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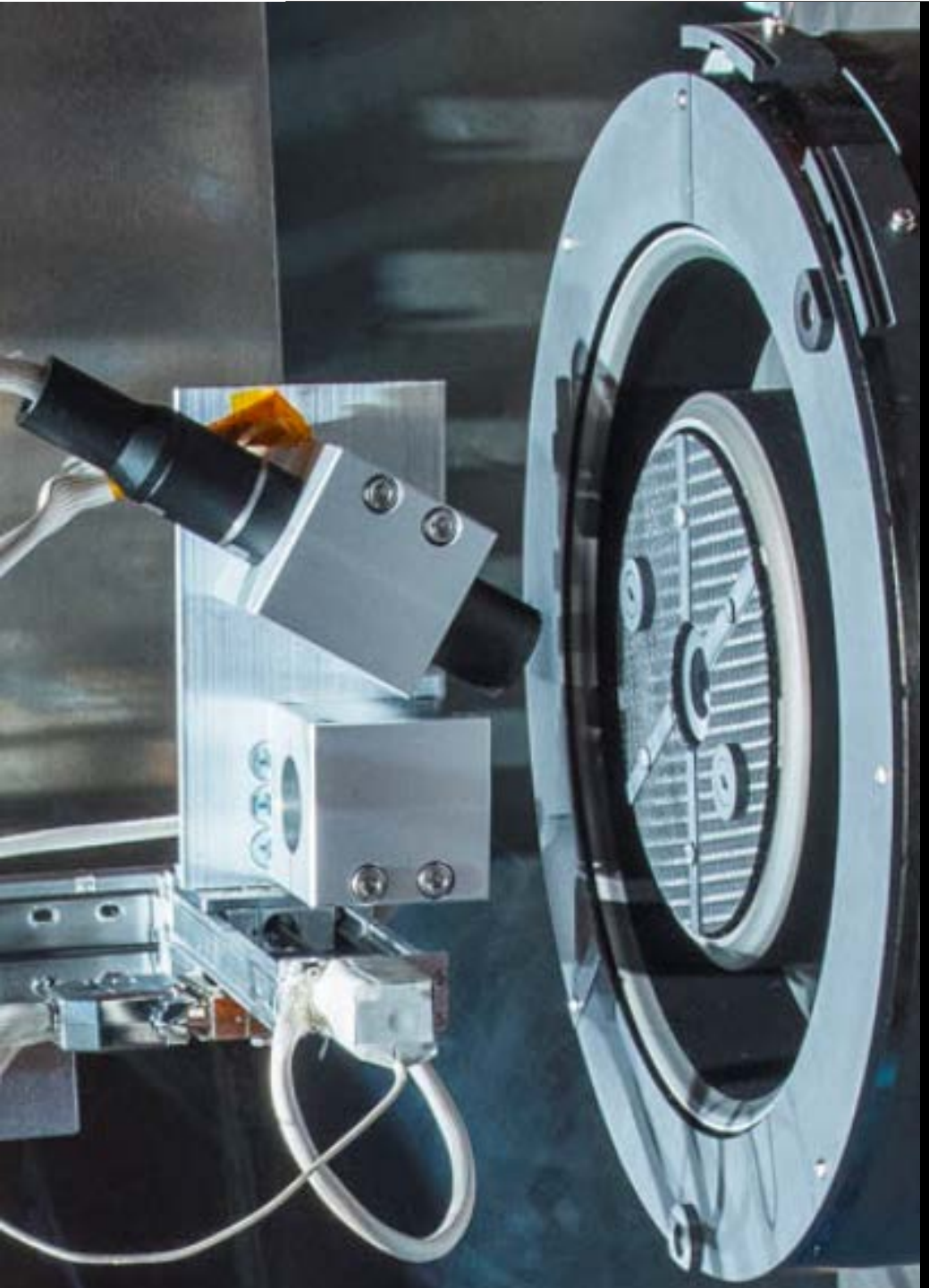

