shorten the service life and inhibit their long term practicality. Because fuel chamber walls are composed of insulating material that protects the spacecraft as a whole, it is imperative to keep wall erosion at a minimum for extended service life means, especially when it comes to deep space objectives (Conversano et al., 2017). MSHTs have been proposed to reduce chamber wall erosion while maintaining similar performance levels to that of unshielded ones, therefore longer service life with no backlash. MS function by altering the topography of electric fields responsible for ion acceleration to line up parallel to the chamber walls (Hofer et al, 2012). In doing so, ions are diverted away from the walls, disposing of abrasive forces. Additionally, ions traveling along deeper reaching electric fields lessens temperature and density discrepancies by interacting more ions at a time, further reducing internal erosion (Mikellides et al, 2013).

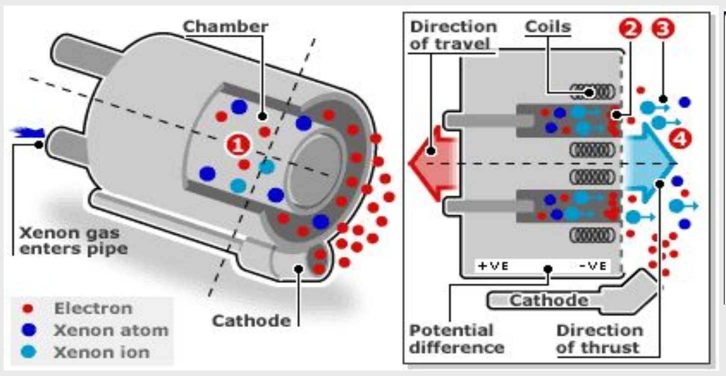

Figure 1. Inner Workings of a Typical Hall Thruster

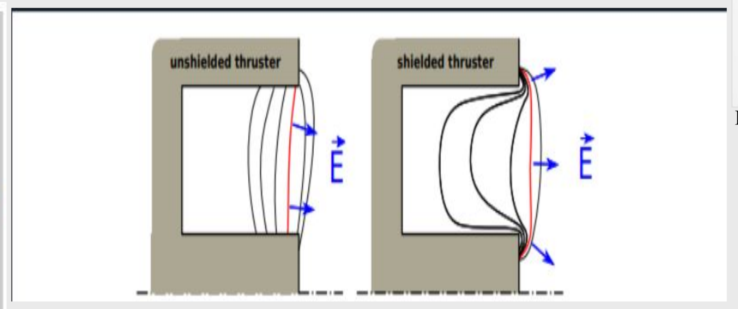

Figure 2. Electric Field (red) changes within the acceleration Chamber

METHODS AND MATERIALS

Literature Search This study was conducted by method of systematic literature review in which academic, peer reviewed articles were compiled as means of data. Scholarly, peer reviewed papers including the performances of the 6kW Hall Thruster were the priority search target. The H6 is laboratory grade HT is meant for research purposes. All numerically significant papers were accessed in English from online American journals.

Data Collection/Analysis For the sake of accuracy, only papers that focused on the 6kW HT's performances on specific impulse and rate of erosion within operation ranges 300V to 800V were included as numerically significant data. Appropriately, papers on USH6 that tested the same specific impulse and erosion rate parameters were compiled and compared using t tests as data.

Research Question

Does Magnetic Shielding in Hall Thrusters effectively reduce internal erosion while maintaining similar performance levels to that of unshielded ones?

Hypothesis

Alternate: Magnetic Shielding will reduce channel erosion while maintaining constant specific impulse values.

