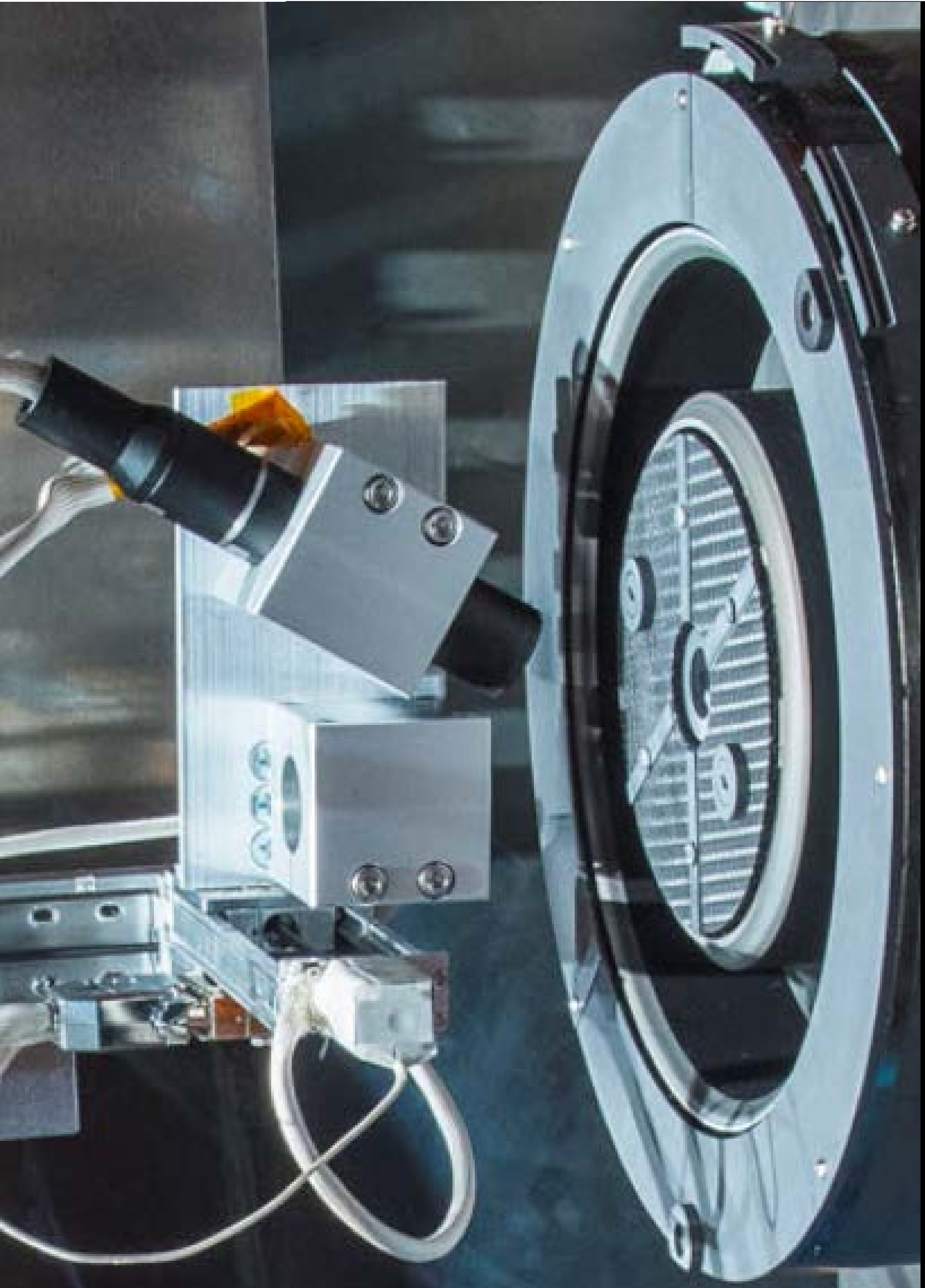

IN-SITU DIAGNOSTIC FOR ASSESSING HALL THRUSTER WEAR

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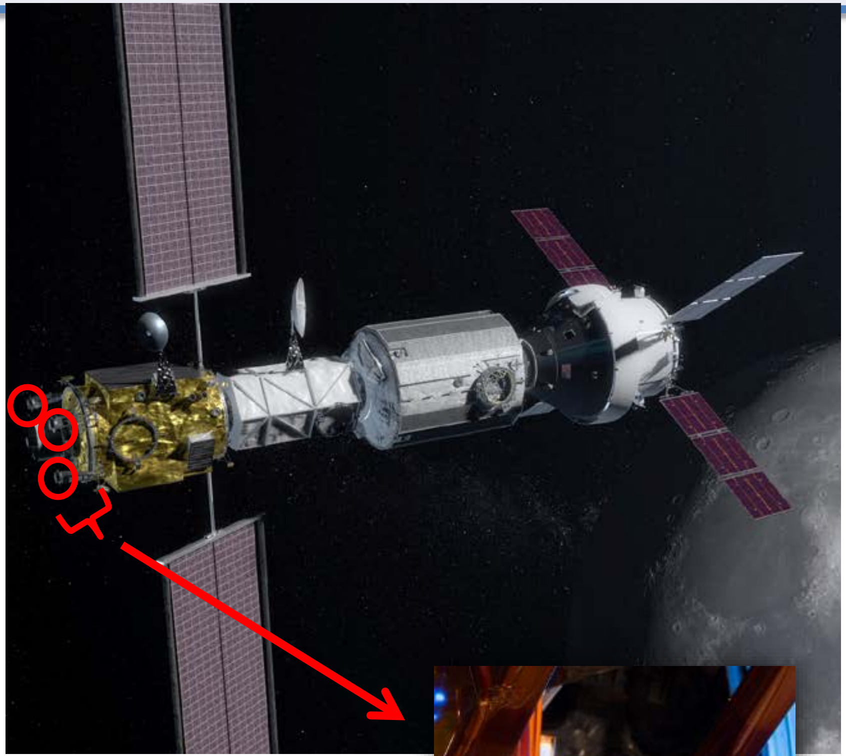
Outline

- Introduction and motivation
- Measurement approach
- Design
- Initial data
- Summary and ongoing work

Introduction

- Hall Effect Rocket with Magnetic Shielding (HERMeS): 12.5-kW Hall thruster
  - Has magnetic shielding to prevent erosion of Hall thruster magnetic channel
- Under development since 2012: Glenn Research Center and JPL, and later Aeroject Rocketdyne under Advanced Electric Propulsion System (AEPS) contract
- To be used for the Power and Propulsion Element of the Gateway
- Different versions of the thruster:
  - Three Technology Demonstration Units (TDU)
  - Engineering Design Unit (EDU) – scheduled to undergo extended wear testing



