Beam Diagnostics for Mini Ion Engines

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Abstract: Mini ion engines are going to have a broad field of applications as they will provide the possibility of accurate fine positioning in space and a precise control of attitude. Strict requirements in terms of position and attitude control are defined for many future missions in science and earth observation and it needs to be proved that these can be fulfilled by the mini ion thrusters. For example in earth observation based on formation flying for monitoring the earth gravitation field, a very high thrust dynamic range of up to 100 is needed.

Not only the design of a thruster suitable for fulfilling such needs is challenging, but also the design of a corresponding detector system which can cope with the high dynamics of the beam. Such detectors shall deliver information about the divergence and the energy distribution of the beam. Only if these beam parameters are known, the exact thrust can be calculated. Moreover, in the special case of a radio-frequency ion thruster (RIT), the mean electron energy inside the plasma can be derived from the ion energy distribution of the beam. This leads to the great advantage of measuring plasma parameters without any perturbation of the plasma itself.

For a very precise scanning of the beam profile we developed a linear Faraday-cup array which is mounted on a moving crank. The special alignment of the cups is optimized for high resolution scanning of the beam of a μN RIT.

Nomenclature

F = total thrust
I = total beam current
U = extraction voltage
η_{div} = divergence efficiency
φ_{div} = divergence angular
ϑ_{95} = angle of beam with 95% of beam current

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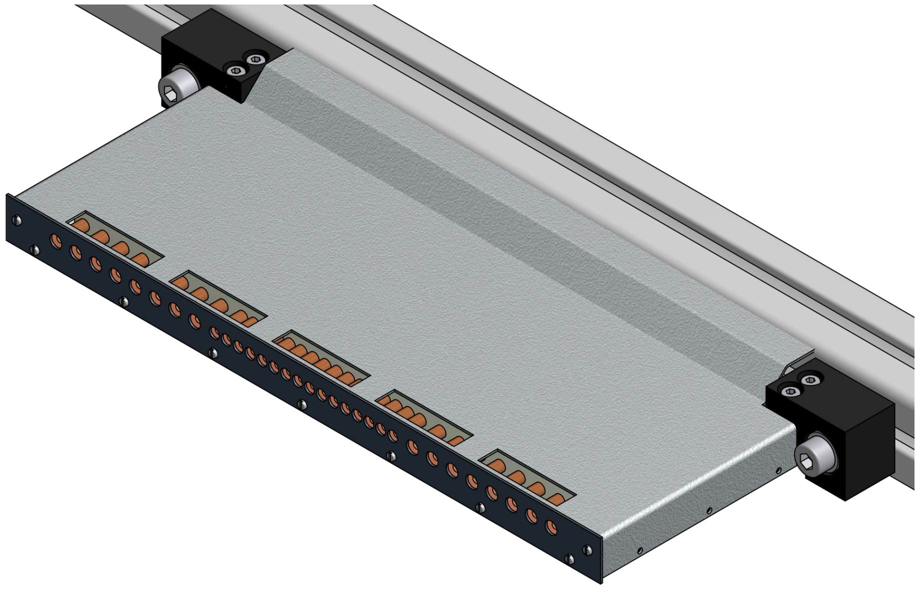


Figure 1. Detector-array with 32 Faraday-sensors and integrated electronics

I. Introduction

This proceeding shows and describes the latest activities in detecting ions in the plasma plume of our μN RIT at the University of Giessen.

II. System at the University of Giessen

At the University of Giessen we build up a new linear array of beam-sensors. The system consists of 32 Faraday-cups, which are aligned in parallel. Each sensor has its own channel to measure the collected current and to digitize the analog signal. The complete electronics is mounted behind the 32 sensors and protected by a metal case (see Fig. 1). In order to measure the complete beam profile one has to move the whole detector around the truster. For this purpose we developed a new moving crank, which moves very precisely to every desired measuring point. Furthermore we wrote a program to perform each measurement fully automatic - the development of the code for deriving all contents from the measured data is under progress and has to be integrated.

III. Evaluation of Raw Data

A. Sources of Error

As can be seen in Fig. 2 each channel of a Faraday-detector looks very simple: it consists of a small cup, which collects all ions flying through an aperture orifice in front of the cup and an electronic circuit, which detects the small current. In the case of our μN RIT we detect currents between a tenth of a nanoampere up to one microampere.
All Faraday-cups need a protection against incoming electrons, and secondary electrons or charged particles which want to escape the inside of the cup. Both effects are affecting the measured current. To eliminate these effects we installed an aperture orifice, to which a negative potential is applied. A secondary grounded aperture is in front of the negative one. This aperture shields most of the negative potential towards the outside of the detector and guards the inside of the detector against the ion beam.

