Electric Propulsion Thruster Diagnostic Activities at IOM

IEPC-2015-392／ISTS-2015-b-392

Presented at Joint Conference of 30th International Symposium on Space Technology and Science
34th International Electric Propulsion Conference and 6th Nano-satellite Symposium,
Hyogo-Kobe, Japan
July 4 – 10, 2015

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Abstract: Current research activities at the Leibniz-Institute of Surface Modification (IOM) focus on the improvement of measurement sensors that have been set up on the Advanced Electric Propulsion Diagnostics (AEPD) system, which is a versatile, modular tool for comprehensive electric propulsion thruster parameter investigation, including telemicroscopic surface imaging, laser-based distance measurement, pyrometric imaging, Faraday scanning, and several ion-optical based methods. Previous limitations with respect to the applicability of some probes, as identified during two former successful test campaigns related to the characterization of RIT-22 and SPT-100 thrusters, have been resolved. First test experiments using the modified sensors show encouraging results, laying the groundwork for the ongoing test campaigns within an ESA founded project, aiming at the qualification the AEPD system for standardized on-ground electric propulsion diagnostics.

I. Introduction

EXEPERIMENTAL diagnostics of electric propulsion systems may provide important data both to judge their performance, and to achieve a better understanding of physical processes in the plume and in the discharge chamber of such systems. Measurements of plasma parameters, as well as monitoring of possible lifetime limiting alteration of the properties of thruster components, such as, for example, the evolution of the grid hole diameter in gridded ion thrusters, yield valuable information for the development and validation of numerical tools. Those codes, e.g. aiming at thruster lifetime prediction related to the erosion of ion thruster accelerator grids[1], may finally help to partially circumvent expensive measurement campaigns with respect to thruster design and performance verification. In this context, several groups have investigated surfaces of thruster components e.g. by telemirococsopy or thermal imaging methods[2-10].

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In order to allow for the in-situ measurement of an extensive set of electric thruster performance parameters, the Advanced Electric Propulsion Diagnostics (AEPD) platform has been designed[11]. The modular, mobile structure may be used in various vacuum facilities and carries, besides the thruster to be tested, a variable number of measurement devices for thruster plume and mechanical part characterization. In recent test campaigns, a gridded ion thruster (RIT-22) and a Hall effect thruster (SPT-100D EM1) have been investigated[2-5]. Here, the measurement sensor equipment included a telemicroscope, that was e.g. used to track grid hole erosion, a triangular laser head to monitor the geometric shape of parts of the surface of interest, a pyrometer to measure surface temperature distributions, as well as an energy-selective mass spectrometer and a Faraday probe for thruster plume characterization. Some sensors consist of commercially available devices with IOM in-house modifications, or have been manufactured at our institute (e.g. Faraday probe).

At present, activities at IOM concentrate on two major topics: The set-up of additional plasmadiagnostic techniques as extension of AEPD capabilities, and furthermore, the implementation of partially new designs of existing sensors as a result of experiences obtained during former measurement campaigns. The first aspect deals with the development and integration of new sensors in the system, such as a retarding potential analyzer, which has been developed for currently ongoing measurements related to electric propulsion application within a ESA funded project, and is, together with further extensions of the AEPD system provided by other project partners, described more detailed in a companion paper[12]. The second aspect concerns rather technical issues, such as modifications related to the vacuum compatibility of some diagnostic heads, size reduction and optimization of the respective sensor housings and working distance geometries as well as the protection of the sensor heads from damage due to ion bombardment.

In this paper, the most recent implementation of the telemicroscope, the triangular laser head, the pyrometer and the Faraday probe, as well as the newly set-up thermocamera, is reported. First measurements to demonstrate the diagnostic head performances are shown. Thereby, present work is related to the approach of standardization of electric propulsion thruster characterization.

