Advanced Electric Propulsion Diagnostics

C. Bundesmann, F. Scholze, H. Neumann

Abstract

We set up an advanced diagnostic system for in-situ characterization of electric propulsion thrusters. The system uses a high precision 5-axis positioning system and several diagnostic tools, such as a telemicroscope, a laser head, a pyrometer, a Faraday probe and a plasma monitor, for gathering a comprehensive set of performance parameters of electric propulsion thrusters, including, for instance, erosion of lifetime limiting mechanical parts, surface temperature of selected thruster parts, current density distribution, ion energy distribution and beam composition. The capabilities of the system are, exemplarily, demonstrated for a gridded ion thruster and a Hall-effect thruster.

Keywords

electric propulsion; in-situ diagnostics; telemicroscope; laser head; pyrometer; Faraday probe; plasma monitor; gridded ion thruster; Hall effect thruster

1. Introduction

Electric propulsion (EP) is a key technology for space missions. Any propulsion system needs to be tested before flying into space. Testing allows evaluating the performance characteristics of the test object but provides also data as input parameters for thruster modeling or for validating modeling results. Hence, thruster diagnostics is an essential tool for performance characterization and optimization.

Here we describe an in-situ diagnostic system for EP thruster characterization [1], which provides a comprehensive set of performance parameters. The special emphasis lies on in-situ measurements, i.e. measurements done inside vacuum and mainly with the thruster firing. Thus, the thruster can be characterized without breaking the vacuum or dismantling it. Because of that, time and costs for test campaigns can be reduced considerably. In the following, the system setup is described and its measurement capabilities are outlined.

2. Experimental Setup

The diagnostic system (Figure 1) is based on a modular bar setup such that it can be easily adapted to vacuum chambers of different size. It uses a 5 axis-positioning system with three linear and two rotary tables for positioning and moving thruster and diagnostic tools very precisely relative to each other. The system allows also line scans, 2- and 3-dimensional mappings, and its operation is fully computer controlled.

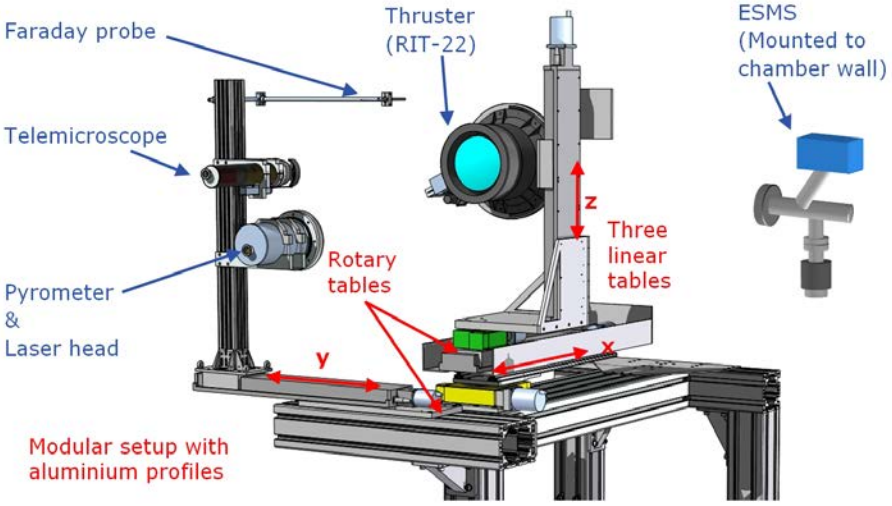

Figure 1 - Drawing of the diagnostic system with modular bar setup, linear and rotary tables, diagnostic tools and mounted thruster RIT-22 [1]

The diagnostic system can be used to perform optical, thermal, beam and plasma characterization of EP thrusters. So far, five diagnostic tools are integrated: a telemicroscope for high-resolution optical imaging, a laser had for surface profile scanning using the triangulation effect, a pyrometer for non-contact temperature measurements of visible parts, a Faraday probe for current density mappings and an energy-selective mass spectrometer (plasma monitor) for energy and mass distribution measurements.

Telemicroscope, pyrometer and laser head are placed inside two separate vacuum sealed housings for safety reasons. The housings are equipped with special windows, separate shutters made of graphite, and a graphite shielding. The plasma monitor is mounted to the chamber wall.

The system was tested in two vacuum facilities, the Jumbo test facility (Uni Giessen, volume 30 m^3) and the large vacuum test facility LVTF (Aerospazio, Italy; volume 120 m^3), with two thrusters, a gridded ion thruster (GIT) RIT-22 (Astrium ST, Germany) and a Hall effect thruster (HET) SPT-100D EM1 (EDB Fakel, Russia).

