Io2 Documentation

Southampton University Electric Propulsion

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1 Introduction

Io2 is the natural successor of Io1 and builds directly from its legacy. Io1 was tested in February 2025 and was successfully ignited.

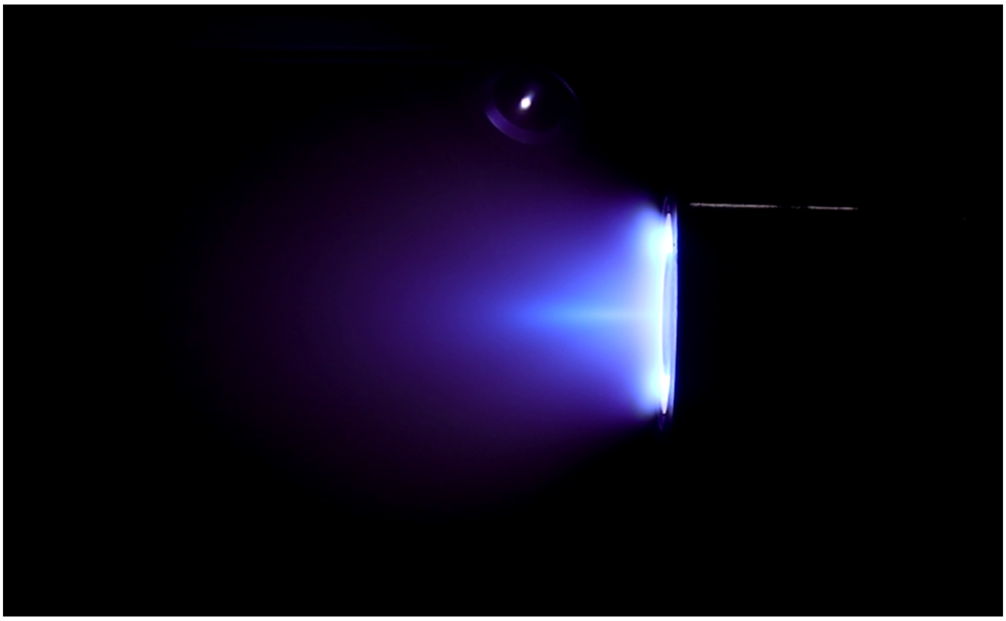

Figure 1: Io1 operating on Krypton gas at the David Fearne Electric Propulsion Labratory.

The thruster was unable to operate steadily, and so we were unable to acquire hard data points. Despite this, we can still infer certain aspects of its performance. Based on prior magnetic field tests, the magnetic field is lopsided, resulting in a non ideal field topology, since for optimum performance, the field should be mostly radial. This directly resulted in the plume being quite divergent, as shown in Figure 1, likely causing many ions to have significant non-axial components in their velocities and not contributing to the overall thrust of the engine. It can also be seen that the plasma appears very dense close to the exit plane of the thruster, indicating that most of the ionisation and acceleration is occurring closer to the exit plane, which could explain instabilities and poor performance. Because of this, for Io2, great care was taken to ensure a highly radial field with magnetic lensing to ensure the greatest performance by keeping the magnetic field strength lower in the channel. In addition, an effort has been made to attempt magnetic shielding to reduce wall erosion, thermals and improve overall efficiency.

Table 1: Input design parameters for Io2.

Parameter	Value
Nominal Discharge Power	$1000W$
Nominal Discharge Voltage	$300V$
Propellant	Argon
Project Budget	£1600

2 Channel Sizing

To size the cross-sectional discharge channel of a Hall effect thruster, it is common practice to utilise scaling laws. Often, a database containing geometric parameters along with performance metrics is used; in our case, we used Lee's database (1). The scaling laws derived can be used to define the mean channel diameter and channel width.

$$P = C_P d^2 V_d \tag{1}$$

$$h = C_{hd} d \tag{2}$$

In Equations 1, 2: P is the discharge power, C_P is the power scaling coefficient, d is the mean channel diameter $d = (d_0 + d_i)/2$, where d_i is the inside diameter, d_o is the outside diameter, V_d is the discharge voltage, h is the channel width and C_{hd} is the channel scaling coefficient.