II. The Advanced Electric Propulsion Diagnostics Platform

The AEPD platform consists of a variable number of measurement sensors, and the five axis positioning system. The positioning system is based on an alumina structure, which supports three linear and two rotary ultra-high vacuum specified moving tables and mounting frames for the thruster and the diagnostic equipment, respectively. Fig. 1 illustrates the set-up. The travel distance is 700 mm for the linear tables at traveling speeds up to 50 mm/s, with a positioning accuracy better than 0.1 mm. The rotary tables are specified at a maximum rotation speed of 3°/s and a position reproducibility better than 0.5°. In the present configuration, one mounting block carrying the thruster involves two linear and one rotary tables, while the diagnostic frame including the telemicroscope, themocamera, pyrometer, triangular laser head and Faraday probe is attached to the two remaining tables. Recently implemented devices[12], e.g. the retarding potential analyzer, are mounted at a fixed position. The present set-up allows for the precise realization of a wide span of geometrical measurement orientations of interest, including single point, line and planar scans as well as programmable measurement trajectories using an in-house developed operating software.

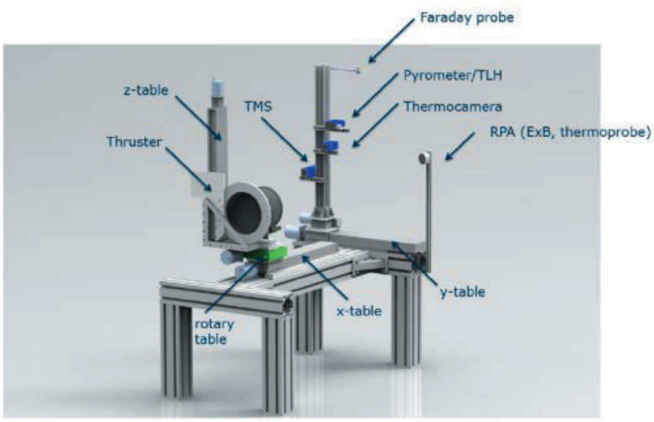

Figure 1. *Set-up of the AEPD system in the current configuration.*

The complete system is designed to be extended or reduced modularly; the diagnostic heads may be arranged depending on the measurement objectives, respectively.

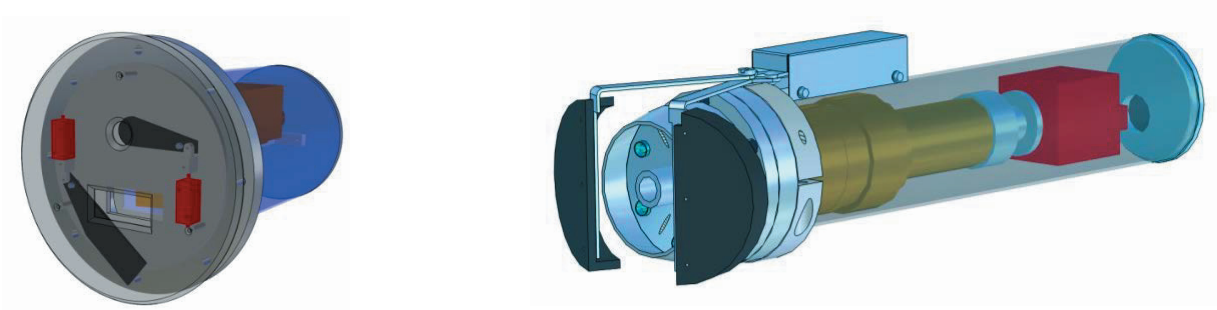

Figure 2. *Vacuum-sealed housings for triangular laser head and pyrometer (left, diameter 200 mm, length 300 mm) and the telemicroscope (right, diameter 120 mm, length 500 mm) with graphite front plates and separated shutters for each diagnostic head, as used during earlier measurements.*

III. Improvements of the Current Set-up and First Test Results

The AEPD system has been used with success in several test campaigns including RIT-22 and SPT-100 thrusters with a total experiment time of more than 400 hours, and extensive data sets were obtained for all applied sensors[2-5].

However, several limitations to be fixed had been identified which can be summarized as follows:

- The sensors were operated in vacuum-sealed housings. In order to minimize risks for thruster and sensor operation in the case of a failure of the sealing, all sensors were currently designed for vacuum use.
- The interaction between the thruster plume and the triangular laser head, telemicroscope and pyrometer sensors due to the size of their housings (see Fig. 2) had to be reduced.
- The previously used energy selective mass spectrometer had to be installed apart from the five axis system at an appropriate position of the wall of the vacuum facility. This instrument was replaced with a retarding potential analyzer and an ExB probe[12], that are more flexible to be handled.