IN-SITU DIAGNOSTIC FOR ASSESSING HALL THRUSTER WEAR

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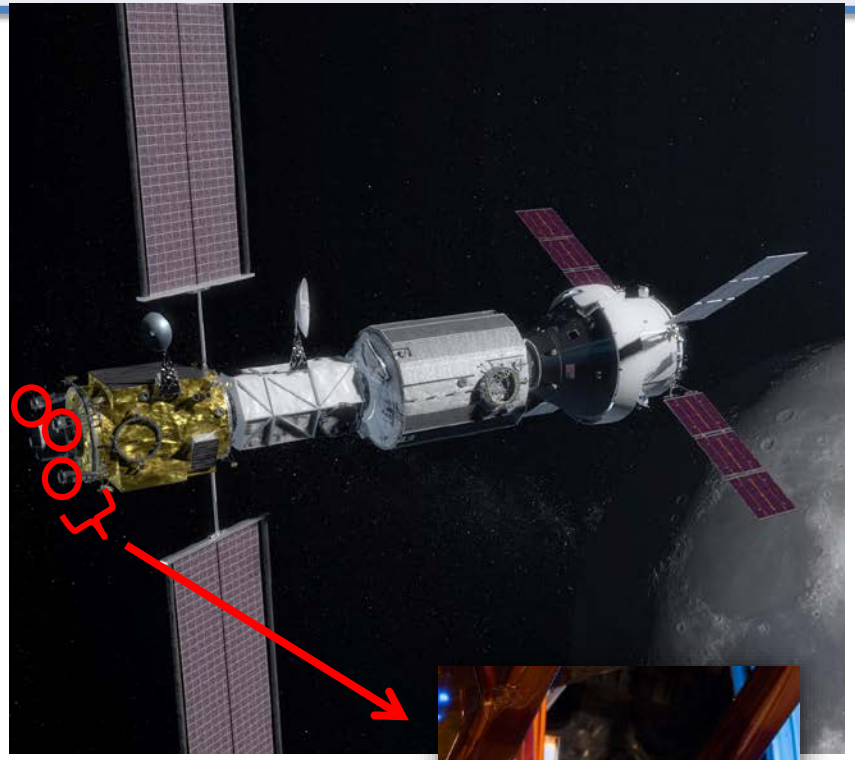
Outline

- 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

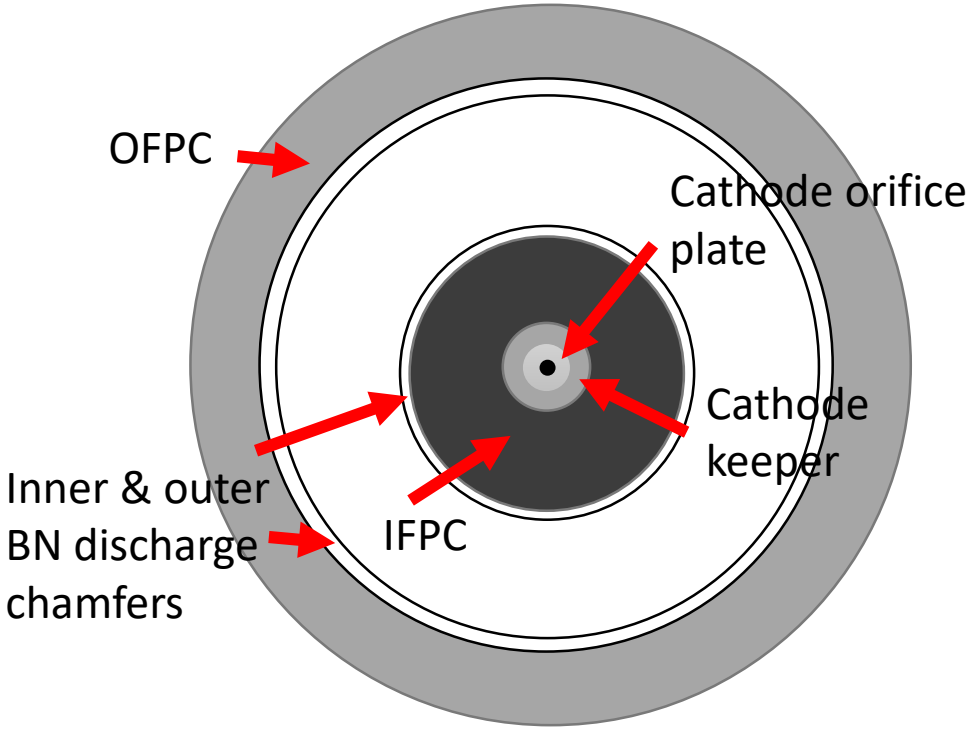
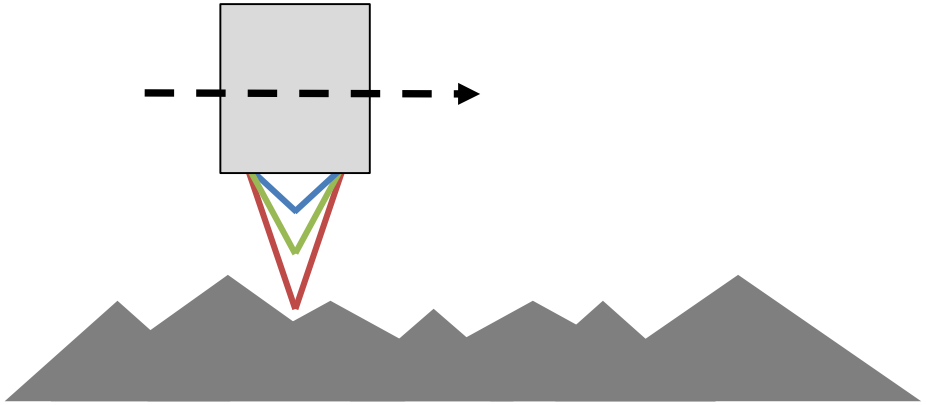


