Design and Testing of 1 kW Hall Thruster

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Design and Testing of 1 kW Hall Thruster

Background

- Advantageous for low thrust missions
- Currently used for station keeping, orbit adjustments, and deep space missions
- High specific impulse

\[ I_{sp} = \frac{F}{\dot{m}g_o} \]

Courtesy of ESA
Hall Thruster Operation

- Electrons trapped by induced magnetic field (Hall Effect)
- Electron/propellant collisions cause ionization
- Propellant ions accelerate out of thruster
- Ions are then neutralized

Courtesy of www.al.t.u-tokyo.ac.jp
Hall Current Measurement

- Hall current characterization method proposed by Rubin, Gelman, and Kapulkin in 2008
  - Embedded sensors monitor magnetic field induced by current loop
  - Hall current measurement used to predict thrust

Courtesy of Dr. Binyamin Rubin
**Problem Statement**

- Design and test a 1 kW Hall thruster to be used for validation of the noncontact measurement method proposed by Rubin, Gelman, and Kapulkin in 2008

- Two additional teams worked concurrently on remaining components required
  - Thrust Stand
  - Sensor Array
Easily modified
Accommodating to sensor placement
**Dimensioning**

- Sizing convention from Russian Hall thruster designers as presented at MIT in 1991
- Discharge chamber diameter of 100 mm was chosen to give approximately 1 kW power output.

Discharge Chamber

- Multiple plate design to accommodate sensor placement
- Compression plates required to hold plates in place
Anode

- Spacers incorporated to vary anode height
- Allowed for fine tuning of thruster output
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Thruster Cross-Section

- Pole Pieces
- Magnetic Screens
- Anode
- Wire Coils
- Acceleration Chamber
- Magnetic Core
Thermal Analysis

- Steady state thermal modeling of the thruster was performed in ePhysics
- Model was fit to match results published by previous Hall thruster researchers
Magnetic Analysis

- Design analysis was performed using Finite Element Method Magnetics (FEMM)
- Effects from coil current and shields height variations quickly calculated
Magnetic Analysis continued
Magnetic Analysis continued

- Maxwell 3D magnetic modeling verified FEMM results

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- Magnetic field mapped using two axis stage and Gauss meter
Equipment

- Steel vacuum chamber (5 ft. diameter, 15 ft. in length) to simulate space vacuum
- Pumps: Edwards GV250 dry mechanical pump, Edwards EH-1200 mechanical booster pump, and two Varian HS-20 diffusion pumps (35,000 l/s pumping speed for air)
- Baseline pressure in the high $10^{-6}$ Torr range ($10^{-5}$ range during thruster operation)
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Testing

[Images of thruster and emitted light]
Results

- The thruster demonstrated steady operation in the following modes operating on argon:

<table>
<thead>
<tr>
<th>Cathode Flow Rate (sccm)</th>
<th>Anode Flow Rate (sccm)</th>
<th>Discharge Voltage (V)</th>
<th>Discharge Current (A)</th>
<th>Discharge Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>55</td>
<td>154</td>
<td>2.02</td>
<td>311</td>
</tr>
<tr>
<td>5</td>
<td>60</td>
<td>146</td>
<td>2.79</td>
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</tr>
<tr>
<td>5</td>
<td>100</td>
<td>125</td>
<td>4.95</td>
<td>618</td>
</tr>
</tbody>
</table>
Thermocouple Placements
Thermal Measurements

Thrust Operating Temperature

- Base Plate
- Thrust Stand
- Outer Coil
- Outer Pole Piece
- Outer Shield

Temperature (°C) vs. Thruster Firing Time (min)
Magnetic core saturation
Problems Encountered

- Remaining magnet field (remanence) inhibited thruster restart

- Procedure implemented to reverse field

Hysteresis Loop

Courtesy of hyperphysics.phy-astr.gsu.edu
Problems Encountered

- Conductive layer built up on discharge chamber
- Caused anode to short
- Prevented thruster restart
Future Work

- Improve the strength of the magnetic field (thicker central core, better magnetic material)
- Fine tuning of anode height
- Complete accurate thermal map
- Integration of sensors
Questions
Conventional Ion Thrusters

- Ions accelerated through grids
- Space charge limited
- Ion current density restricted
- Thrust restricted

Courtesy of NASA
Hall Thruster Advantage

- Formation of quasi-neutral plasma
- Not space charge limited
- Higher thrust to weight ratio

Courtesy of Drexel University