In the following, the new diagnostic head design is described.

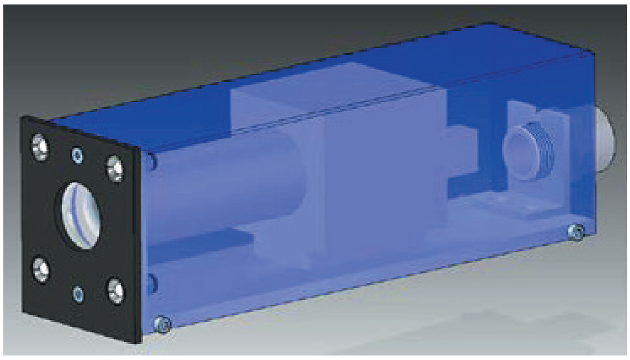

Figure 3. Illustration of *the modified set-up of the telemicroscope with reduced size of the protective housing.*

A. Telemicroscope

The telemicroscope is used for in situ inspection of mechanical parts such as accelerator grids or Hall effect thruster extraction channels to monitor corresponding erosion processes precisely. The new set-up includes a 1600x1200 pixel CCD camera (DFK 51AU02, The Imaging Source) equipped with a f/2.8 lens (Pentax C5028). The working distance is 92 mm, resulting in a field of view of 3.7x3.7 μm^2 per pixel. Extension tubes may be used if appropriate. The size of the housing has been reduced significantly, with presently 60x70x214 mm^3. The housing is equipped with a graphite front plate and a standard optical window to protect the telemicroscope optics, and includes four LEDs for object illumination. Fig. 3 displays the modified set-up of the telemicroscope. As vacuum feedthroughs,

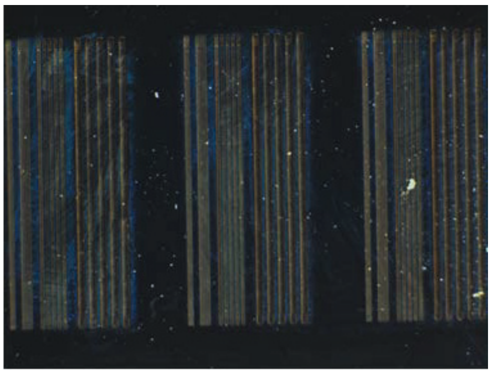

Figure 4. *High-resolution telemicroscope image of the calibration test sample.*

an ISO-KF40 flange with USB connectors is available.

Adjustment and calibration of the telemicroscope is performed by imaging a specially manufactured test structure. The structure exhibits pairs of lines that are scribed in a TiO_2 layer on a silicon substrate. An image of the structure obtained for the working distance of the telemicroscope is shown in Fig. 4. Four pairs of 5 lines each with line spacings of 100, 50, 20 and 10 µm are visible and may be used for definition and verification of the lateral resolution.

B. Triangular Laser Head

The triangular laser head is used to determine precisely spatial distances between a point defined by the size of a laser spot on the surface of interest and the sensor. This enables e.g. the measurement of the grid curvature under thruster operation, as well as the altering shape of grid holes, or the extraction channels of Hall effect thrusters.

The set-up consists of a commercial laser head (Keyance L-KG 152), which operates at a working distance between 110 and 190 mm. In this geometry, the laser spot is small enough to allow for a spatial resolution of about 1 µm. The sensor is embedded in a 95x47x127 mm^3 protective housing, which is significantly smaller than in former applications (Fig. 5). An ISO-KF40 flange with appropriate vacuum feedthroughs is available.

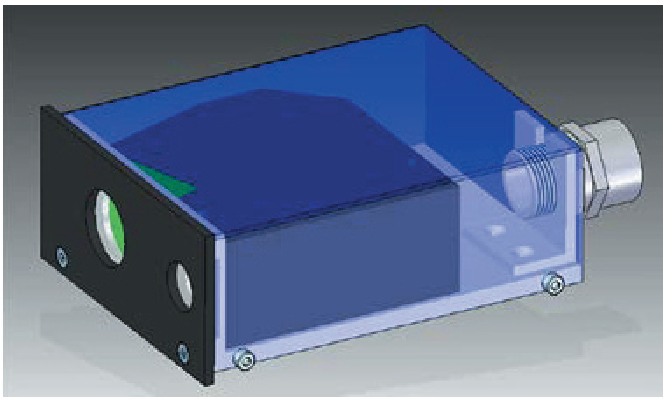

Figure 5. *Illustration of the modified set-up of the triangular laser head with reduced size of the protective housing.*