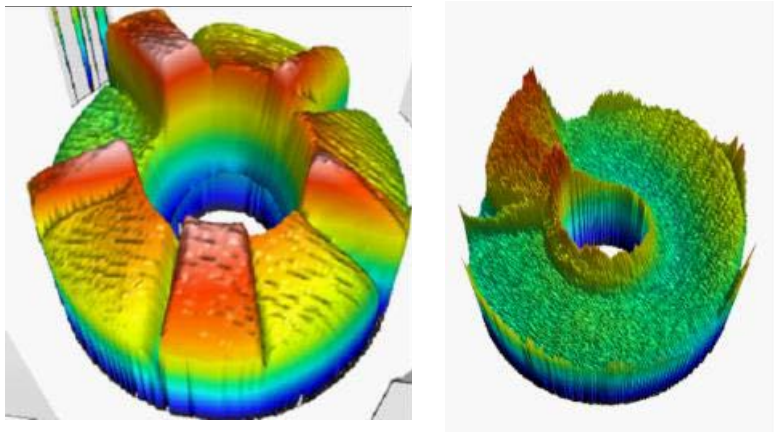
Diagram showing thruster surfaces of interest

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

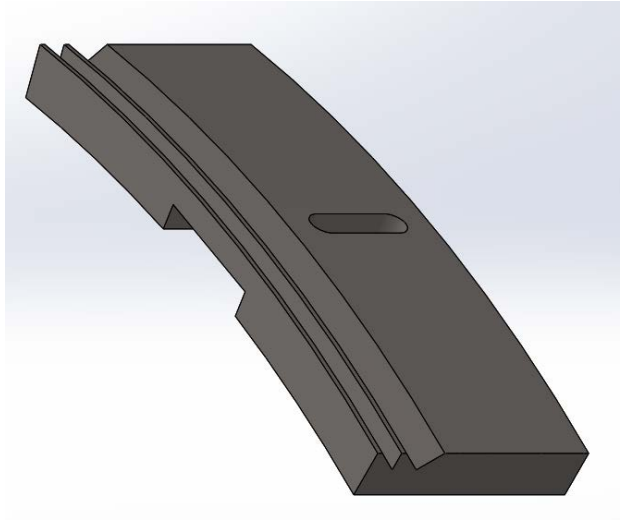
- Goal of in-situ diagnostic: Provide real-time assessment of trends and erosion rates (not replicate tabletop accuracy)
- Accurate measurement requires:
  - Accurate location of sensor (fine position stages)
  - Accurate motion of sensor
  - Capability to focus optics
- Challenges of an in-situ design:
  - 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