Above: Gateway with HERMeS Hall thrusters circled[1]

Right: HERMeS TDU-1 Hall thruster[2]

[1]Herman, D., et al., IEPC-2017-284
[2]Williams, G. J., et al., IEPC-2017-207

Motivation

- Erosion of thruster surfaces – lifetime limiter
- Main objective: Characterize the time-resolved erosion of thruster surfaces during long duration testing
- Particular focus on the wear of potential life limiting surfaces:
  - Hollow cathode assembly (HCA): keeper surface and cathode orifice plate
  - Inner front pole cover (IFPC)
  - Boron nitride (BN) discharge channel edges
  - Outer front pole cover (OFPC)
- Also, want to measure changes in the distances between thruster components and identify any changes to these gaps over time
  - Assess the design's ability to handle thermal cycling

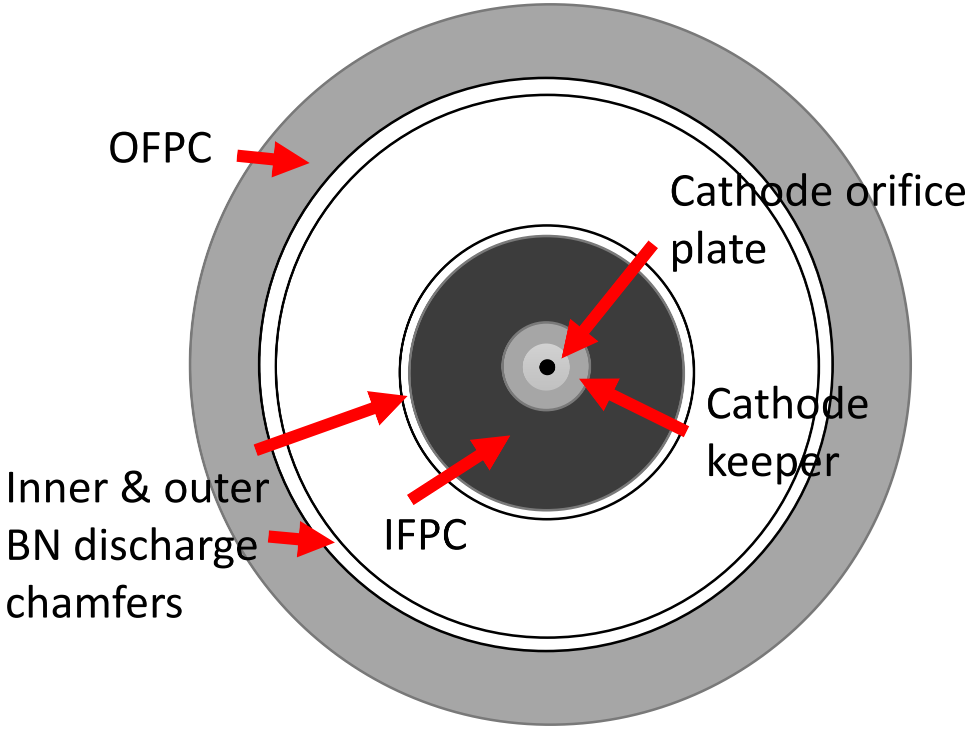
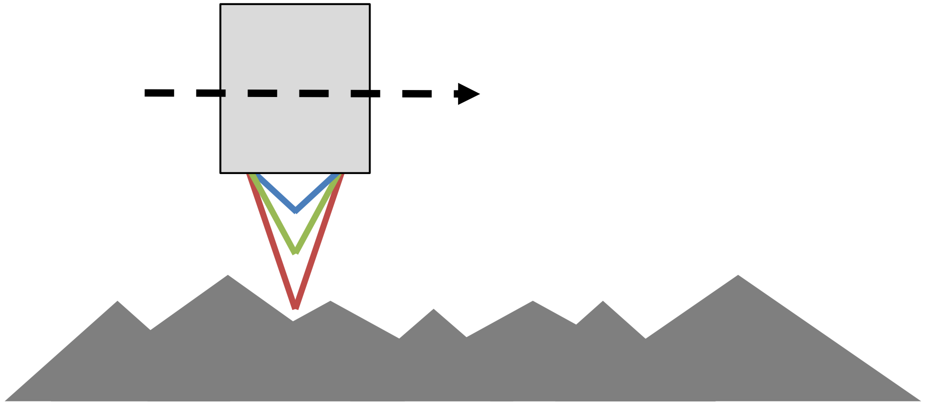


