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Technical Notes

Electrical Facility Effects on Faraday Probe Measurements

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I. Introduction

THE high specific impulse, thrust efficiency, and thrust density provided by Hall effect thrusters (HETs) makes them an appealing choice for use as the primary propulsion system onboard a number of commercial and government Earth-orbiting satellite missions. In addition to the mass savings offered by these performance attributes, developments in in-space power and the growing Western flight heritage portfolio of HETs have also increasingly made them prime candidates for more ambitious deep space missions.

During HET ground testing, the plume ion current density profile is commonly measured using Faraday probes [1]. However, previous studies have shown that these measurements are sensitive to facility backpressure effects. Specifically, investigations have shown that elevated facility pressures lead to an increase in charge exchange collisions; these collisions introduce additional plume components and artificially increase the ion current density measured by Faraday probes in the regions of the HET plume at large angles with respect to thruster centerline. These observations have prompted the development of several techniques to correct measurements of ion current density for the impacts of facility background pressure. Examples of this prior work can be found in [2–4], and a complete summary and citation list is available in [1].

Recent work has identified an additional set of electrical facility effects caused by the interactions between the conductive walls of the test facility and the HET circuit [5]. Specifically, increases in facility wall bias have been shown to cause a corresponding increase in the plume plasma potential and the ion current density measured by Faraday probes in the regions of the HET plume at large angles with respect to centerline [5,6]. However, it is not clear from these results if the measured increase in off-axis ion current density is indicative of changes in the plume or is an artificial effect introduced by the change in plasma potential with wall bias. This work seeks to clarify these observations by directly investigating electrical facility effects on Faraday probe measurements.

II. Experimental Setup

A. Vacuum Facility

All experiments were performed in Vacuum Test Facility 2 (VTF-2) at the Georgia Institute of Technology High-Power Electric Propulsion Laboratory. A schematic of this facility is shown in Fig. 1, and the facility is described in detail by Kieckhafer and Walker [7]. Pressure in VTF-2 was monitored using two Agilent BA 571 hot filament ionization gauges controlled by an Agilent XGS-600 Gauge Controller. One gauge was mounted to a flange on the exterior of the chamber, and the other was mounted 0.6 m radially outward and centered 0.3 m upstream of the HET exit plane. To prevent plume ions from having a direct line of sight to the ionization gauge filament of the interior ion gauge and potentially affecting the pressure measurement, a neutralizer identical to the one described in the pressure measurement recommended practices was attached to the gauge orifice [8]. The nominal operating pressure for this work as measured by the interior and exterior ion gauges was 1.1×10^{-6} and 1.2×10^{-6} Torr corrected for xenon, respectively [9].

B. T-40 Hall Effect Thruster

All experiments detailed in this work were performed using the Aerojet-Rocketdyne T-40 HET. Frieman et al. provide a complete description of this HET as well as the electrical circuit, propellant feed system, and cathode used in this work [10]. The thruster body was electrically grounded, whereas the discharge circuit was floating for all presented measurements.

C. Witness Plates

To simulate a metallic facility with controllable wall bias, two $0.91 \times 0.91 \times 0.16$ cm square aluminum plates were mounted adjacent to, but electrically isolated from, the walls of the vacuum test facility. The axial plate was located 4.3 m downstream from the exit plane of the thruster. The radial plate was located 2.3 m radially outward from the thruster centerline and was centered on the exit plane of the T-40 HET. Figure 1 shows the physical location of the plates with respect to the T-40 HET. Identical plates have been used in previous studies of electrical facility effects [5,6]. For this work, the bias voltage of each plate was controlled using a TDK-Lambda GEN150-10 power supply. Consistent with previous work, the plate not actively being biased was electrically floating [6].