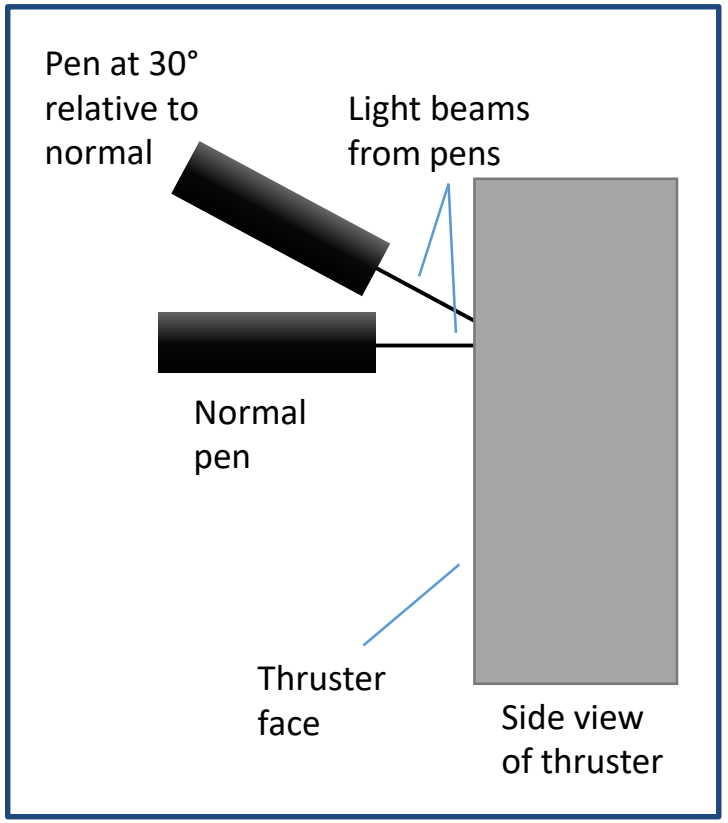


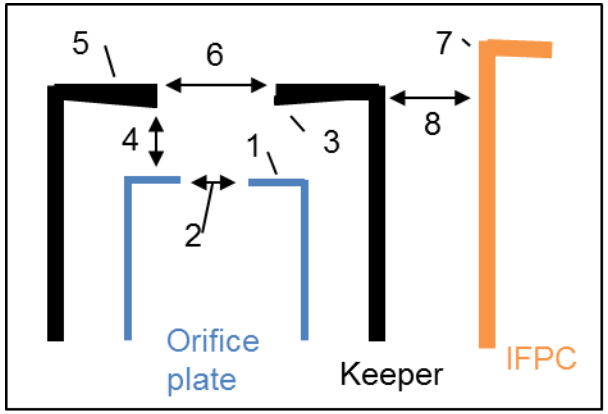
Diagram of pen orientation

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

Measurement Approach: Features

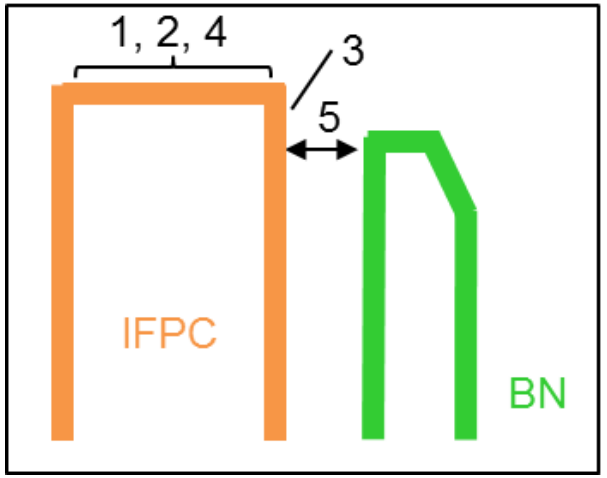
- Simplified diagrams of the features to be scanned are shown here:

Cathode assembly



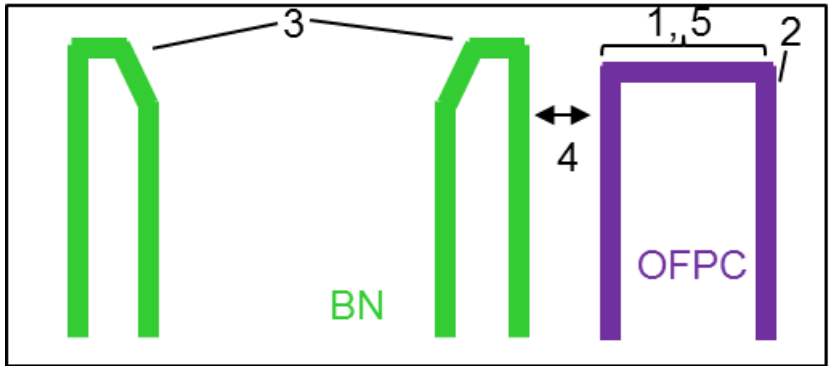
#	Measurement
1	Orifice plate surface erosion
2	Orifice plate orifice diameter change
3	Deposition thickness on keeper
4	Gap between keeper and orifice plate
5	Keeper surface erosion
6	Keeper orifice diameter erosion
7	IFPC inner bore erosion
8	Keeper to IFPC gap