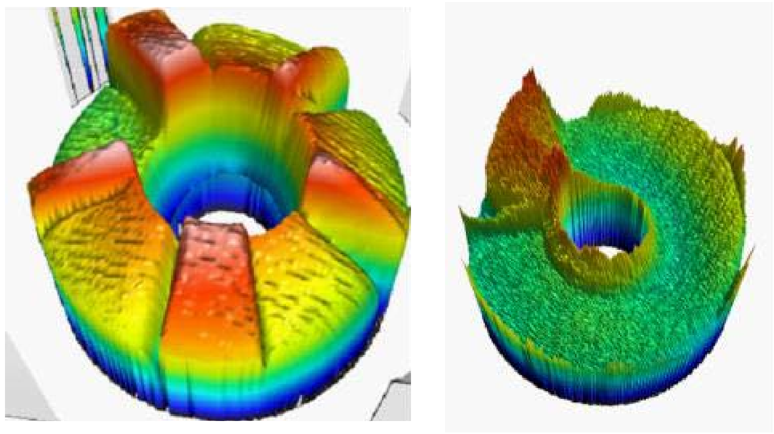
Diagram showing thruster surfaces of interest

Measurement Approach

- Since 2015, erosion has been measured with a benchtop white-light, non-contact profilometer at NASA GRC
  - Idea: White light is refracted into colors at different focal lengths
  - When passed over a surface, only certain wavelength is in focus and measured → corresponds to feature height
  - See:
    - Williams, G., et al., AIAA 2016-5025.
    - Williams, et al., IEPC 2017-207.
    - Frieman, J. D., et al., AIAA-2018-4645.
- Problem: Need to take thruster out of vacuum facility for scanning
  - Reduces overall duty cycle and introduces uncertainty
- Upcoming 23,000 hour test – can't take thruster out to scan surfaces
- Therefore, in-situ wear erosion diagnostic was designed



White-light axial chromatism diagram showing profilometer scanning a surface



Previous erosion measurements of TDU-3 and TDU-1 keepers, respectively[1]

[1]Williams, G. J., et al., IEPC-2017-207

Context: General Idea

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Measurement Approach

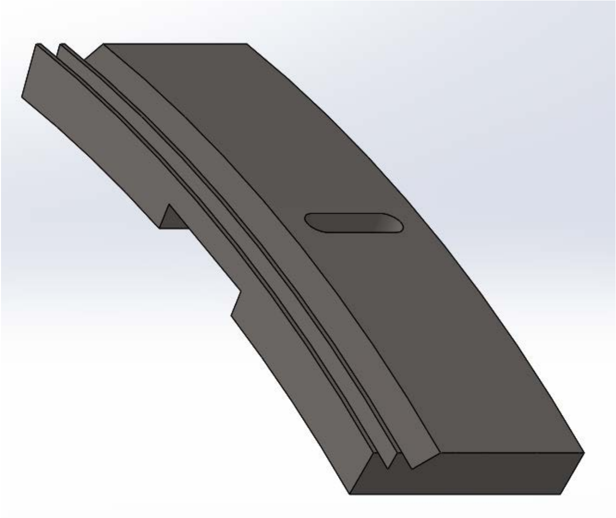
- Goal of in-situ diagnostic: Provide real-time assessment of trends and erosion rates (not replicate tabletop accuracy)
- Accurate measurement requires:
  - Accurate location of sensor (fine position stages)
  - Accurate motion of sensor
  - Capability to focus optics
- Challenges of an in-situ design:
  - Thruster is on moving thrust stand, not fixed in space
  - Multiple surfaces are eroding/depositing relative to each other, and thus no fixed reference surface
    - Requires addition of protected reference surface for use on each scan
  - Long term instrument exposure to:
    - Thruster plume
    - Facility back sputter