The database used by Lee assumes all thrusters are operating on xenon and that in the centre of the channels have a peak magnetic field strength of $200G$; From this database, scaling coefficients were defined as $C_P = 633$ and $C_{hd} = 0.242$. Using the scaling coefficients, the channel variables are calculated to be $d = 72.6mm$ and $h = 17.6mm$ when using Table 1's parameters.

Thomas Munro shows the channel length to be inversely proportional to the first ionisation reaction rate coefficient in (2), in which he uses an analytical method to determine this quantity and relates it to the channel length by the following expression.

$$\lambda_i = \frac{v_n}{n_n \langle \sigma_i \nu_e \rangle} \ll L \tag{3}$$

Where λ_i is the ionisation mean free path in mm, v_n is the neutral velocity, n_n is the neutral number density, $\langle \sigma_i \nu_e \rangle$ is the ionisation reaction rate, and L is the discharge channel length.

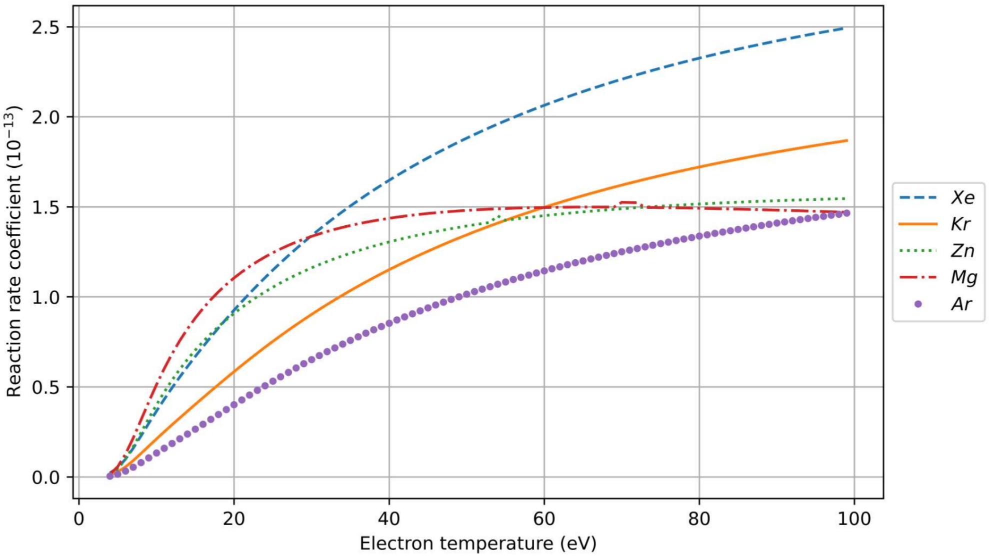

Figure 2: The calculated reaction rate coefficient against bulk electron temperature for propellants: Xenon, Krypton, Zinc, Magnesium and Argon (2)

$$T_{eV} = 0.12V_d \tag{4}$$

Using Figure 2 along with Equation 4, which shows the linear correlation between the averaged electron temperature, T_{eV}, in the discharge channel and the discharge voltage, V_d (3); An estimate of the reaction rate coefficient can be calculated. Taking the nominal discharge voltage along with several other assumptions made by Thomas in (2): $n_n \approx 1.2 \times 10^{19} m^{-3}$, which is an approximation for the number density of neutral particles in the discharge channel. The ionisation mean free path for argon can be calculated, $\lambda_i = 0.521mm$ where $T_{eV} = 36eV$. Comparing this to other thrusters from literature, it was decided to set the channel length, L to $35mm$, the channel is made longer than typical thrusters to give more time for ions to be formed, due to Argon's lower ionisation energy, while also satisfying Equation 3.

3 Magnetic Field Design

The goal of the magnetic field design is to create a sufficient magnetic field strength near a channel length away from the anode and provide magnetic shielding to maximise channel wall lifetime.