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



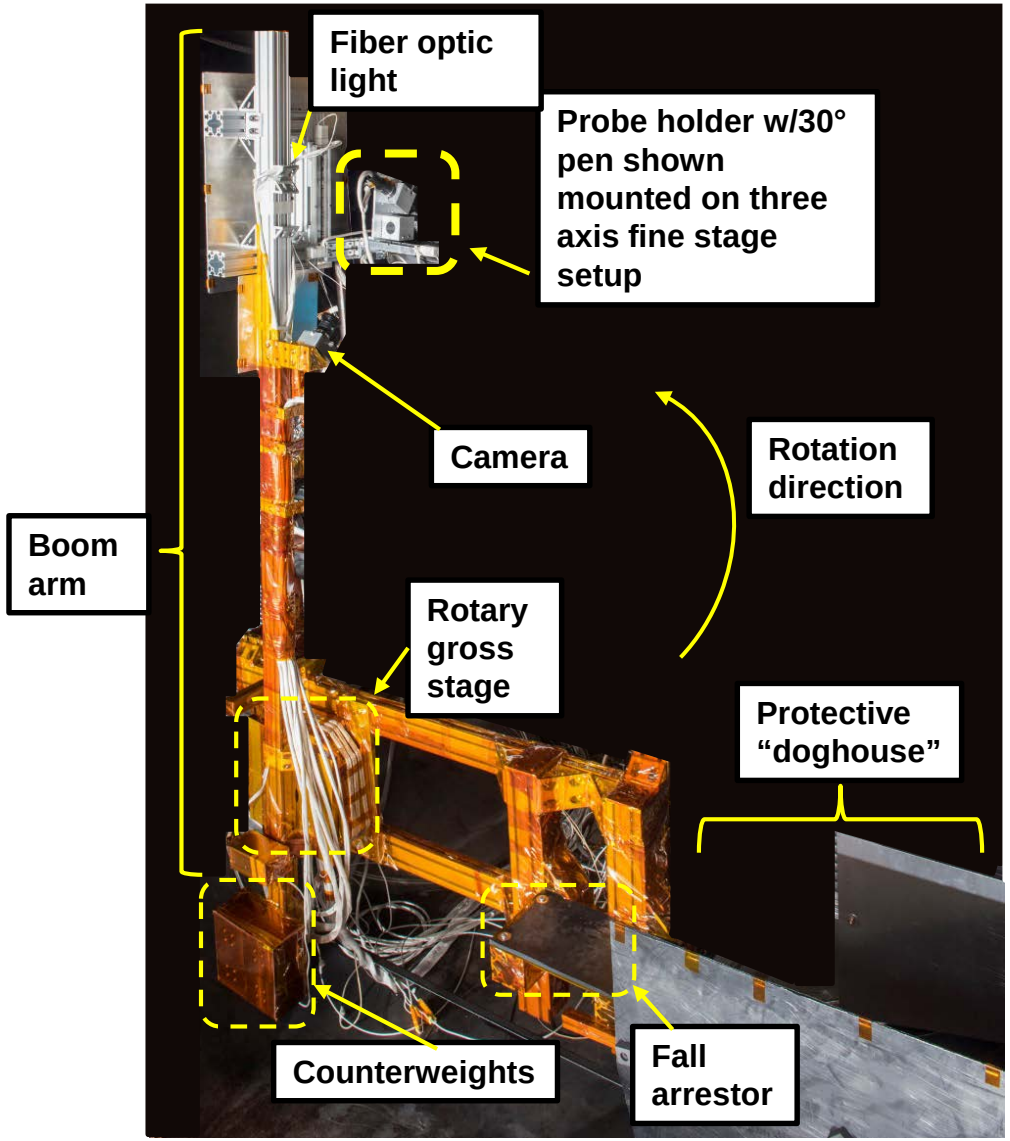
#	Measurement
1	OFPC erosion: surface
2	OFPC thickness: outer walls
3	BN deposition or erosion
4	OFPC to channel gap
5	OFPC bushing

