
# Virtual Research Presentation Conference

## A New Approach for Large Diameter Ion Accelerator Systems for Gridded Ion Thrusters

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**Program: Spontaneous Concept**

Assigned Presentation RPC-248

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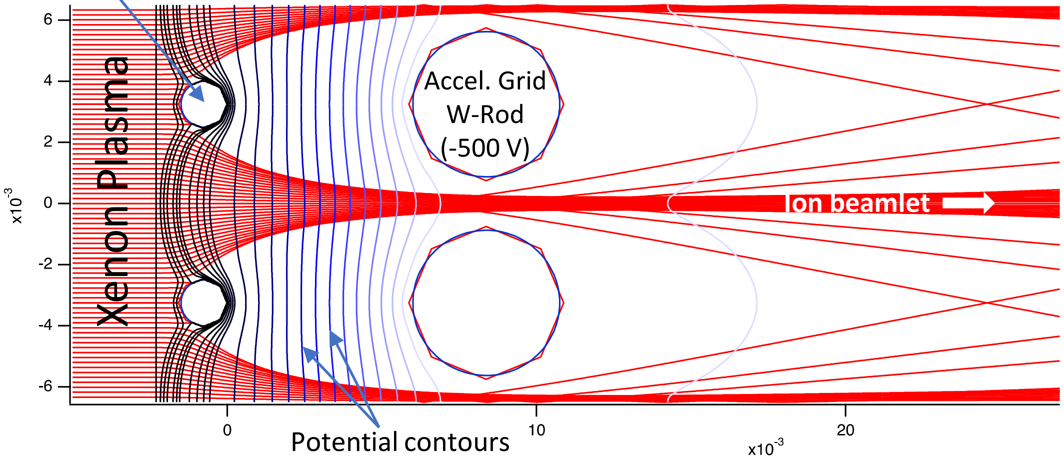
# Tutorial Introduction

## Cross-Section of Slotted-Tungsten-Rod (STR) Ion Accelerator System




**Abstract**

It was observed in the course of testing the ion thruster developed to operate with lithium-propellant that the slotted grids used on that 25-cm diameter thruster—which were made up of parallel tungsten rods—appeared to maintain the desired grid gap under extreme thermal loads. This grid design was implemented on the lithium ion thruster as a cost-savings approach and was not optimized for performance, but was simply intended to be good enough to do proof-of-concept testing of that thruster. The design uses parallel tungsten rods embedded in a stainless steel support ring in such a way that the rods are free to expand thermally at one end. This enables the rods to maintain their shape under varying thermal loads**. Innovation:** The successful implementation of the unoptimized slotted-tungsten-rod (STR) accelerator system on the lithium-ion thruster suggests that it could provide a low-cost path to the development of large-diameter (> 60 cm), high-performance, flat ion optics with applications to solar system exploration missions and planetary defense by ion beam deflection. This research task was designed to demonstrate for the first-time the feasibility of this capability for xenon thrusters.

# Problem Description

a) Context (Why this problem and why now)

Ion propulsion demonstrated its ability to deliver a large spacecraft $\Delta V$ on the Dawn mission. Dawn's ion propulsion system provided a record-smashing $\Delta V$ of 11.5 km/s. The highest $\Delta V$ provided by a chemical propulsion system in deep space is < 3 km/s. To provide this $\Delta V$, however, the Dawn ion propulsion system needed to operate for over 50,000 hours. This places a premium on the service life capability of the ion thrusters. Thruster lifetime is limited by erosion of the ion accelerator system. In addition, the overall performance of an ion thruster is dominated by the performance of the accelerator system. This creates the need for the development of better ion accelerator systems.

a) SOA (Comparison or advancement over current state-of-the-art)

SOA ion accelerator systems, such as that on the Dawn mission, use chemically-etched molybdenum electrodes. This fabrication approach is expensive and difficult to scale to the larger size thrusters that are expected to be needed for future, higher-power missions. Alternatively, some ion thrusters have flown with graphite electrodes (BepiColombo) and or carbon-carbon electrodes (Hayabusa I and II). These approaches are also expensive and difficult to scale up. The slotted-tungsten-rod ion accelerator system proposed herein may provide a low-cost fabrication approach that also results in increased thruster service life.

a) Relevance to NASA and JPL (Impact on current or future programs)

The ability to provide spacecraft $\Delta V$s greater than 10 km/s enables numerous missions that would otherwise be impractical. A key example is the Ceres sample return featured in the recent pre-decadal Planetary Mission Concept Study. This mission requires a $\Delta V$ of ~14 km/s, but would return samples from the most accessible ocean world. Ion propulsion with ion thrusters larger than those used on Dawn are the key to making this mission possible.

