

Xenon Ion Beam Detachment From a Helicon Double Layer Thruster

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Abstract—Ion magnetic detachment in the helicon double layer thruster exhaust beam is studied by calculating the orbits of the ions accelerated by the double layer and analyzing the curvature of the trajectories in the diverging magnetic field. An image of the detachment flux surface is presented for standard operating conditions, where a xenon ion beam has been experimentally observed. The results of the simulation are compared with that of the experiment.

Index Terms—Ion beams, plasma engines, propulsion.

A COMMON physical phenomenon in astrophysical plasmas and electric propulsion is particle detachment from a magnetized plasma. It has been studied theoretically [1] and, by computer simulation [2], in the context of plasma propulsion. The helicon double layer thruster (HDLT) is a new type of plasma engine based on ion acceleration in an electric double layer [3], [4]. In this paper, we present an image obtained from an analysis of ion detachment in the HDLT exhaust. The study is performed for xenon, and the computed results are compared with the experiment.

The HDLT is mounted on the Chi Kung chamber (Fig. 1), and the system has been previously described [4], [5]. The HDLT consists of a helicon plasma source made of a pyrex source tube surrounded by an RF antenna and two axial solenoids. The main axis is z , the thruster/chamber interface is located at $z = 30$ cm, and the current-free double layer forms at $z = 25$ cm. The high potential side is inside the HDLT, and the ions accelerated in the potential drop of the double layer form a beam which propagates to the right in the diverging magnetic field. The xenon ion beam has been measured experimentally in the exhaust of the HDLT, using a retarding field energy analyzer [5] positioned at $z = 37.5$ cm (Fig. 1).

The xenon ions are accelerated at $z = 25$ cm by a 25-eV double layer. Their orbits are simulated in the diverging magnetic field (~ 120 G at $z = 25$ cm to ~ 20 G at $z = 40$ cm), using a particle-trajectory method previously described [6]. The calculated curvature of each particle orbit [7] increases as a function of z to a maximum value before asymptotically approaching zero (no curvature). Detachment is defined as the

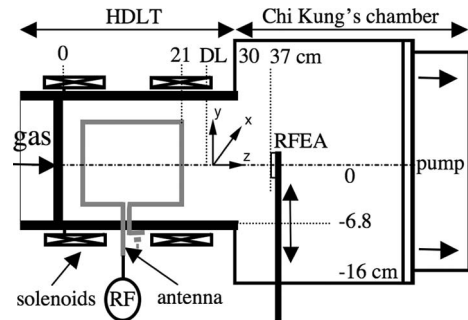


Fig. 1. Schematic of the experimental setup.

z position of maximum curvature. A polynomial interpolation based on 23 ion orbits with launch points r_i : $0.001 \leq i \leq 0.067$ m along the radial cross section $(r, z) = (r_i, 0.25)$ m is used, and the pitch angle of initial ion acceleration to the magnetic-field line is set at 0° . The result of the simulation is a detachment surface in the form of a “paraboloid” opening in the direction of the expanding plasma with its base positioned at about $z = 39$ cm, as shown by the image in Fig. 2. The computed beam radius at detachment is $r = 7.2$ cm, which is slightly greater than the internal plasma source tube radius of 6.85 cm, giving a beam divergence at detachment of 2° . The measurements of the ion beam profile at $z = 37.5$ cm, using an energy analyzer, gave a beam radius of less than 8 cm and a divergence of less than 5.7° [5], which are in good agreement with the present simulation.

The image provides additional information which cannot be easily obtained experimentally: The surface of the paraboloid is discontinuous at the magnetic axis, and the base of the paraboloid oscillates smoothly along r (x and y in Fig. 2).

In this paper, only orbital detachment is considered. Future studies will aim at including the faster transport of electrons and the associated ambipolar electric field. The pitch angle at the point of acceleration is an important parameter, which is related to the position of the double layer with respect to the magnetic-field configuration and the shape of the double layer itself. This parameter will be investigated in future studies.

In conclusion, an image of a detachment flux surface computed in the exhaust of an HDLT is successfully compared with the initial experimental results in xenon. Although there is a diverging magnetic field, the study shows that the main component of the ion velocity remains axial.