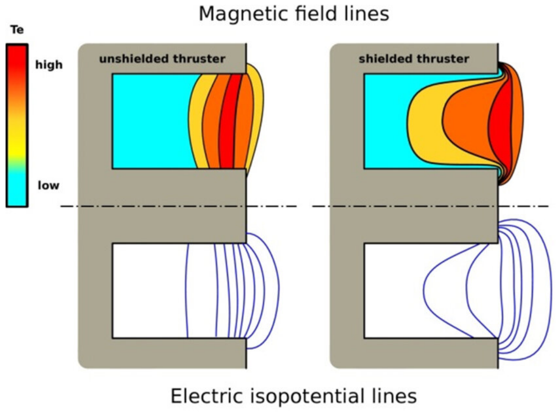

Figure 3: Magnetic Sheilding

4 Anode Design

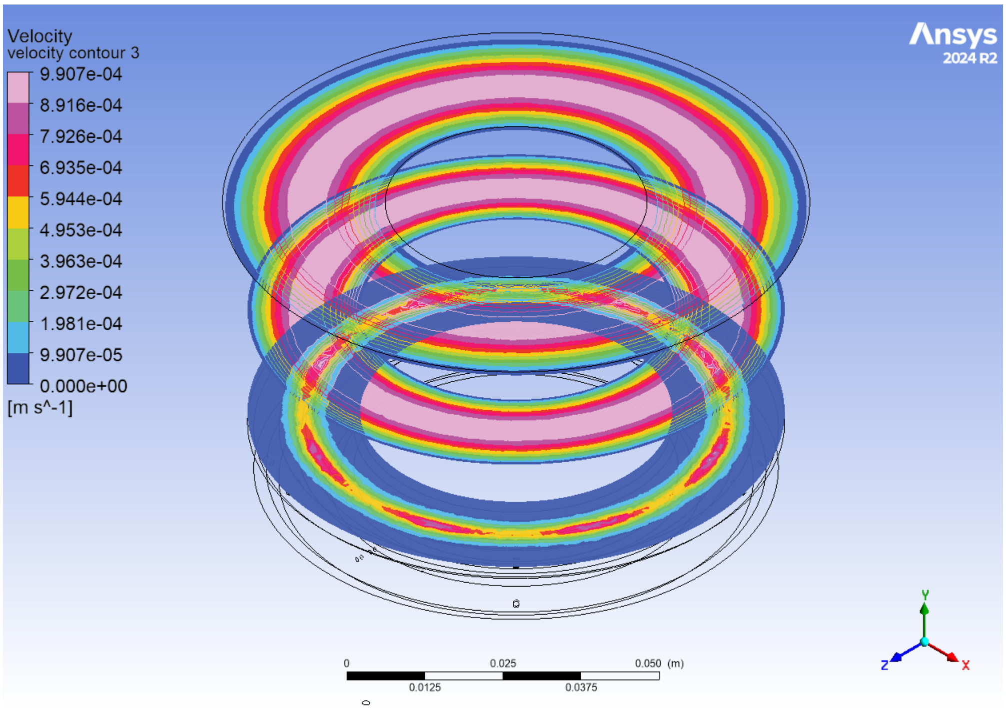

Figure 4: Figure showing the velocity contour distribution showing relatively uniform outflow.

5 Thermal Design

References

[1] E. Lee, Y. Kim, H. Lee, H. Kim, G. Doh, D. Lee, and W. Choe, "Scaling approach for sub-kilowatt hall-effect thrusters," *Journal of Propulsion and Power*, vol. 35, pp. 1–7, 08 2019.

[2] T. Munro-O'Brien and C. Ryan, "Design, manufacture and testing of a magnetically shielded krypton hall effect thruster," 03 2021.

[3] K. Dannenmayer and S. Mazouffre, "Elementary scaling relations for hall effect thrusters," *Journal of Propulsion and Power*, vol. 27, pp. 236–245, 01 2011.