The performance of the laser head was verified under vacuum conditions measuring variable distances between the senor and a test object adjusting the sensor position using a precise linear stage. Care has been taken to re-calibrate the sensor with respect to expected deviations caused by the 2 mm sapphire protective window, which results in a linear correction of 770 µm at 150 mm measurement distance.

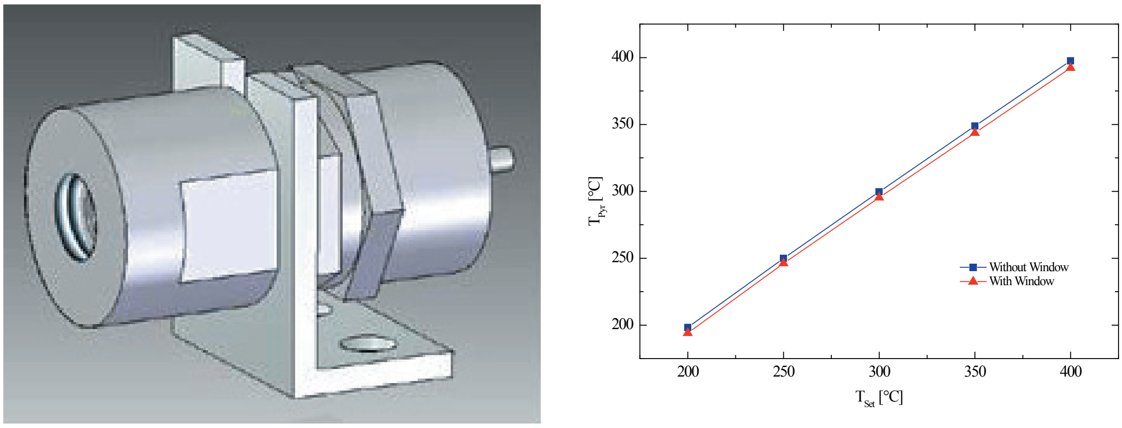

Figure 6. *Left: Modified housing of the pyrometer. Right: Calibration of the measured temperature of the pyrometer against a thermocalibrator, data points in red and blue are obtained with and without the sapphire protection window, respectively.*

C. Pyrometer and Thermocamera

In order to measure the local temperature e.g. on the accelerator grid of an ion thruster, both a pyrometer and a thermocamera have been implemented. The pyrometer is a commercial instrument (Optris CT3M, spectral range around 2.3 µm, temperature range 150 to 1000°C), designed for a working distance around 110 mm. The measurement spot is 1.5 mm, which is narrow enough to investigate the small areas between grid holes. The sensor including the protective housing is significantly smaller than during previous measurements (approx. 25x30x47 mm^3, see Fig. 6 left). To account for the spectral transmission characteristics of the used sapphire protection window, the pyrometer is re-calibrated using a thermocalibrator (Fig. 6 right).

In addition, temperature monitoring can be performed using a thermographic head, consisting of a miniaturized thermocamera (Optris Pi, spectral range 7.5 to 13 µm, temperature range -20 to 900°C). The working distance is 500 mm, providing a lateral resolution of ~1.5 mm. Fig. 7 shows the sensor in its protective housing with a size of 56x60x143 mm^3. Re-calibration due an integrated ZnS window is performed using a thermocalibrator.