Null: Magnetic Shielding does not change or increase channel erosion while maintaining constant specific impulse values

RESULTS

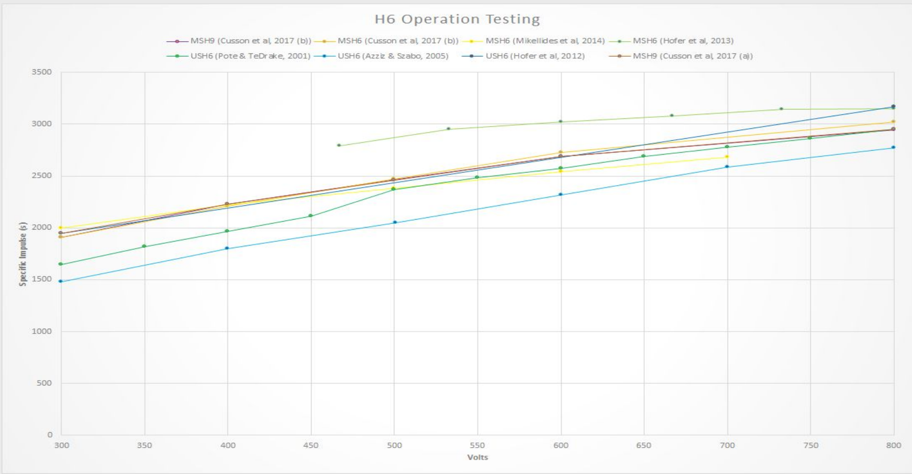

Figure 3. Erosion Rate of US and MS (300V)

Source	Magnetically Shielded?	Erosion (mm/kh)
(Goebel et al, 2012)	No	10
	Yes	6.8x10^-2
(Goebel et al, 2014)	No	9
(Hofer et al, 2012)	No	4.19
	No	4.75
	Yes	0
	Yes	2.4x10^-2
(Hofer et al, 2014)	No	6.37
	No	9.52
	Yes	0
	Yes	2.4x10^-2
(Mikellides et al, 2013)	No	8.7
	Yes	5.6x10^-1
(Jorns et al, 2015)	No	10
	Yes	7.78x10^-2

Table 1. Specific Impulses of the H6 from 300V to 800V

DISCUSSION

In two tailed figure tests, the specific impulses for unshielded models with a degree of freedom of n=26 yielded a t value of 0.013, showing mathematical insignificance. Therefore, the performance levels of the US and MS H6 in terms of specific impulse can be considered numerically equal from 300V to 800V. With this, the alternate and null hypothesis of this study are both validated as they require similar base performances between both models. Calculations for the MSH6 with a degree of freedom of 7, yielded a numerically similar value of 9.16789877, a large number that suggests that MSHT's reduce erosion rate by a significant degree. Characterization of magnetically shielded Hall Thrusters show high performance in efficiency, electron acceleration, and degradation reduction, demonstrating a promising future for more efficient electron propulsion models and aerospatial advancement as a whole.

CONCLUSIONS

From wear testing conducted on a 6kW laboratory grade HT, results showed a thousandth of the original erosion rate under magnetic shielding. Under low power operations, erosion was completely mitigated as the CMM showed no volume changes before and after testing. As operating voltage increased, traces of chamber abrasion were detected on the walls of MS, but were reduced by factors of 73 times, ranging from 9.82 x 10 to 5.3x10^4 um/h (Hofer et al., 2014 (b)). Higher magnitudes of ion density and electron temperatures found in the USH6 were associated with higher rates of erosion due to discrepancies that made the Xenon propellant behave non ideally, resulting in backsputter against the channel walls.

Further Work

Magnetic shielding's ability to reduce channel erosion and reduce ion discrepancies constitutes much room for mechanical improvement. Presuming that MS will continue to divert ions away from channel walls, traditional insulator walls serve less of a purpose to protect the spacecraft from ion on wall abrasion (Grimaud & Mazouffre, 2017). Essentially, ion current's inability to reach the insulating material inside chamber walls suggest that the ceramic insulators are an unneeded component since magnetic shielding already provides sufficient containment measures. Instead, conducting walls consisting of metals that further support already existing electric fields are being proposed (Dotson et al, 2013). However, it is only possible with the success of magnetic shielding to negate the need for such Bi or BNSiO2 insulators. If the state magnetic shielded Hall Thrusters continue to prove more effective in the future, conductive wall Hall Thrusters are to be investigated as a potential aerospatial vessel.

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