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

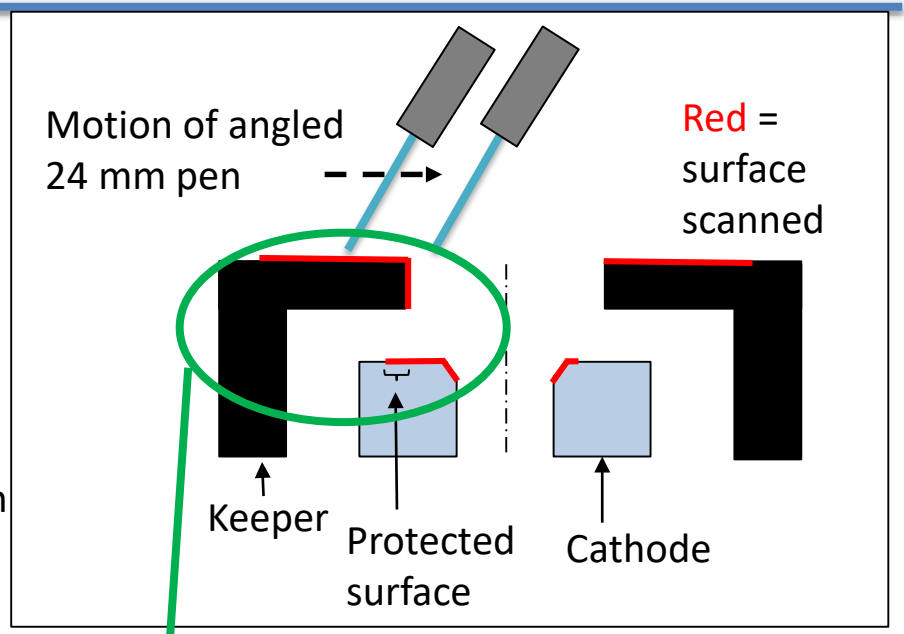
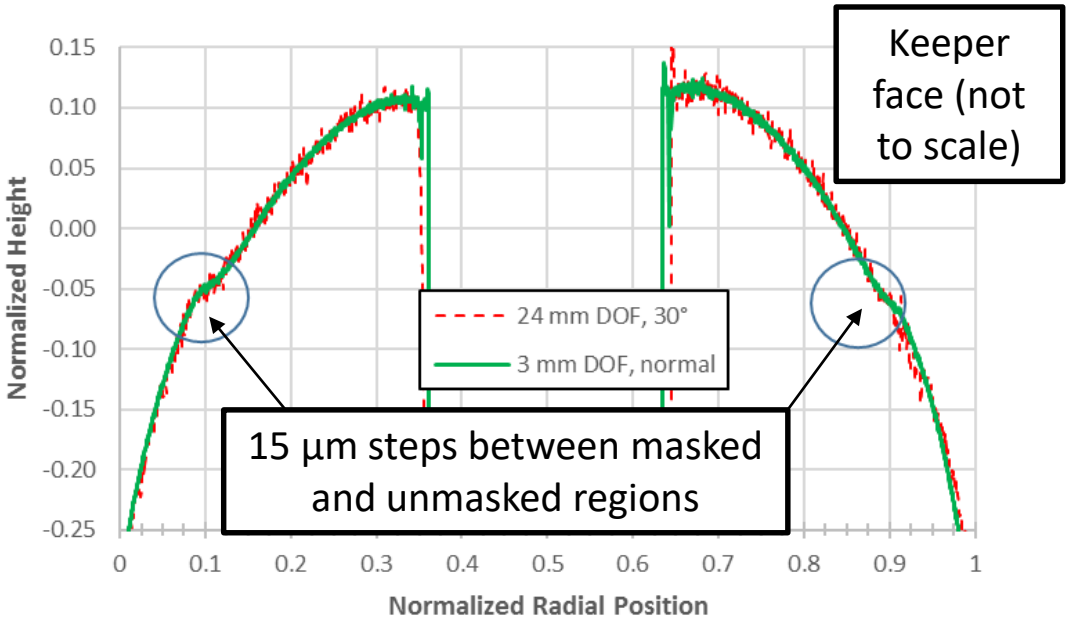
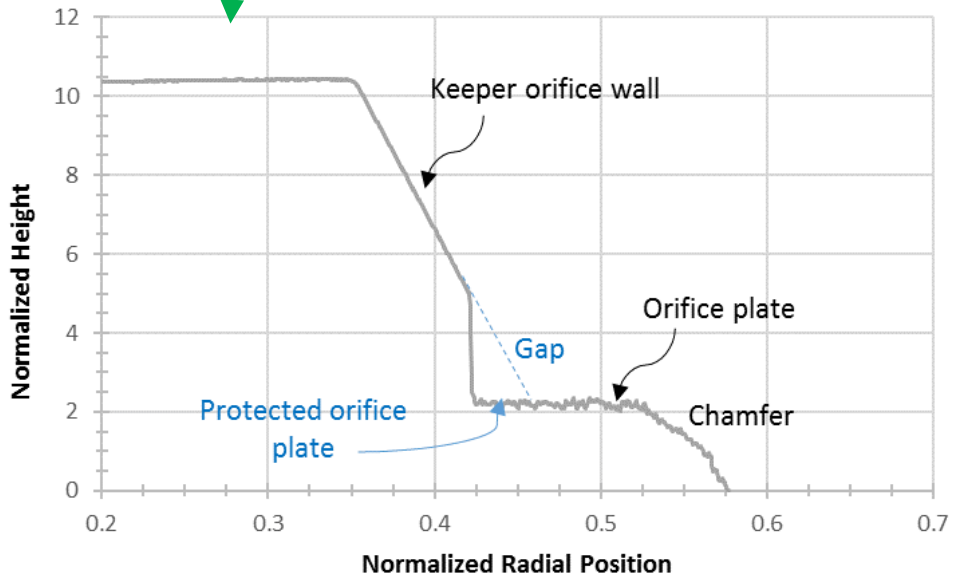