At last we have to consider some possible errors and to correct the measured raw data.

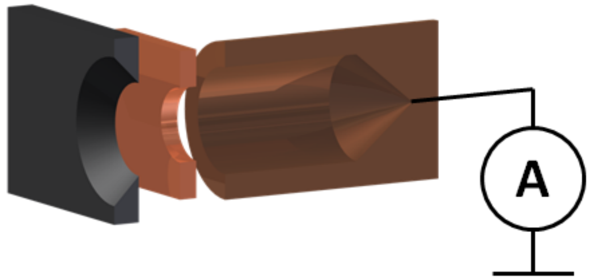


Figure 2. Schematic drawing of a Faraday-sensor

Each channel of the electronic has to be calibrated separatly, otherwise we cannot compute the total beam current. In addition the electronic has to detect the current in a short period of time, because the detector is moving through the beam.
It should be noted that the observable in the measurement is not a current, but a current density. Because of the aperture hole in front of the Faraday-cup, all detected ions fly through a well defined area. So by dividing the measured current by the opening area of the entrance orifice this observable can be obtained on principle. However, care needs to be taken to account properly for the orientation of this area towards the thruster. If all entrance orifices are perpendicular to the ion velocity, the situation is simple and no angle correction is required. In all other cases correction factors need to be derived depending on the geometric opening area, the depth of the aperture hole and the distance between sensor and centerline of the beam.

B. Content of the Data

The geometry of the detection arrangement is the following. Assuming that the center of the thruster exit is located in the origin of a cartesian coordinate system such that the center of the ion beam defines the x-direction, then the central Faraday-cup of the linear array is positioned at a distance r along the x-direction from the exit fully facing the beam. The array itself is aligned parallel to the z-direction. The measurement takes place by moving the array in a circle with radius r about the z-axis such that the central cup remains in the xy-plane. During that movement the central Faraday-cup, with its aperture opening being always perpendicular to the central beam direction, directly records the complete radial distribution of the beam current density (see Fig. 3). If one assumes that the beam profile possesses rotational symmetry about the x-axis, the radial distribution of the beam current (see Fig. 4(a)) and the total beam current can be calculated directly. As the other Faraday-cups are located on the tangent to the sphere with radius r and are not facing the origin of the coordinate system, their readings are no direct measurement of the radial current density at their position. Their readings need to be corrected for the geometry. However, taking these readings allows one to verify that the middle cup is indeed moving in the xy-plane during the data acquisition.

The total beam current I is directly proportional to the thrust F of the thruster

$$F = I\sqrt{2\frac{m}{q}U} \tag{1}$$

where m and q are the mass and the charge of the accelerated ion and U is the acceleration voltage. Using Eq. 1 we assume that the ion energy is constant for all ions and shows no angular dependence. The derivative of the radial distribution contains the information how much current leaves the thruster in a specified direction (see Fig. 4(b)). Using this information the divergence efficiency η_{div} can be calculated

$$\eta_{div} = \frac{\sum F_i \cdot \cos\varphi_i}{\sum F_i} \tag{2}$$

where F_i is the part of thrust in the direction φ_i. Using this divergence efficiency the divergence angle φ_{div} can be calculated