D. Faraday Probe

A nude Faraday probe similar in design to the one previously used by Xu [11] and Walker et al. [12] was used for this work. The probe consists of a tungsten-coated aluminum collector that is 2.31 cm in

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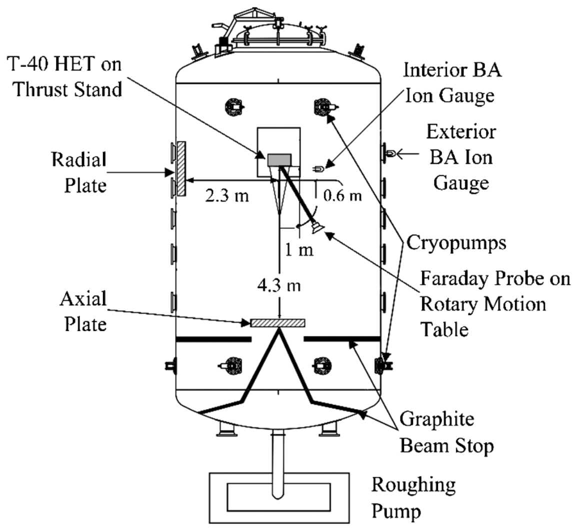

Fig. 1 Schematic of VTF-2 (not to scale).

diameter surrounded by an aluminum shield electrode with a 1.15 mm gap distance. The guard and collector were both biased to −30 V using a Xantrex XEL 60-1.5 power supply; this bias voltage was chosen using the procedure outlined in the Faraday probe measurement recommended practices [1]. The collector signal was passed through a 100-Ω shunt, and the resultant voltage drop across the resistor was measured using an Agilent 34970A Data Acquisition/Data Logger Switch Unit (DAQ) to determine the current collected by the Faraday probe.

For this work, the Faraday probe was placed on a 1-m-radius arc centered on the intersection of the exit plane and centerline of the HET. The probe was swept from −90 to 90 deg relative to thruster centerline at a speed of 2 deg/s yielding a distance between measurements of approximately 0.5 deg. The location of the Faraday probe along the arc was controlled using a Parker Daedal 200RT series rotary table, which has a positional accuracy of ±0.17 deg. The angular traverse of the probe through the plume and the DAQ were simultaneously controlled using a LabVIEW Virtual Instrument to ensure synchronous recording of the angular position of the probe and the spatially resolved collected current.

To reduce any systematic directional bias, two angular sweeps of the Faraday probe were taken in succession at each measurement condition in opposing directions (i.e., one sweep was taken each from −90 to 90 deg and from 90 to −90 deg). The recorded data were then analyzed using the correction factors and methods detailed by Brown and Gallimore [2]. The reported ion beam currents and plume divergence half-angles represent the average of the results computed for each of the two angular sweeps taken for every plate bias voltage. The uncertainty associated with this method is approximately 5% for the beam current and 1.5% for the plume divergence half-angle [1,11]. It is important to note that the employed measurement and analysis techniques are consistent with the recommendations in the Faraday probe measurement recommended practices [1].

III. Results and Discussion

Figures 2a and 2b show the 95% divergence half-angle and average ion beam current of the T-40 HET calculated from the measured ion current density profiles as a function of axial and radial plate bias voltage, respectively. Consistent with previous results, the divergence half-angle and ion beam current appear to monotonically increase as a function of axial plate bias [6]. Specifically, the divergence half-angle and ion beam current increase by approximately 2 and 3.5%, respectively, as the axial plate bias voltage is increased from −10 to 50 V; this change is greater than the empirical uncertainty for the divergence half-angle but not the ion beam current.

A potential explanation for the observed increase in divergence half-angle is the changing nature of the Faraday probe bias relative to the plasma potential with axial plate bias. During measurements, the Faraday probe is biased negatively with respect to facility ground. Measurements in previous work have shown that increasing the axial plate bias uniformly increases the plasma potential V_P in all regions of the plume through which the Faraday probe was swept [5,6]. As shown in the representative HET potential distribution depicted in Fig. 3, this in turn causes the Faraday probe bias V_F, to become increasingly negative relative to the plasma potential V_P. As the potential difference between the probe and the plasma increases, the plasma sheath around the probe expands, thereby providing a larger effective collection area for CEX ions [5]. Because CEX ions are the dominant ion species in the off-axis wings of the plume; this is expected to result in an artificial increase in current collected at large

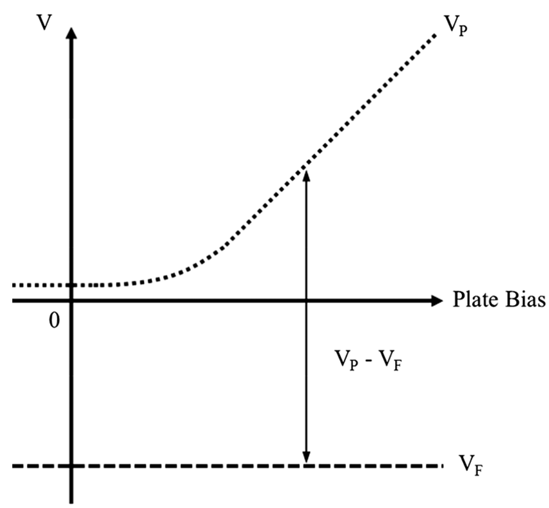

Fig. 3 Representative T-40 HET plume and Faraday probe potential distribution.