Measurement Approach: References

- Reference measurement is needed to determine how much a feature changes on an absolute scale
- To measure erosion, need a feature to reference against
  - For absolute erosion rates, need an unchanging feature
  - To measure overall erosion trends, can use previous measurements of the desired feature
- Three types of reference measurements used in this study:
  - Separate known feature with an unchanging surface (e.g., a face that does not experience erosion or deposition)
  - Previous measurement of the desired feature (e.g., previous measurements of a diameter)
  - A surface apart from the thruster that does not experience erosion/deposition

Left: Graphite reference surfaces (at ~12:00 and 2:00 positions on thruster)

Right: CAD model of a graphite reference surface



Measurement Approach: Pen Orientation

- Two different pens used in the in-situ diagnostic design:
  - One normal to thruster surface
    - 3 mm depth of field
  - One canted at 30° relative to this perpendicular pen
    - 24 mm depth of field
- 30° pen allows for:
  - Measurements of feature heights
  - Scanning features hidden from view of the perpendicular pen
    - Recessed cathode keeper and orifice plate

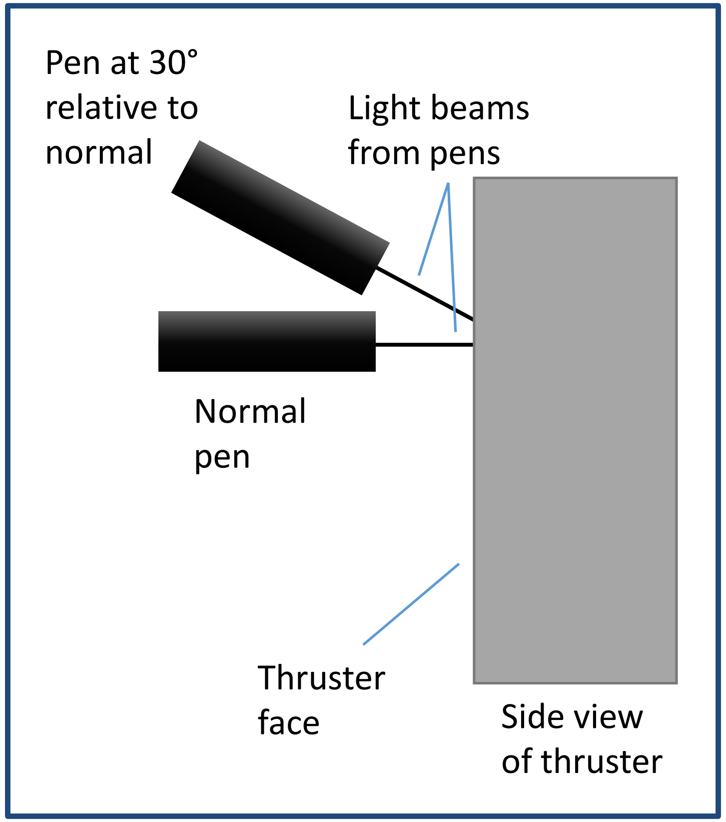


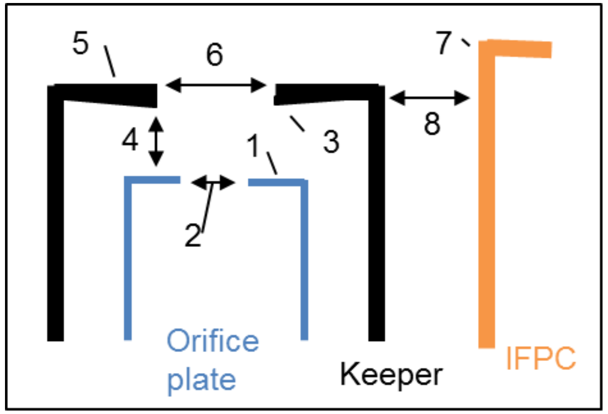
Diagram of pen orientation

Actual pen orientation in front of thruster (only one pen shown)

Measurement Approach: Features

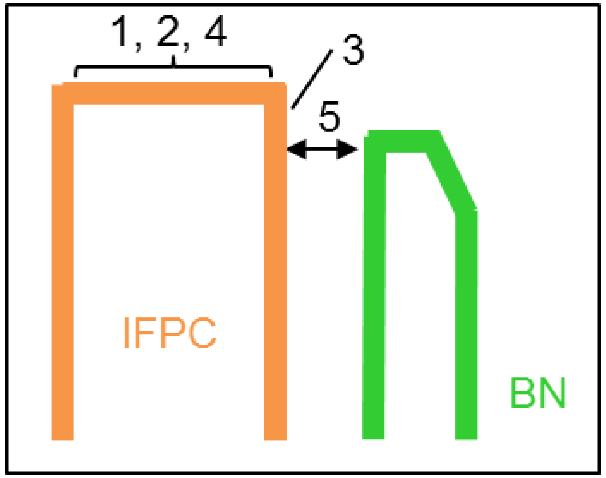
- Simplified diagrams of the features to be scanned are shown here:

