Ion Beam Transport in Discharge Channels: Interpretation of Experimental Results*

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Discharge plasma channels are of interest for the current and space charge neutralized transport of intense ion beams for various applications. The channel transport in laser initiated discharges is currently studied at GSI [1]. In a series of experiments an uranium beam from the UNILAC with 11.4 MeV/u was transported through the 50 cm channel and was stopped in a fast scintillator behind the discharge. The picture at the left hand side of fig. 1 shows the force free drifting beamlets that are formed by a mask in front of the channel before the discharge is ignited. The mask consists of two perpendicular lines of 1-mm diameter holes with a distance of 2 mm between holes, forming a cross with the central hole missing. Three holes are drilled on each side, only two are visible, the last hole is clipped by the aperture in the cathode in front of the scintillator. An additional beamlet in the lower left sector serves to identify the orientation of the mask. The other seven pictures are taken at different times during the discharge with an exposure time of 100 ns. The exposure time, total

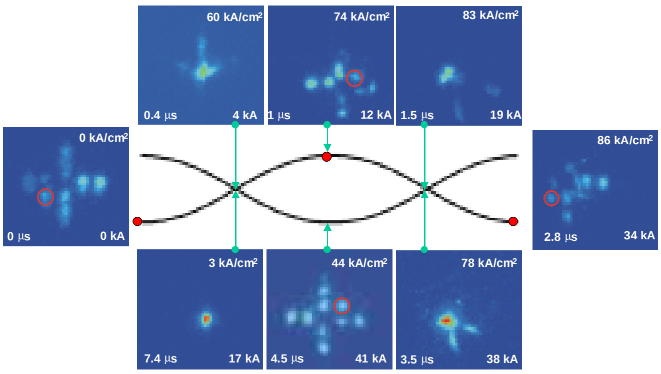

Figure 1: Image of the pepper-pot mask on the scintillator at different times during the first half wave of the current pulse

discharge current, and current density at exposure time are marked on the pictures. A representation of the betatron oscillation of the beamlets in the channel is shown in the center of fig. 1. The position of the asymmetric beamlet is marked by a dot. Arrows show at what phase of the oscillation the beamlets were intersected by the scintillator at the end of the discharge channel depending on the sinusoidal discharge current waveform. From the distortion of the image at 0.4 µs where a focal spot is expected, and at 1 µs where an inverted image is expected, it is obvious that the focusing field is nonlinear. At 1.5 µs the focusing is more linear and due to the expanding radius of the discharge channel the outermost beamlets become now visible as blurred spots below and right of the central spot. At a radius of 6 mm these beamlets were focused mainly in the decaying nonlinear magnetic field surrounding the discharge channel. At 2.8 µs the beamlets have performed a full betatron oscillation and the image of the mask is inverted twice. The outermost beamlets appear again as two blurred lines in the lower right sector of the cross. Although the total current is still increasing the current density and bending power of the channel is decreasing at 3.5 µs. The second focus is visible, the outermost beamlets show up more clearly now because the channel has expanded further and these beamlets were only for a short distance focused in the nonlinear field surrounding the channel. The peak current of 41 kA is reached at 4.5 µs, but due to the rapid expansion of the discharge channel the bending power is further decreasing so that the inverted image of the mask becomes visible again. At 7.4 µs the first focal spot appears again on the scintillator. By that time the channel has expanded to a diameter of more than 2 cm and the small size of the focus indicates a very linear field in the channel.

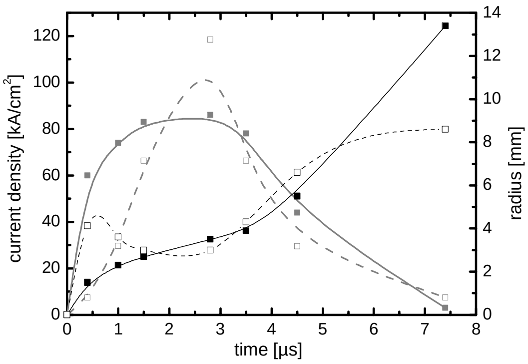

Figure 2: Development of current density and channel radius for a discharge in 17 mbar NH_3. Dashed lines are inferred from the beam transport assuming a homogeneous current distribution, solid lines from direct measurements.

An interpretation of the transport results is given in fig. 2. Measurements of the discharge current were evaluated together with framing pictures of the discharge channel to determine the discharge radius and the current density. For a first simple modelling the FWHM value of the light emission from the channel was assumed as the width of a homogeneous current distribution. The resulting radius and current density are plotted as solid lines in fig. 2.

$$J = \frac{2\pi\Re}{\mu_0}\left(\frac{kL}{L}\right)^2 \qquad (1)$$

Assuming again a homogeneous current flow in the discharge a current density J was determined according to equ. 1 from the phase of the beam betatron motion of the beamlets from fig. 1 with the beam rigidity $\Re$ and a phase kL of the betatron oscillation at the end of a channel with length L. For the first focal point, the inverted image, the second focus, and for the twice inverted image the phases of the oscillation are $\pi/2$, π, $3\pi/2$, and 2π respectively. The current density from equ. 1 and the resulting discharge radius are plotted in fig. 2 with dashed lines. Deviations during the first microsecond can be explained by the skin effect in the discharge, deviations at the end of the current half wave are probably due to the inverse skin effect [2].

References

[1] A. Tauschwitz et al. Proc. Int. Conf. on Inertial Fusion Sciences and Applications (IFSA), Bordeaux, 521 – 526 (1999)

[2] M.G. Haines, Proc. Phys. Soc. **74**, 576-586 (1959)

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