Diagram of 24 mm pen at 30° scanning the keeper and cathode (cross-section)

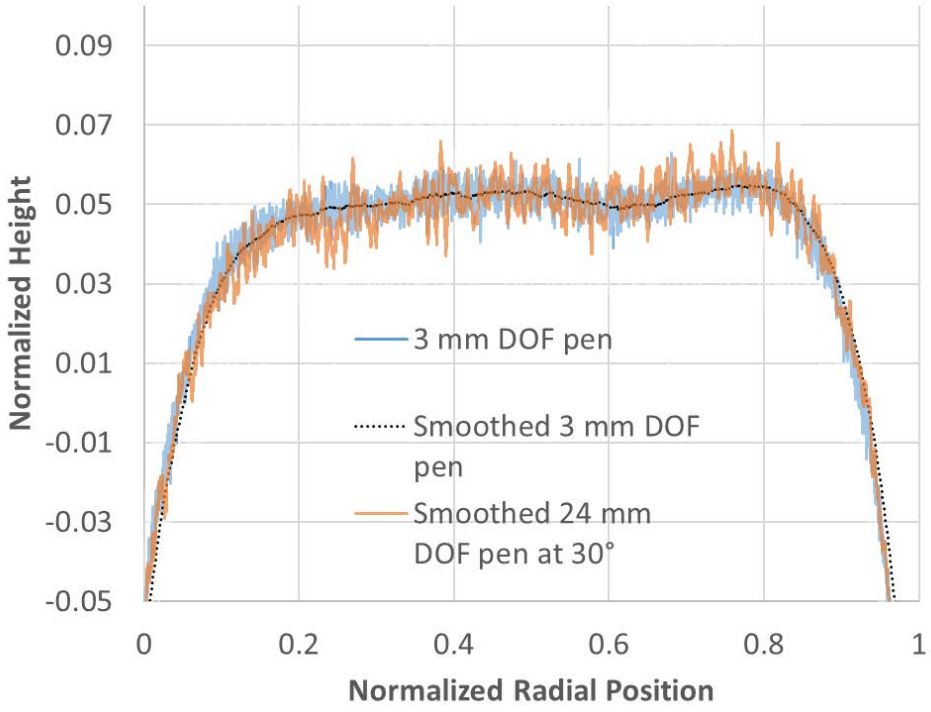


Corresponding scan, with protected reference surface shown



Initial Data: Tabletop Measurements

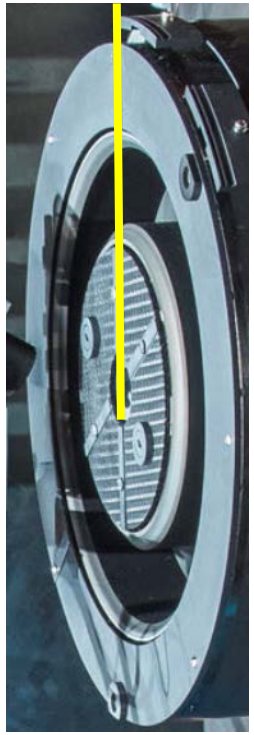
- Further tabletop measurements were done to compare resolutions of two pens on IFPC
  - Both pens show same curvature on IFPC surface
- Based on previous data, at 600 V, the first detectable erosion on IFPC will be along edges at 425 hours into long duration test
  - Erosion across entire IFPC estimated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



