Calculation of the Current Density Distribution in a Plasma Lens to Produce Ring-like Ion Beam Profiles

S. Hakuli, U. Neuner
GSI Darmstadt and Institut für Kernphysik, TU Darmstadt

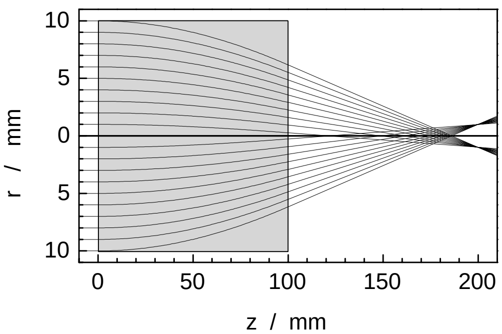

Figure 1: Schematic of focusing a 10 mm radius parallel ion beam into a 1 mm radius ring with a 100 mm long plasma lens with a negative radial gradient of the current density and a 100 mm long drift length.

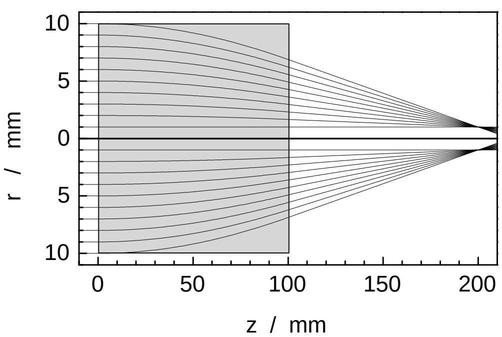

Figure 2: Same as Fig. 1 with a positive radial gradient of the current density.

A good understanding of the shaping of intense ion beams into hollow cylindrical form [1] was achieved by interpreting the experimental data [2] with numerical calculations.

The ion beam is shaped in a plasma lens, where an axially directed current produces an azimuthally directed magnetic field. In this field the ion trajectories of an initially parallel beam are bent towards the axis. This allows for the two focusing schemes plotted in Figs. 1 and 2, where all ion trajectories between 1 and 10 mm initial radius converge into a ring in the focal plane 100 mm after they exit from the plasma lens.

We simulated this focusing for a zero emittance beam in paraxial approximation. Since ions pass through radial regions of different focusing strength inside the plasma lens, the calculations were performed as follows: We divided the plasma lens into 100 thin slices, in which the radial variation of the trajectory is so small, that the focal strength can be approximated to be constant. The shape of the trajectories results from a calculation of the Lorentz force inside the plasma lens' slices. The radial current density distribution is discretized into shells of constant values. Increasing in radius one-dimensional nonlinear optimizations yield these values for the two focusing modes as mentioned above.

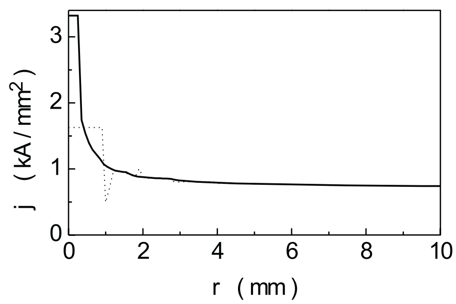

Figure 3: Current density distribution in the pinch mode.

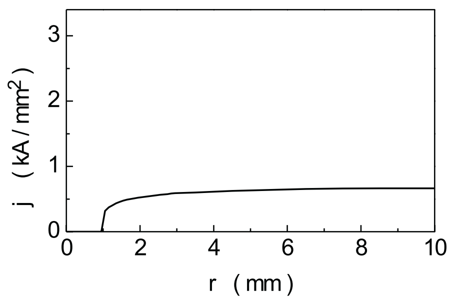

Figure 4: Current density distribution in the skin mode.

The solid curve in Fig. 3 shows the calculated current density in the plasma lens as a function of radius, that leads to focusing into a ring as shown in Fig. 1. Such a negative radial gradient can be realized in a pinch-like discharge. The dotted curve is also a valid solution for this focusing, however it seems unlikely to be realized in any known discharge. The current density in Fig. 4 corresponds to the focusing mode shown in Fig. 2. Positive radial gradients like this can be realized in skin effect dominated discharges.

With these results we now can experimentally optimize the plasma lens to produce ideal hollow cylinder shaped beams. They are required by the future experiments [3, 4, 5, 6].

References

[1] U. Neuner *et al.*, Phys. Ref. Lett. **85**, 4518 (2000).

[2] U. Neuner *et al.*, GSI-2000-1, 127 (2000) and GSI-2000-2, 3 (2000).

[3] D. A. Callahan-Miller and M. Tabak, Nucl. Fusion **39**, 1547 (1999).

[4] D. A. Callahan-Miller and M. Tabak, Phys. Plasmas **7**, 2083 (2000).

[5] N. A. Tahir *et al.*, Phys. Rev. E **62**, 1224 (2000).

[6] N. A. Tahir *et al.*, Phys. Rev. E **63**, 016402 (2001).