3. Experimental Results

Figure 2 shows high resolution optical images of the top surface of a section of the plasma channel wall of the HET at the start and end of the test campaign taken with the telemicroscope [2].

The radial erosion can be clearly seen. It amounts to be of about 2.5±0.1 mm. By moving the thruster closer to the telemicroscope, the focus moves along the eroded edge, which gives access to the axial erosion (not shown here). The axial erosion is found to be 7.5±0.5 mm. It could be demonstrated that lateral resolution can be as high as 0.01 mm.

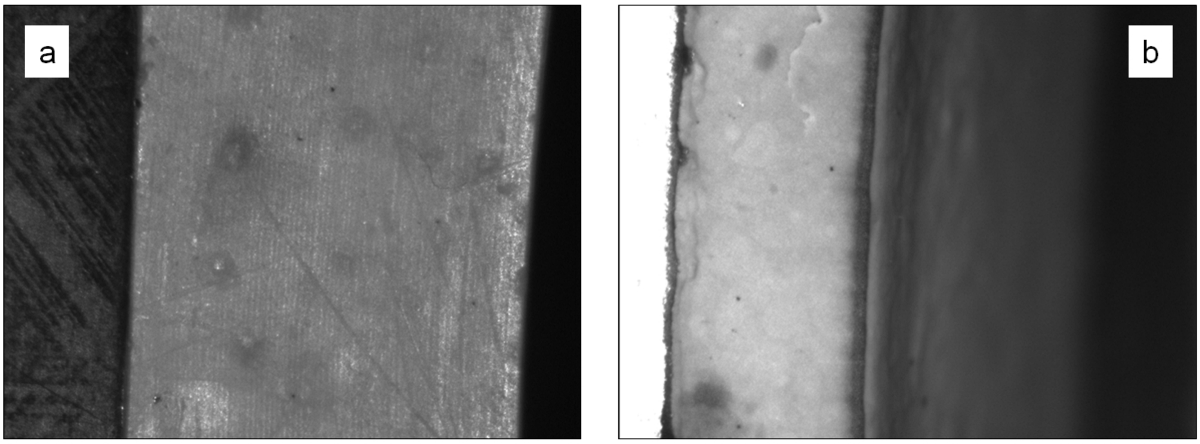

Figure 2 - Telemicroscope images of the top surface of the HET taken at the start (a) and end (b) of the test campaign [2]

Parallel to telemicroscope measurements, the surface profile of the HET is measured with the laser head. The results for the start and the end of the test campaign are shown in Figure 3 [2]. Again the erosion of the top part of the plasma channel walls can be seen clearly. The radial and axial erosion are found to be 2.5±0.2 mm and 7.5±0.2 mm, respectively, and agree very well with the telemicroscope results.

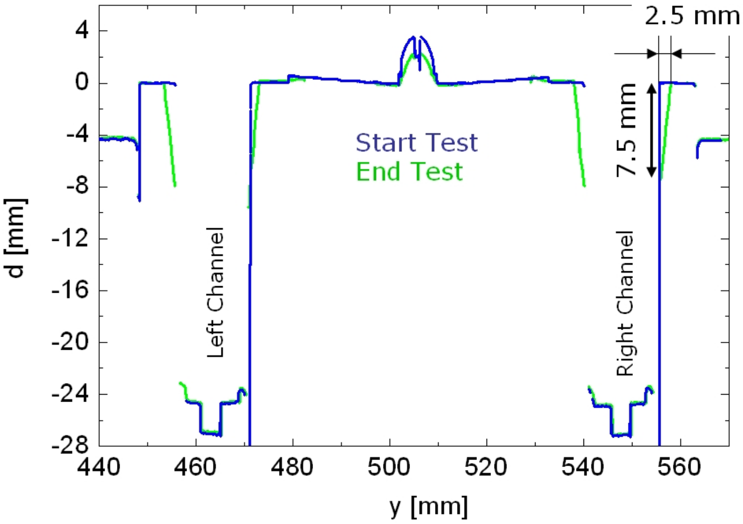

Figure 3 - Surface profile scans across the centre of the HET measured with the laser head at the start (a) and end (b) of the test campaign [2]

Figure 4(a) shows pyrometer line scans across the diameter of the GIT operated at different beam power levels [4]. The measured temperature increases with increasing beam power level, as expected. However, the curves are modulated with interference-like structures, which are related to the fact that the pyrometer measurement spot diameter is similar to the grid hole diameter and the distance between neighboring grid holes. Therefore, the pyrometer spot covers always both grid and grid holes with different portions giving rise to the modulations. By calculating these portions in dependence on the position y, it is possible to extract the grid surface temperature [3]. The calculated temperature data are presented in Figure 4(b).