Cathode assembly



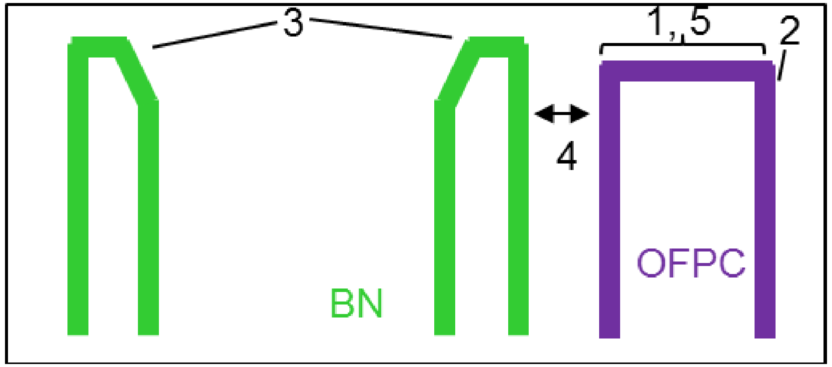
#	Measurement
1	Orifice plate surface erosion
2	Orifice plate orifice diameter change
3	Deposition thickness on keeper
4	Gap between keeper and orifice plate
5	Keeper surface erosion
6	Keeper orifice diameter erosion
7	IFPC inner bore erosion
8	Keeper to IFPC gap

IFPC



#	Measurement
1	IFPC erosion: surface
2	IFPC erosion: bushing
3	IFPC erosion: side wall
4	Graphite vs. C-C erosion (utilizing graphite strips in C-C IFPC)
5	IFPC to channel gap

OFPC and BN channel



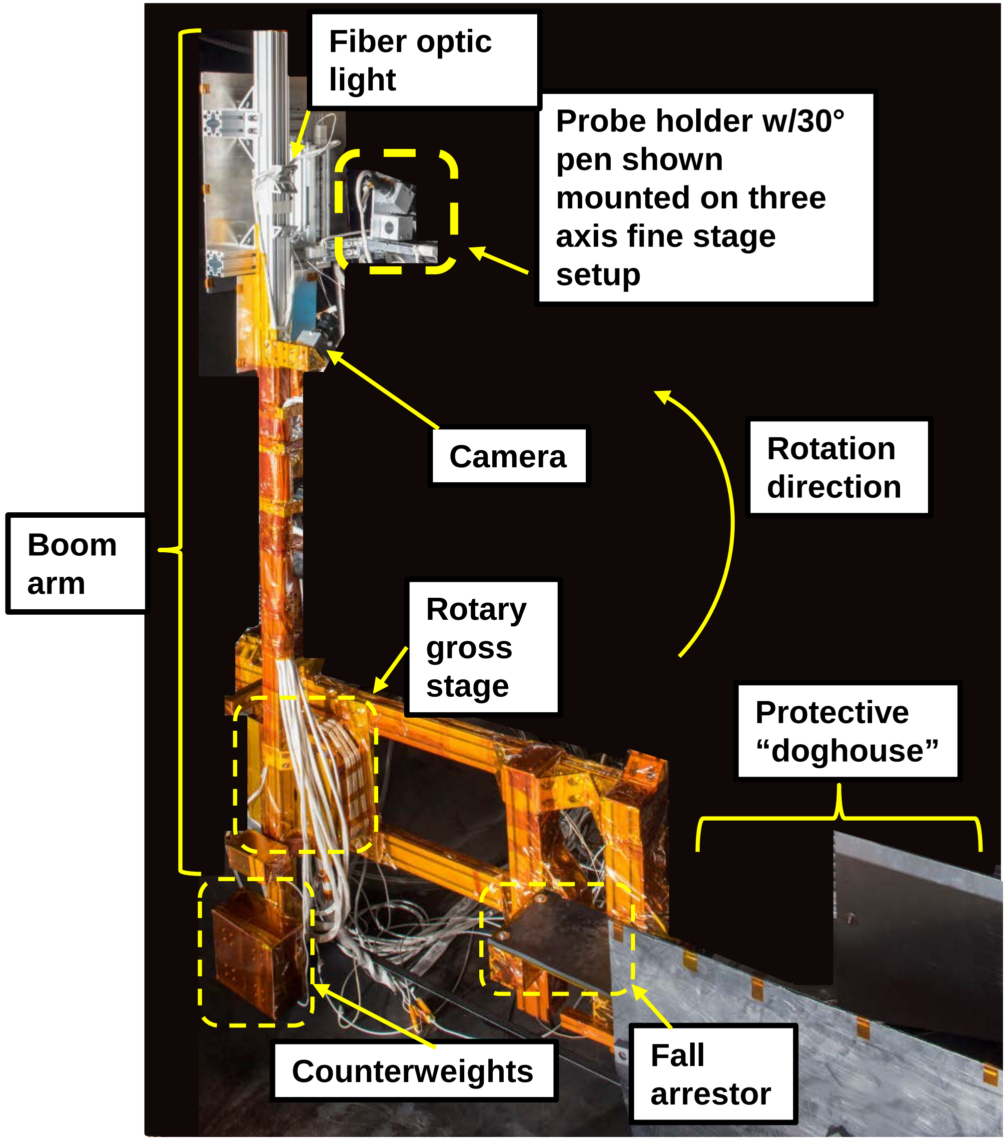
#	Measurement
1	OFPC erosion: surface
2	OFPC thickness: outer walls
3	BN deposition or erosion
4	OFPC to channel gap
5	OFPC bushing

