Spatially resolved optical emission spectroscopy in the plasma plume of a Hall Effect thruster

Application Note

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To characterize the rotationally symmetric plasma of an SPT50 Hall-Effect thruster, an optical, non-invasive and spatially resolved method is applied. The plasma plume is examined by optical emission spectroscopy (OES), which detects the entire fluorescence emission of the plasma in its line of sight (LOS). The resulting signal is processed using an inverse Abel transformation to allow the determination of the spatially resolved radiation intensity from the line integrated measurements.

1. Introduction

Most commonly the plasma plume of electric satellite propulsion systems is diagnosed with probes placed within the plasma. However, interaction of particles and also the magnetic field of the thruster with the probe influence the measurement signal. The probe on the other hand perturbs the flow of plasma influencing the acceleration of particles. Passive optical measurement techniques, such as the optical emission spectroscopy (OES) can be employed to avoid these perturbations but are limited to the acquisition of a line of sight (LOS) integrated signal. To determine the local emission of radiation of the plasma plume, the inverse Abel transformation was used with a fitting method based on the approximation of the spatially resolved quantities by a Fourier series.

2. Theoretical Background

The Abel transformation allows the determination of a LOS integrated quantity, in this case the radiation intensity, from a local quantity. The inverse Abel transformation, or Abel inversion, on the other hand, allows the reverse calculation of the local quantity from a LOS integrated measurement. The main assumption that must be fulfilled is the rotational symmetric behavior of the measurement object. The relationship between a LOS integrated $F(y)$ and local quantity $f(r)$ is given by:

$$F(y) = 2 \int_{r=y}^{\infty} \frac{f(r)r}{\sqrt{r^2-y^2}} dr \quad (1)$$

where r is the radial axis from the center of a rotational axis within a cross section of the plasma plume and y is the axis along the vertical direction as shown in figure 1. In the case of this study the values of $F(y)$ are measured at discrete positions on the y-axis with the optical axis along the x-axis. For the determination of $f(r)$ a Fourier approach was used. The local quantity distribution is approximated by a Fourier series:

$$f(r) = \sum_n A_n f_n(r) \quad (2)$$

By inserting eq. (2) in eq. (1) the coefficients A_n can be determined by fitting the equation to the measured values of $F(y_i)$ at the discrete positions i using the least squares method. For a more detailed description of the numerical Abel inversion Fourier method the reader may take a look at reference [1].

3. Experimental Method

The plasma flow is generated by an electric satellite propulsion system. The so-called Hall-effect thruster is a stationary thruster that generates and accelerates ions by the Hall-effect. Figure 2 shows the operation of the SPT50 thruster used within this study with argon as propellant. The radiation intensity is measured with a spectrometer (Andor iDus DU420A-BR-DD CCD detector and Shamrock SR-500i-D1-SIL spectrograph) perpendicular to the flow direction through an optical access to the vacuum chamber. By moving the optical axis of the spectrometer, the integrated LOS measurements were performed at several y-axis positions along a single plasma flow cross section.

Figure 2: Hall Thruster in operation with argon as propellant [2]

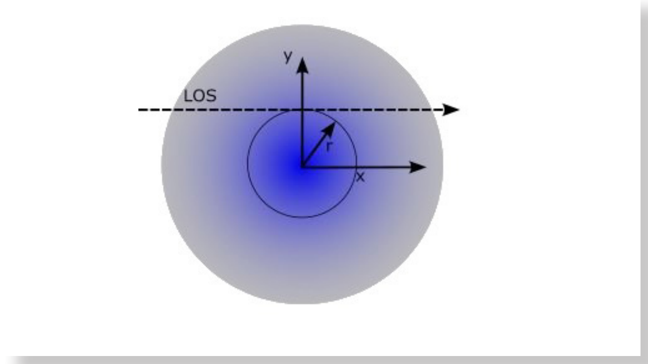

Figure 1: Plasma cross section with relevant coordinate axes.

4. Results

Measurements were performed at a distance of around 30 mm from the exit plane of the thruster. For each measured spectrum the radiation for a beam with a diameter of 5 mm was collimated towards the entrance slit of the spectrograph and the LOS was moved 10 mm along the y-axis of the plume between two measurements. Figure 3 shows a LOS integrated spectrum recorded at the center of the plume. The most dominant lines are between 690 to 800 nm which represent deexcitation processes of argon neutral.

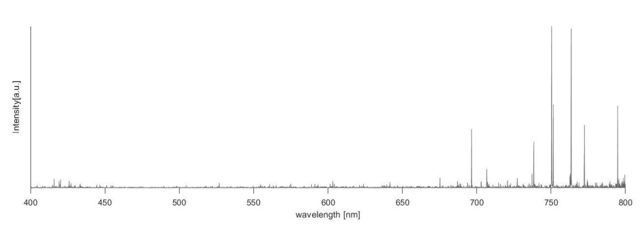

Figure 3: LOS integrated emission spectrum of the argon plasma flow.

The measured values compared to the values determined with the Abel inversion for two dominant lines at 772.4 nm and 763.5 nm are represented in figure 4. These initial results possess a poor radial resolution but give an overview of the technique used.

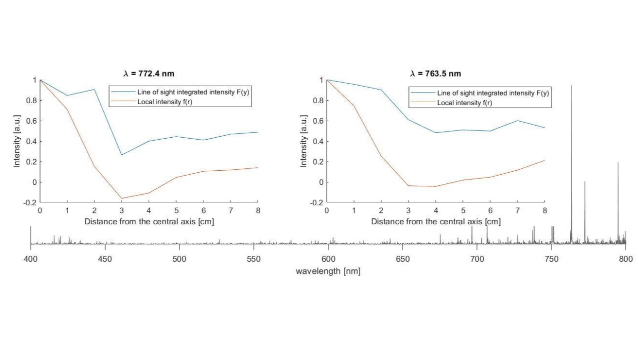

Figure 4: Comparison between LOS integrated measurements and calculated local intensity values for the wavelengths 772.4 nm (left) and 763.5 nm (right)

References

[1] G. Pretzler, A New Method for Numerical Abel-Inversion, Z. Naturforsch., vol. 46a, p. 639-641, 1991

[2] C. Walter, T. Sander, P. Smirnov, J. Schein, Ch. Mundt, Laser-induced Fluorescence for the Characterization of the Capacitively Coupled RF-Plasma Thruster C-STAR, 73rd International Astronautical Congress (IAC), IAC-22,C4,6,x69350, Paris, France, Sep 2022.

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