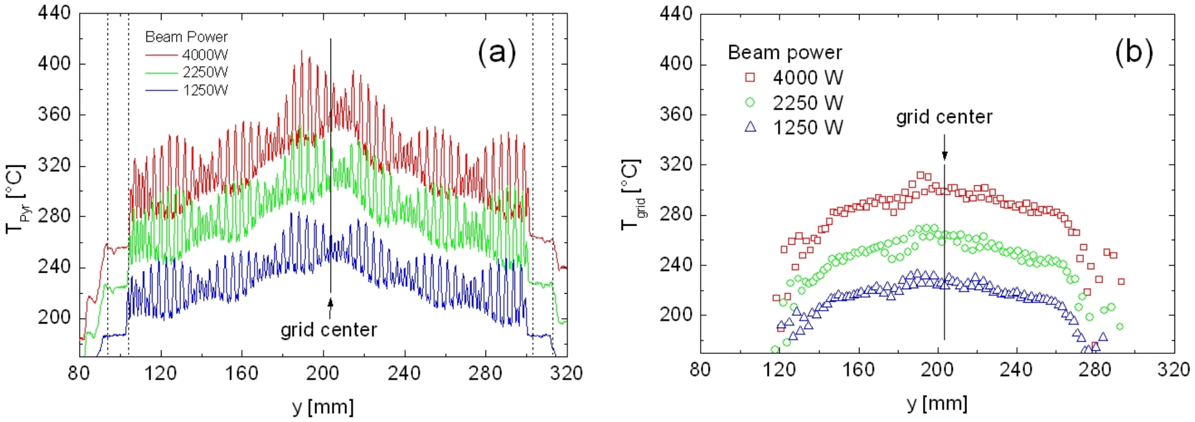

Figure 4 - (a) Pyrometer line scan curves measured across to the diameter of the outer grid of the GIT operated at different beam power levels. (b) Extracted accelerator grid surface temperatures [3]

In Figure 5 current density maps of the GIT at different distances are plotted. A positive current density profile related to the Xenon ion beam is observed. It is nearly rotational-symmetric. The symmetry is broken by a negative current density related to the electrons ejected by neutralizer. At a distance of 100 mm the negative current density is located at the lower left side of the thruster, where the neutralizer is mounted. When moving further away from the thruster, it seems that the electron beam is circulating around the ion beam such that the negative current density occurs on the upper left side of the ion beam at a distance of 600 mm. This behavior has been predicted by model calculations by C. Othmer et al [5] and depends closely on the properties of the electrons.

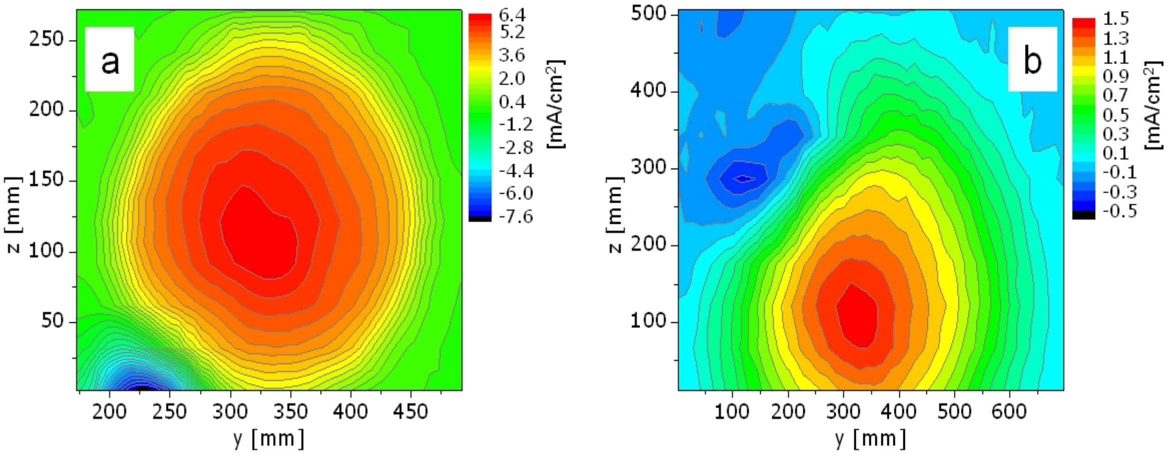

Figure 5 - Faraday probe maps of the GIT (beam power 4000W) measured at distances of 100 mm (a) and 600 mm (b) [4]