Design: Requirements

- Main requirement: Diagnostic shall not interfere with thruster operation or existing test apparatus
  - Can't contact/negatively affect the thruster or test stand
- During power/communications failure, diagnostic can't stay in front of thruster
  - Would prevent thruster from turning on and would require opening vacuum facility
- Collects data when thruster off, and when not in use, remain protected from thruster plume
  - Avoids damage to profilometer system
- Data collection also has to occur within 1-2 days
  - Otherwise would negatively affect duty cycle

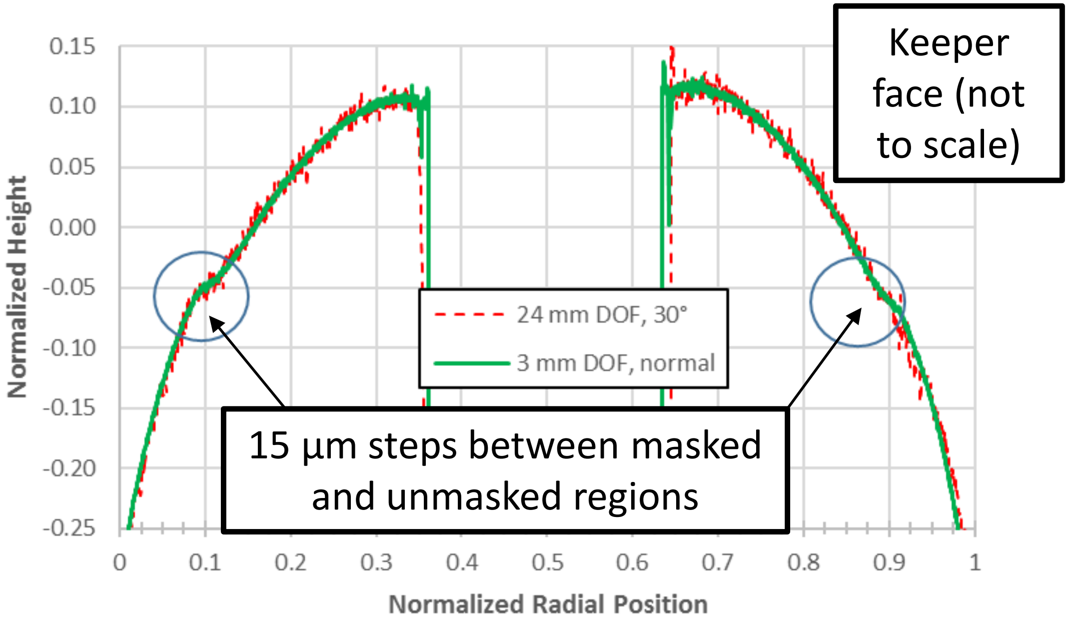
Overall Design

- Boom arm that rotates to scan thruster face
  - Motion with direct-drive rotary motion stage
- Profilometer pens mounted on three-axis precision motion system
- One end of boom arm is profilometer assembly, other end is counterweight to minimize moment of inertia
- In the event of a power loss, boom arm and stage freely fall back to rest position inside “doghouse”
  - Fall arrestor (Viton pad) provides damping for boom arm
- Protective “doghouse” reduces beam and backsputter impacts
  - Protects against erosion and deposition of backsputtered material
- Fiber optic light and camera provide video monitoring



Initial Data: Tabletop Measurements

- Tabletop measurements were performed to compare 3 mm and 24 mm depth of field (DOF) pens (24 mm DOF pen is at 30°)
- Also desired to verify keeper and cathode surfaces could be measured with angled pen
  - 24 mm pen data – lower resolution, but overall similarity to 3 mm pen data
  - Ability to measure protected surface proven