$$\eta_{div} = \cos\varphi_{div} \tag{3}$$

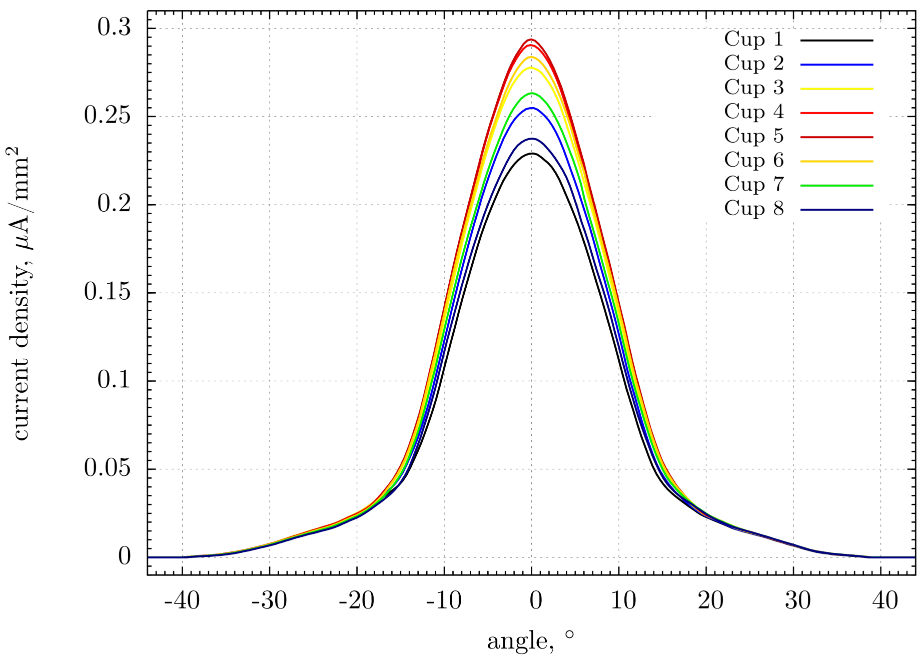


Figure 3. Radial distribution of the beam current density the so called beam profile (measured with eight Faraday-cups)

Furthermore we can derive the angle of beam, which contains a part of the total beam current. For example ϑ_{95} means the angle which contains 95% of the beam current.

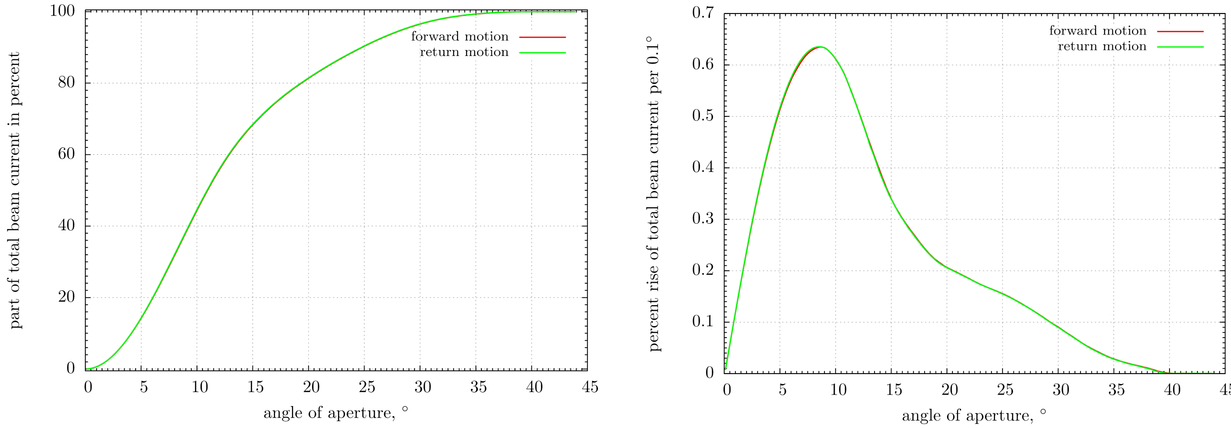
Another interesting question is the center of thrust called thrust vector. The thrust vector can be calculated using the two-dimensional array of current densities. This array can also be used to generate a miscolored image of the whole beam as shown in Fig. 5. All measurements shown in this section were done by the precessor system - instead of the new one it consists of eight Faraday-sensors only.

IV. Outlook

With the new detector system it will be possible to gain more information about the ion beam leaving the thruster in the outside sectors below and above the great circle. Furthermore in the middle of the detection area the density of the sensors is increased by the factor two. Based on this additional information about the beam profile, it will be possible to perform a more precise determination of the thrust vector.

In the long run, we hope to find a correlation between ions out of the plasma and charge exchange ions created in the extraction channels.

In addition to the existing system the beam diagnostics will be improved with a retarding potential analyzer (RPA) yielding additional information about the ion energies. Thus, it will be possible to fully determine thrust and thrust vector.



(a) radial distribution

(b) radial incresement

Figure 4. Radial distribution of the beam current

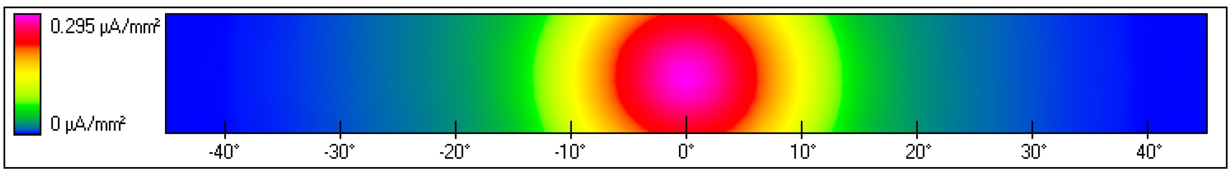


Figure 5. 2D-plot of the beam profile

Acknowledgments

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