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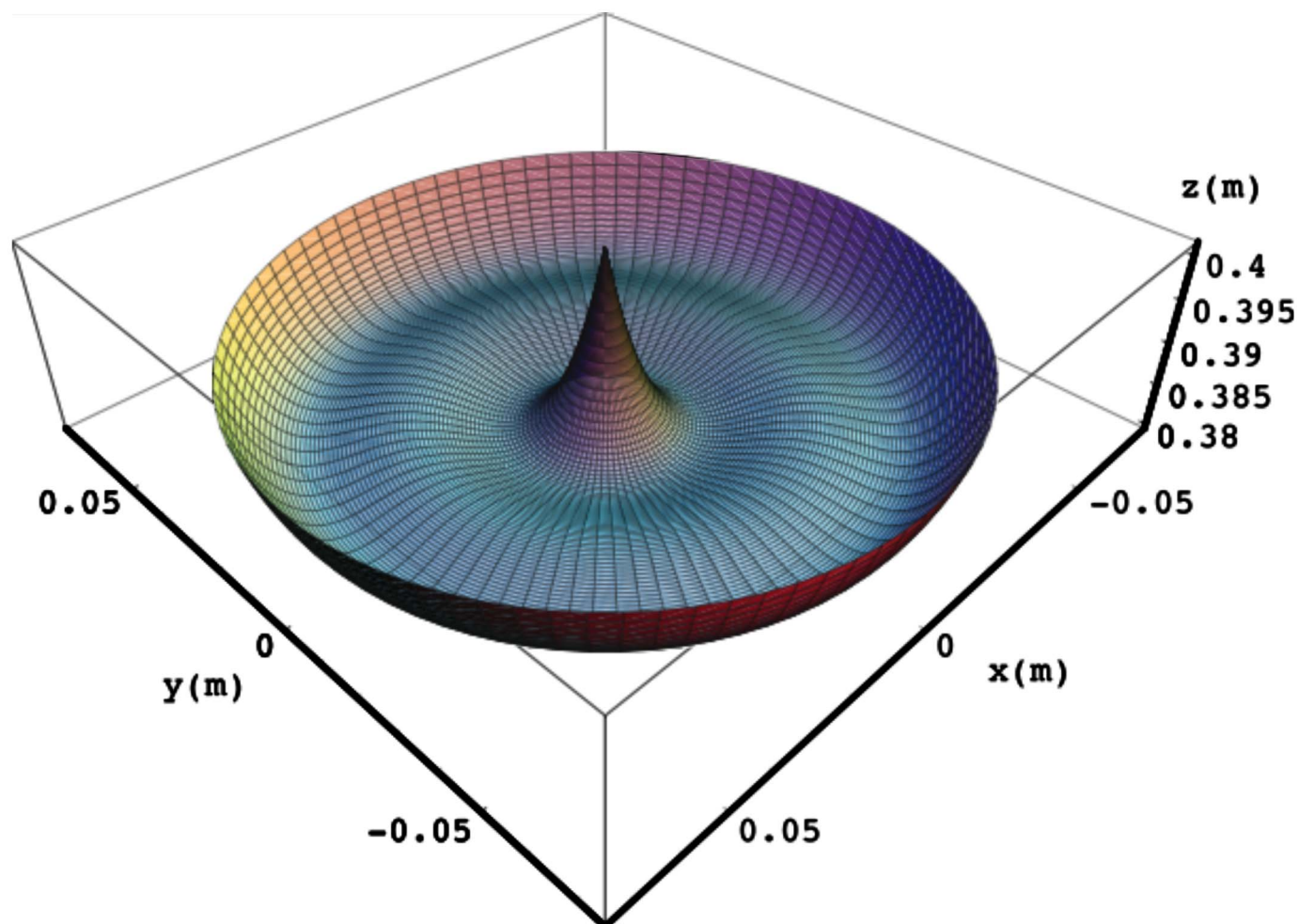


Fig. 2. Detachment flux surface of the xenon ion beam. x - and y -axis represent r , and the “paraboloid” has a radius of $r = 7.2$ cm. Its base is located on average at $z = 39$ cm, which is the position of detachment. The scale of $z:r$ is 2:1 to highlight the shape of the surface, which is discontinuous at the magnetic axis.

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