LONG DURATION WEAR TEST
OF THE NASA HERMES HALL
THRUSTER

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Motivation

- NASA has been developing Hall Effect Rocket with Magnetic Shielding (HERMeS) to serve as high-power EP capability for future missions
  - *Power and Propulsion Element of NASA’s Gateway*

- HERMeS Long Duration Wear Test (LDWT)
  - Comprised of multiple segments with the aim of addressing potential risk areas for the Advanced Electric Propulsion System (AEPS) development effort
    1) TDU-1 Wear Test (Williams, et al., AIAA-2016-5025, 2016)
    2) TDU-3 SDWT (Williams, et al., IEPC Paper 2017-207, 2017)
    3) TDU-3 LDWT
      a) Demonstrate performance, plume, and wear of the TDU-3 Hall thruster over an extended operation time
Experimental Apparatus

**HERMeS TDU-3**

- Same thruster used for SDWT with minor modifications:
  - Thickness and position of cathode keeper
  - New magnet coils (field shape unaltered)
- Changes relative to TDU-1 detailed by Kamhawi et al. (IEPC 2017-392)
  - Resulted in minimal variation in operating characteristics
- Thruster electrically configured per recommendations from Peterson et al. (AIAA Paper 2016-5027)
  - Thruster body electrically tied to cathode
  - Dielectric coating on all surfaces within 1 m of exit plane
- Power and propellant supplied using calibrated commercial laboratory systems
  - Flow rate uncertainty: 1%
  - Voltage uncertainty: ±0.06 V
  - Current uncertainty: ±0.03 A
- Thrust measured with inverted pendulum thrust stand (± 0.8% uncertainty) (Mackey, AIAA-2018-4516)
Experimental Apparatus

GRC VF-517-22

• Facility dimensions:
  – Diameter: 4.6 m
  – Length: 18.3 m

• Pumping capacity:
  – Nominal pumping speed: ~700 kl/s on xenon
  – Nominal operating pressure: 4.5 µTorr at 12.5 kW throttle point

• Pressure measured with 2 internal BA-style hot-cathode ionization gauges
  – IG #2
    • Faces downstream
    • 0.8 m radially outward from thruster centerline
  – IG #3
    • Faces radially
    • 0.7 m radially outward, centered 0.08 m upstream of thruster exit plane
  – Gauges EP configured:
    • Calibrated on Xe
    • Elbow with additional plasma screen
    • Housing grounded to facility

• Facility configuration consistent with previous HERMeS wear tests
Experimental Apparatus: Wear Measurements

- Graphite IFPC, keeper, and OFPC modified to enable wear measurements
  - Components polished pre-test to maximize surface uniformity
  - Graphite masks installed to provide unexposed reference surfaces:
    - IFPC: two graphite strips covering approximately 95% of radius at 2 and 8 o’clock
    - Keeper: graphite ring with a tab protruding radially inward
    - OFPC: series of graphite strips covering approximately 95% of radius

- Erosion measurements made with a chromatic, white-light, non-contact profilometer
  - Data analyzed per ISO 5436-1 guidance for a type A1 step
  - Typical uncertainties ±2 µm accounting for:
    - Instrument error
    - Surface roughness
    - Non-flat surface geometry
Test Overview

- The LDWT has accumulated approximately 1720 h of total operating time divided into four test segments:

<table>
<thead>
<tr>
<th>Segment</th>
<th>Operating Condition</th>
<th>Operating Time (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>600 V/1 B</td>
<td>1015</td>
</tr>
<tr>
<td>II</td>
<td>300 V/1 B</td>
<td>248</td>
</tr>
<tr>
<td>III</td>
<td>300 V/0.75 B</td>
<td>213</td>
</tr>
<tr>
<td>IV</td>
<td>300 V/1.25 B</td>
<td>239</td>
</tr>
</tbody>
</table>

- Wear assessed at the end of each segment as well as at the mid-point of segment I
- Performance periodically characterized at 6 reference firing conditions (RFCs)