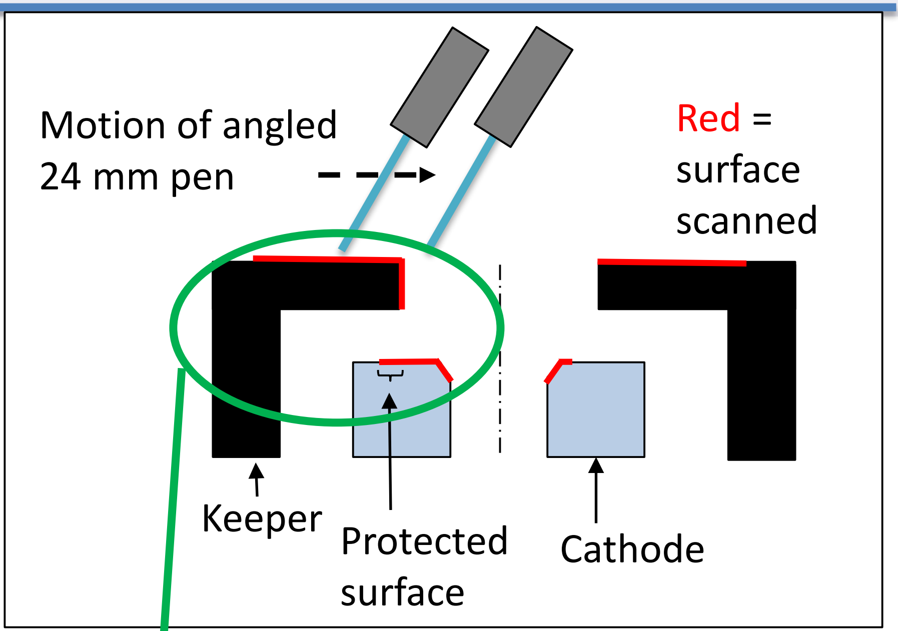
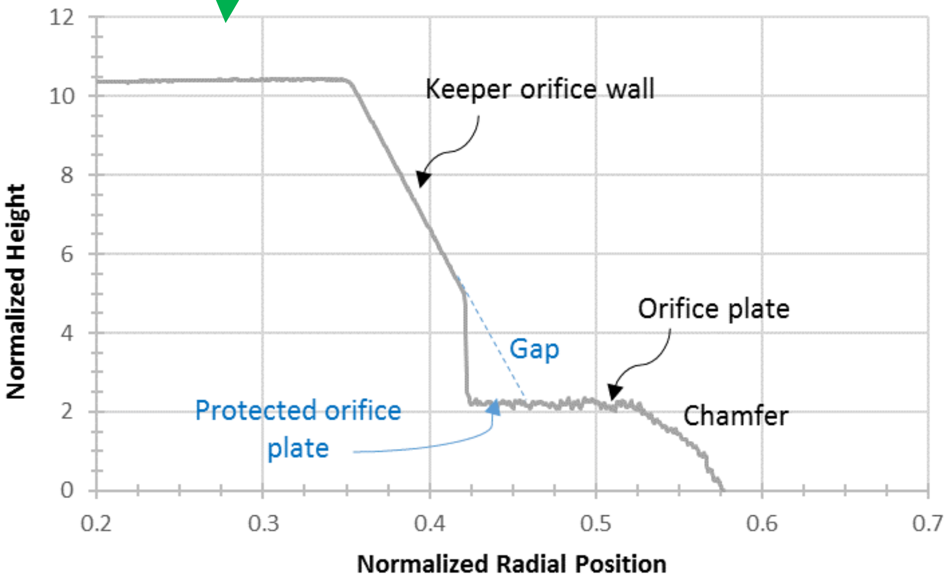


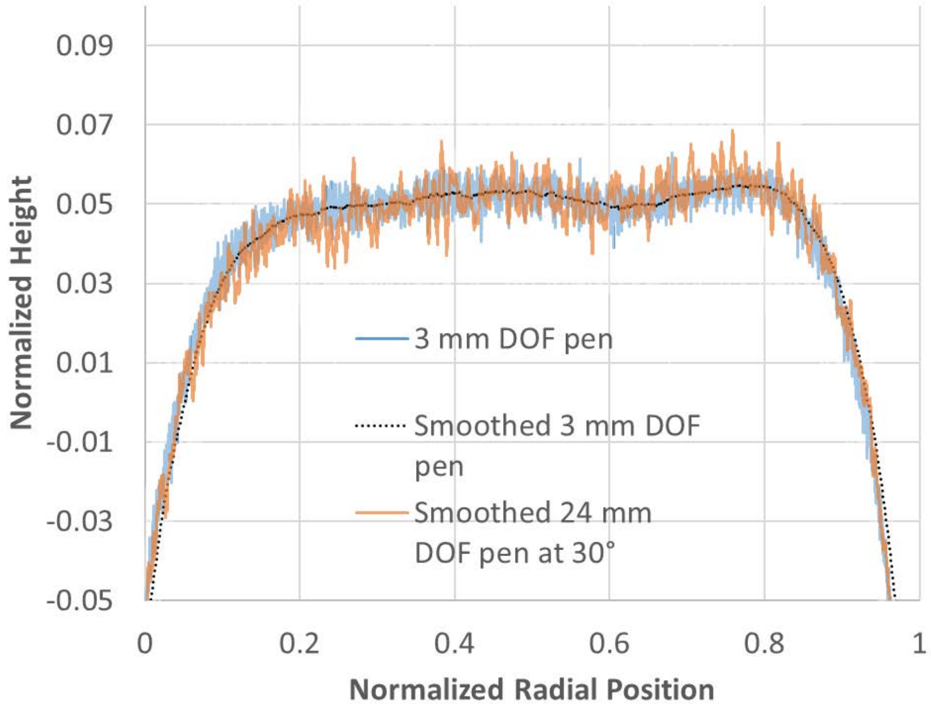
Diagram of 24 mm pen at 30° scanning the keeper and cathode (cross-section)