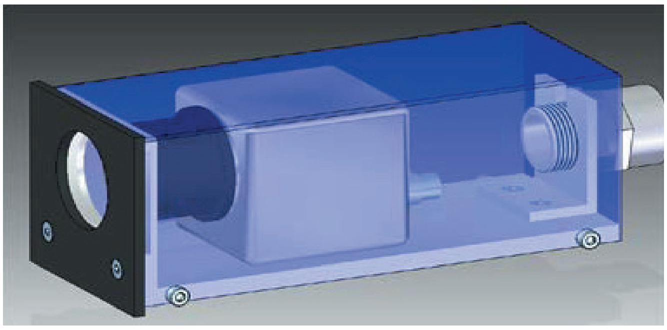

Figure 7. *Drawing of the protective housing of the thermocamera.*

D. Faraday Probe

The configuration of the Faraday probe is displayed in Fig. 8. A graphite ion collector rod is embedded in a ceramic tube surrounded by a thin metal setting of stainless steel with a length of 101 mm. The ion collecting area is as small as 2.8 mm^2 to allow for measurements with high spatial resolution. The ion collector is connected via a shielded BNC cable and a corresponding vacuum feedthrough to an external high precision resistor board allowing for the measurement of a large range of signal amplitudes. Data is recorded using a 12 bit analogue digital converter. With a sampling rate up to 20 kHz, maximum ion current densities up to 40 mA/cm^2 with a resolution of 0.05 mA/cm^2 can be detected.

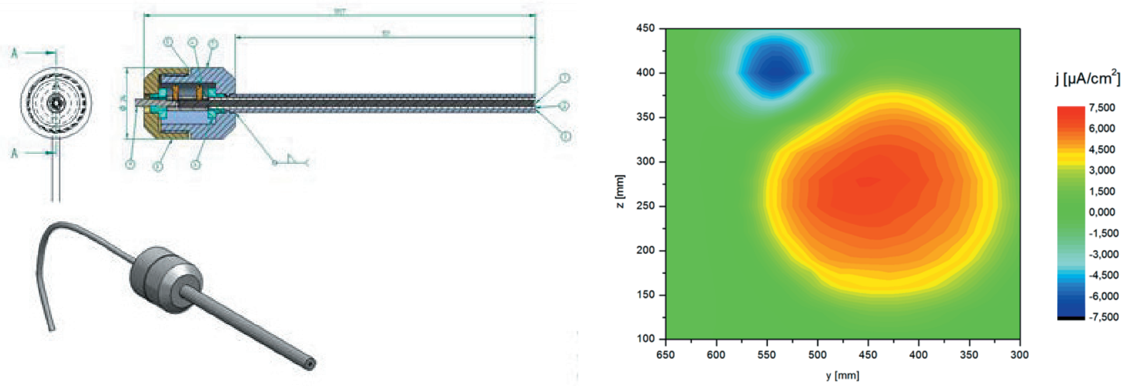

Figure 8. *Left: Schematic view of the Faraday probe. Right: Exemplary measurement in the plume of a RIT-22 thruster.*

E. Further Diagnostics Activities

Beyond the presented methods that are part of ongoing ESA project, non-intrusive plasmadiagnostic techniques are currently set up as extension, or in association with the AEPD platform. A probe based on emission spectroscopy to determine local electron temperatures has been set-up and tested[13]. Further development and the implementation on the AEPD complex are planned after completion of the current ESA activity. In addition, work on a two-photon laser absorption spectroscopy set-up for the local determination of particle densities in the plume of electric propulsion devices is already in progress.

IV. Summary and Outlook on Ongoing Test Campaigns

The telemicroscopy, triangular laser, and pyrometer diagnostic heads implemented on the AEPD platform have been improved using novel housings of reduced size and tested for vacuum compatibility. Additional sensors to be used on the AEPD system in an extended set-up include a thermocamera and a retarding potential analyzer, have been tested in appropriate environments and installed on the AEPD system. At present, the system has been installed in the JUMBO vacuum facility at Giessen University, and tests campaigns using RIT-µX (Airbus Defence and Space, Lampoldshausen) and SPT-100 (ICARE, Orléans) thrusters are performed within an ESA funded project aiming at the qualification of the sensors as standardized tools for EP testing. Following a second planned measurement campaign in a vacuum facility at Aerospazio tecnologie later this year, results will be published in a forthcoming paper.

Acknowledgments

The authors gratefully acknowledge support of R. Woyciechowski, S. Daum and M. Müller for mechanical and electrical construction work at the IOM institute. Work was funded by the European Space Research and Technology Center (ESTEC) within ESA project 4000107451/12/NL/RA. The authors thank the project coordinators A. Bulit and J. Gonzalez del Amo, as well as R. Blott (Space Enterprise Partnership, UK) for valuable discussions and ongoing support.

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