<table>
<thead>
<tr>
<th>RFC</th>
<th>Discharge Voltage (V)</th>
<th>Discharge Current (A)</th>
<th>Discharge Power (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>300</td>
<td>9.00</td>
<td>2700</td>
</tr>
<tr>
<td>2</td>
<td>300</td>
<td>20.83</td>
<td>6250</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>20.83</td>
<td>8333</td>
</tr>
<tr>
<td>4</td>
<td>500</td>
<td>20.83</td>
<td>10417</td>
</tr>
<tr>
<td>5</td>
<td>600</td>
<td>20.83</td>
<td>12500</td>
</tr>
<tr>
<td>6</td>
<td>630</td>
<td>20.83</td>
<td>13123</td>
</tr>
</tbody>
</table>
Results: Performance and Stability

Performance and stability vary by less than the uncertainty during LDWT and when compared against previous TDU wear tests.
Results: IFPC Wear

Key Observations:
1) The erosion rate varies with radius
   - 300 V strongly varying
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![Graph showing erosion rate vs. normalized radius with data points for different conditions and maximum near 0.97.](image)
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2) The erosion rate at 600 V decreases with time
   - Consistent with TDU-1 wear test

3) The erosion rate at 600 V/1 B is 76% less than 300 V/1 B
   - Driven by axial shift in acceleration zone
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4) At 300 V, the erosion rate increases with magnetic field strength
   - Cause not presently known
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5) IFPC wear is azimuthally symmetric
Results: Keeper Wear

- Keeper position and thickness changed relative to SDWT to try to mitigate elevated wear rates

SDWT: Keeper Coplanar with IFPC

LDWT: Keeper Upstream of IFPC
Results: Keeper Wear

- Keeper position and thickness changed relative to SDWT to try to mitigate elevated wear rates
- Radially-averaged keeper erosion rates for operation at 600 V, 12.5 kW, nominal magnetic field:
  - SDWT: 80 µm/kh (Coplanar Keeper)
    - Rates increase near IFPC and decrease near orifice
  - LDWT: 13 µm/kh (Upstream Keeper)
    - No significant radial variation in erosion rates observed
- Trends qualitatively supported by 3D keeper surface maps

**Results: Keeper Wear**

![Graph of erosion rates](image)

- **SDWT: Keeper Coplanar with IFPC**
- **LDWT: Keeper Upstream of IFPC**

Masked Region

Eroded Region (~200 h)

Eroded Region (1015 h)

Masked Region

Orifice

IFPC
Key Observations:
1) The erosion rate varies with radius
   - Maxima near channel
2) The erosion rate at 600 V/1 B is 25% of 300 V/0.75 B
3) At 300 V, the erosion rate at 1.25 B is 1.4x higher than at 0.75 B
Results: OFPC Wear

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   - Pre-test surface finish different
   - Suggests possible link between surface finish and erosion rates
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   - Pre-test surface finish different
   - Suggests possible link between surface finish and erosion rates
   - Link would also explain apparent time dependence of IFPC erosion rate

Beginning of Test: Surface Polished
Higher Erosion Rates

End of Test: Surface Roughened
Lower Erosion Rates
Conclusion

- The NASA HERMeS TDU-3 Hall thruster was successfully operated over 1,720 hours in four different operating conditions in a long duration wear test.
- The TDU-3 demonstrated consistent performance and stability over the course of the LDWT and relative to previous wear tests.
- The TDU-3 measured wear rates, at several operating conditions, provided detailed insight into the expected life of the thruster and most importantly provided invaluable data for the HERMeS thruster modeling effort.
  - Upstream shift in keeper position mitigated elevated erosion rates observed during SDWT.
  - IFPC and OFPC wear were observed to:
    - Increase between operation at 600 V and 300 V.
    - Increase with magnetic field strength at the 300 V operating condition.
  - A potential link between surface finish and erosion rates was observed, which could explain:
    - Time variation of IFPC erosion at the 600 V operating condition.
    - Apparent asymmetry in OFPC wear at the 300 V, 1.25 B operating condition.