Corresponding scan, with protected reference surface shown

Initial Data: Tabletop Measurements

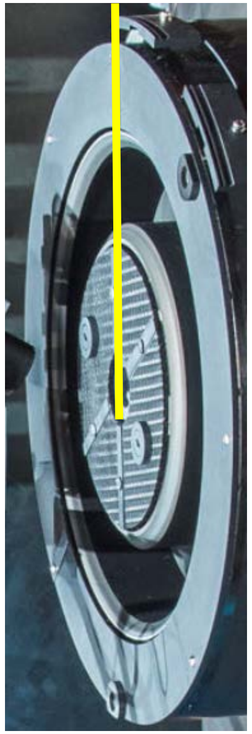
- Further tabletop measurements were done to compare resolutions of two pens on IFPC
  - Both pens show same curvature on IFPC surface
- Based on previous data, at 600 V, the first detectable erosion on IFPC will be along edges at 425 hours into long duration test
  - Erosion across entire IFPC estimated to be detected no later than 1500 hours into test



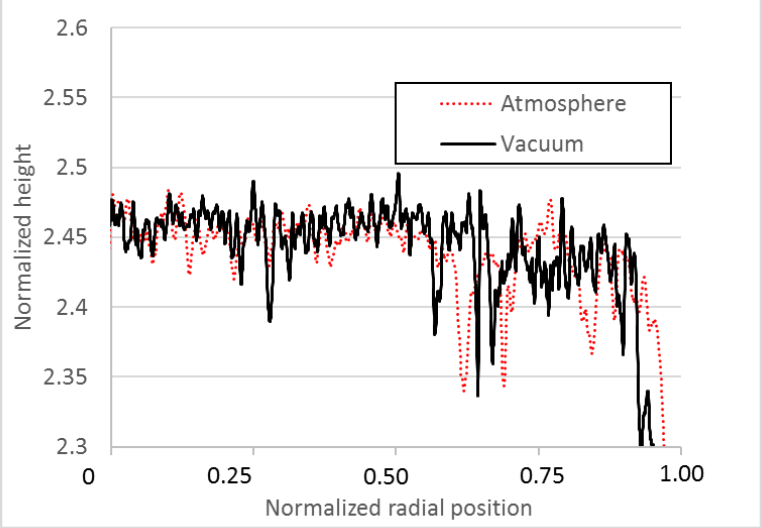
IFPC scan

Initial Data: In-Chamber Measurements

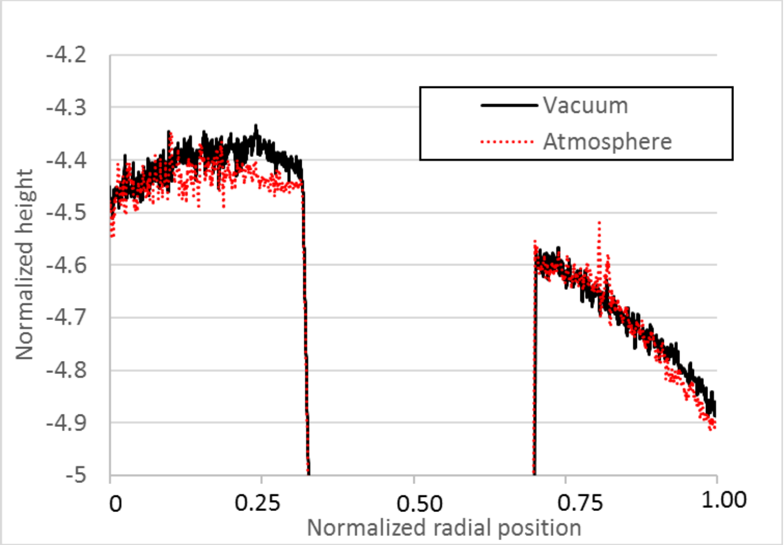
- In-situ diagnostic measurements taken at atmosphere and vacuum:
  - Noise similar for atmosphere and vacuum → vibrations did not affect data
  - Radial scan was taken across thruster → can measure known gaps
  - Reasonable agreement of overall features
  - Area scans omitted due to some issues with fine stages
  - Further refinement needed to determine accuracy of stages
- Data at vacuum also to be used as baseline comparisons for future measurements



Approx. location of radial scan



Edge of IFPC



Keeper orifice

Summary and Ongoing Work

- Diagnostic has been developed to measure thruster erosion without removing the thruster or venting the vacuum chamber
- It incorporates profilometer work previously done at GRC
- Design requirements have been met, and baseline scans completed
- Ongoing work:
  - Scans have recently been taken at 500 hours of thruster runtime and are being analyzed
  - Improvements to fine stages are being examined

Acknowledgments

- Space Technology Mission Directorate through the Solar Electric Propulsion Technology Demonstration Mission Project for funding the development of this diagnostic as well as for providing funding for the development of the HERMeS Hall thrusters
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Thank you!

Questions?