Finally, Figure 6 shows selected plasma monitor data of the HET [2]. In Figure 6(a) an energy distribution curve is plotted showing a broad peak with the intensity maximum at about 753 eV, which corresponds quite well to the main voltage. Other experiments (not shown here, [2]) revealed, for instance, energy distributions with multiple peak structures with energies exceeding the energy related to the main voltage by far (up to several hundreds of eV), depending on position within the beam. This is related to the complex ion creating mechanisms of the HET. In Figures 6(b, c) mass scans corresponding to the energy scan in Figure 6(a) are plotted for two different energies, the maximum of the energy distribution at 753 eV and for a lower energy of 710 eV. Both mass scans reveal a dominating peak of single charged ions but also multiple charged ions (up to Xe^{5+}) can be seen. From the relative intensities it can be concluded that the fraction of multiple charged ions is up to 10 %. This fraction depends on ion energy, but can be also influenced by the position within the beam and thruster operation parameters (not shown here). Again, this indicates a complex ion creating mechanism.

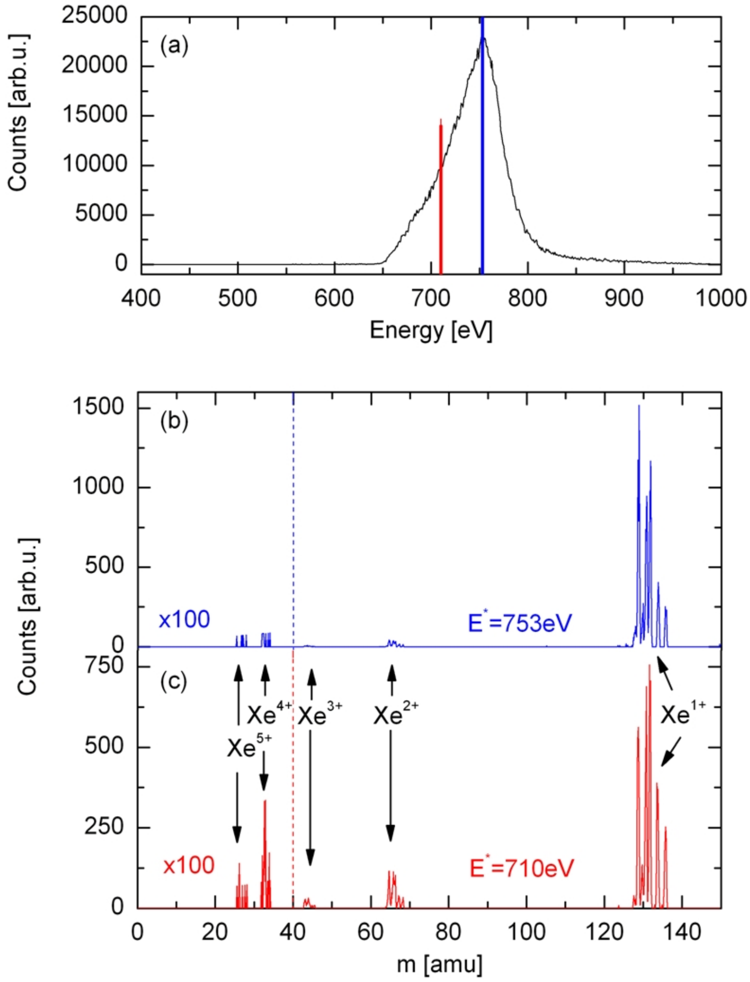

Figure 6 - Energy scan (a) measured across the centre of the HET operated at 750 V/2.6 A. Corresponding mass scans at the energy of the centre peak of the energy scan at E=753 eV (b) and below the centre energy at E=710eV (c) [2]

4. Conclusions and Outlook

We have set up an in-situ EP diagnostic system, which allows collecting a comprehensive set of important thruster parameters. These parameters can help to address interesting questions, such as investigation of fundamental physical processes but also modeling and optimization of the thruster performance.

For future activities, some things need be optimized. Firstly, possible interactions of the diagnostics with the energetic particle beam must be further reduced. Designated tasks are reducing the dimension of the diagnostic tools or testing of other measurement strategies. Secondly, alternative devices shall be integrated, for instance, a thermocamera for temperature imaging or a retarding potential analyzer for beam characterization.

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