# Methodology

a) **Objective:** The objective of the proposed task is to develop the first ever low cost, high-performance ion optics for xenon electric propulsion use based on the success of the initial slotted-tungsten-rod (STR)-based accelerator system. In the proposed task a new accelerator system would be developed to demonstrate the ion beam extraction characteristics with xenon propellant needed for solar system exploration missions and for planetary defense applications, i.e., high-current density, high screen grid transparency to ions, low accelerator grid transparency to neutral atoms, high electron-backstreaming margin, and low ion beam divergence.

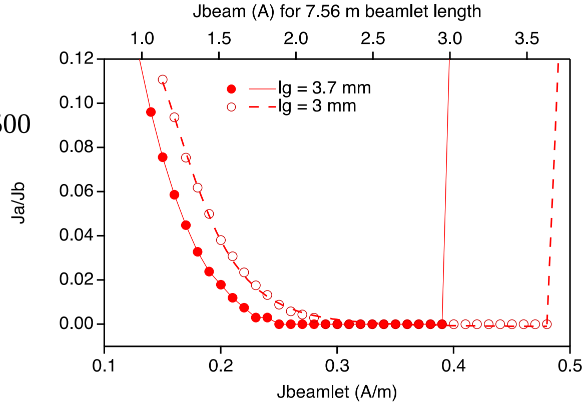
b) **Approach:** The intended approach was to design, fabricate, and test a new STR accelerator system. Ion optics modeling is conducted to design the ion accelerator system. Tests would be performed using the discharge chamber and vacuum facility test set up previously developed for the lithium ion thruster. This is the most cost effective approach because the test set up exists and the thruster provides a flat plasma density profile to the ion accelerator system that is essential for understanding the grid behavior. Testing would be performed using xenon, the current propellant of choice for exploration and planetary defense applications. Key measurements would be made of the ion accelerator system's perveance (ion current density extraction capability), grid transparencies, and electron-backstreaming voltage margin. These data would provide the required insight into the thermal/mechanical behavior to determine if scaling to larger thruster diameters is feasible.

c) **Innovation:** The successful implementation of the unoptimized STR accelerator system on the lithium-ion thruster suggests that it could provide a low-cost path to the development of large-diameter (> 60 cm), high-performance, flat ion optics with applications to solar system exploration missions and planetary defense by ion beam deflection. This research task was designed to demonstrate the first-time feasibility of this capability for xenon thrusters.

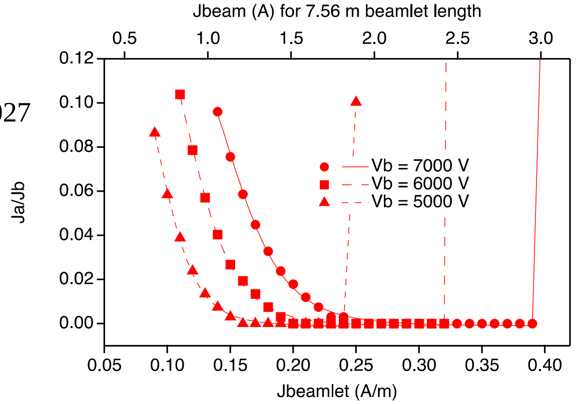
# Results

a) Extensive modeling was performed using JPL's CEX2D computer code [1] to optimize the geometry of the ion accelerator system. The CEX2D software models the trajectories of ions through the accelerator system, the resulting shape of the beamlets, and the fraction of ions that strike the downstream electrode (i.e., the accelerator grid). This modeling effort determined the diameter of screen grid and accelerator grid rods, the spacing of the rods, the grid-to-grid spacing, the screen and accelerator grid voltages and the range of acceptable upstream plasma density. The geometry that enabled the largest range of upstream densities was selected. This selection makes operation of the grid system easier on a real thruster which has radial density variations. It also makes thruster startup easier which typically requires walking up the beam current and beam voltage together. Engineering drawings of the grid piece parts (tungsten rods and support structure) were created. The support structure was fabricated at JPL and the tungsten rods with diameters of 1.5 mm for the screen grid rods and 3.96 mm for the accelerator grid were procured.