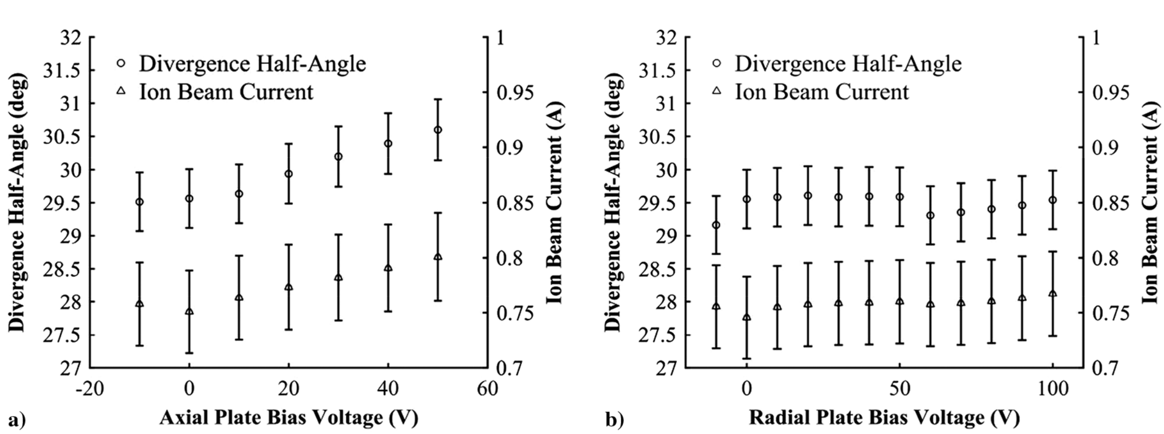

Fig. 2 Plume divergence half-angle and ion beam current as a function of a) axial, and b) radial plate bias.

angles and, consequently, an increase in measured plume divergence half-angle with increasing axial plate bias [2].

To test this explanation, the bias of the Faraday probe was varied as the axial plate bias was held constant at 60 V. As the Faraday probe bias was decreased from −30 to −60 V relative to facility ground, the potential difference between the probe and the plasma increased and caused the sheath to expand; this in turn caused the ion beam current and divergence half-angle to increase by approximately 10%. This variation is outside of the measurement uncertainty for both quantities and matches the trends observed in Fig. 2a. It is therefore likely that the observed increase in average divergence half-angle is simply due to the changing nature of the Faraday probe bias relative to the plasma potential and not a physical change in the ion current density profile. As previous work has shown, the coupling between the radial plate bias and plasma potential is much weaker, so no clear trends are observed for the divergence half-angle or beam current as a function of radial plate bias [5].

IV. Conclusions

This work empirically investigated electrical facility effects on Faraday probe measurements. It was shown that the changes in plasma potential associated with biasing of the axial witness plate impacted the current collection characteristics of Faraday probes. Specifically, it was shown that increases in plasma potential with axial plate bias led to artificial increases in the measured divergence half-angle. This observed distortion indicates that electrical facility effects may influence terrestrial Hall effect thruster (HET) efficiency analyses. Specifically, the observed artificial changes in divergence half-angle could lead to overestimation of the power losses associated with radial plume acceleration and, consequently, for a fixed overall efficiency, underestimation of losses associated with other processes such as thruster heating as compared to what would otherwise be found in the absence of the conductive facility walls. Unless accounted for, this misallocation of power losses could cause ground tests to misrepresent the various efficiencies of a given HET during design and testing. To eliminate these effects, the process for selecting probe bias detailed in the Faraday probe measurement recommended practices should be repeated any time the electrical boundary conditions are altered.

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