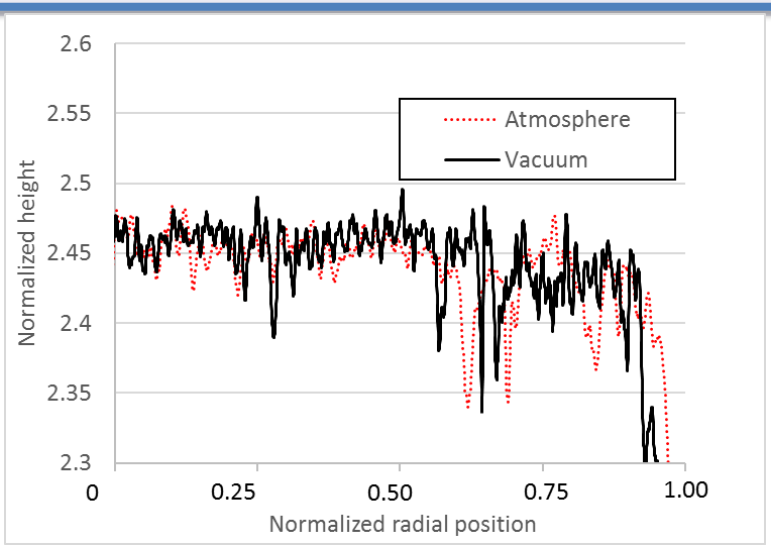
IFPC scan

Initial Data: In-Chamber Measurements

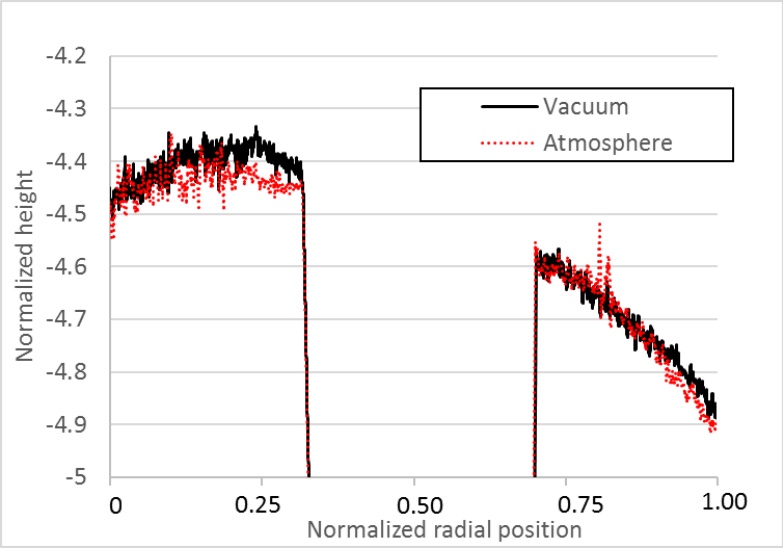
- In-situ diagnostic measurements taken at atmosphere and vacuum:
  - Noise similar for atmosphere and vacuum → vibrations did not affect data
  - Radial scan was taken across thruster → can measure known gaps
  - Reasonable agreement of overall features
  - Area scans omitted due to some issues with 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

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Thank you!

Questions?