$V_B$ = 7000 V
$E$ = 2027 – 2500 V/mm




$l_g$ = 3.7 mm
$E$ = 1486 – 2027 V/mm



**Slotted Grid Design**

Accel. grid physical transparency: 39%

Screen grid effective transparency 83%

Beam Divergence: 7.4 degrees

Total Slot Length = 7.56 m

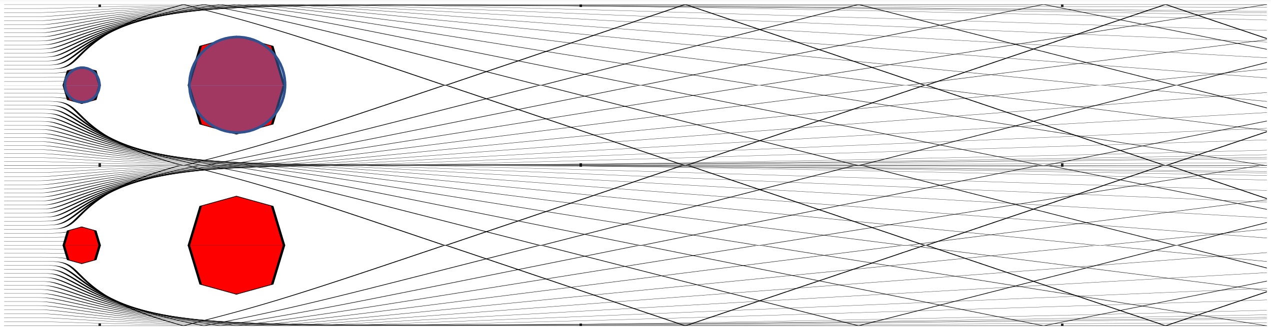
$d_s$ = 5.0 mm, $t_s$ = 1.50 mm
$d_a$ = 2.0 mm, $t_a$ = 3.96 mm
$l_g$ = 3.7 mm, $l_{cc}$ = 6.5 mm
$\phi_s$ = 0.77, $\phi_a$ = 0.39
$j_b$ = 0.11 A/m

$J_B$ = 1.66 A
$V_B$ = 7000 V
$V_A$ = -500 V
$E$ = 2027 V/mm
$l_g/d_s$ = 0.74

**Cross-over**

Impingement-Limited

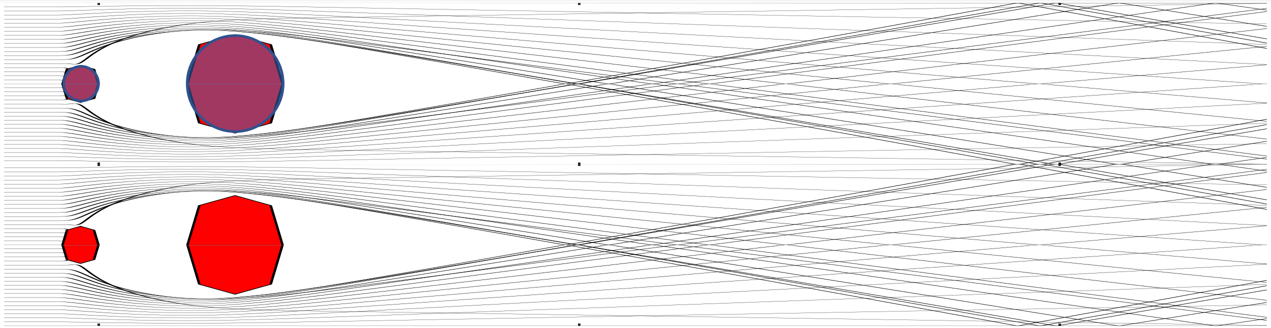
Lower Plasma Density



**Direct**

Impingement-Limited

Upper Plasma Density



# Results (continued)

a) All the parts for the accelerator system were received just prior to the Laboratory shutdown for COVID-19. This brought the project to a halt and no further work was performed. The accelerator system assembly was not completed. The accelerator system was not installed on the thruster, the necessary vacuum test facility modifications for operation with xenon were not performed, and no tests of the STR accelerator system were conducted.

# Results

b) **Significance.** The modeling effort revealed that slotted grid systems have a smaller range of acceptable upstream plasma densities than conventional circular-aperture grid systems. This will limit the applicability of slotted grid systems. So, while slotted grid systems may be significantly less expensive to fabricate than conventional grid systems, the poorer dynamic-range performance will likely make them unattractive for deep-space mission applications.

c) **Next steps.** None

# Publications and References

## References

[1] Wirz, R. E., Anderson, J. R., and Katz, I., “Time-dependent erosion of ion optics,” Journal of Propulsion and Power, v. 27, n. 1, pp. 211-217, 2011.

## Publications

None