Ion Beam Extracted from a 14GHz ECRIS of CAPRICE Type

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Abstract An ion beam extracted from an ECRIS suffers from the inhomogeneous distribution of cold electrons within the minimum B configuration, necessary to confine the plasma. Especially for higher ion currents, the space charge force is not negligible any more, and because of the nonlinear force, emittance growth will occur.

Measurements of the profile and the emittance of the beam directly behind the source show the complicated correlation between extraction voltage and plasma density. The emittance has been measured with a pepper pot device to account for the inhomogeneous azimuthal distribution of the beam. These results indicate that further information about the profile is required. To visualize the beam profile a tantalum foil with a thickness of 20μm has been used for an electrical beam power between 10 and 50W. Looking on the back side of the foil with a CCD camera it is possible to record the profile in real time. As a more sensitive diagnostic tool viewing targets made from BaF has been used.

Three dimensional computer simulations have been used to identify the reason for the structures, observed in measurements.

Key words ECRIS extraction, extraction simulation, beam profile

1 Introduction

To optimize the beam transport at the high charge state injector (HLI) at GSI, especially with respect to the upgrade plan to equip the injector with a 28GHz ECRIS[1], beam parameters for different ion source settings of our ECRIS of CAPRICE type have been measured. These measurements have been performed at our test facility EIS[2], which is exactly the same setup as at the HLI. The test bench shown in Fig. 1 is equipped with Faraday cups, grids, and a horizontal, moveable slit behind the dipole to provide the required resolution of the beam line. To improve the diagnostics, we have installed additional pepper pot devices directly behind extraction and behind the analyzing magnet to measure the beam emittance, and viewing targets (VT) to display the beam profile. These measurements should clarify general properties of ion beam extraction, as predicted by simulation[3].

2 Experiment

The source has been operated in cw, with argon and helium as working gas, and support gas. For several experiments we have also used oxygen and nitrogen, but no significant differences have been observed. To heat the plasma our regular 14.5GHz klystron generator has been used.

The ion beam is extracted from the ion source with an accel-decel extraction system and focused by a magnetic solenoid lens. The beam leaving the intermediate focus is then vertically focused and horizontally defocused by a magnetic quadrupole singlet, and analyzed by a 135° magnetic dipole spectrometer. A first order layout is given in[2].

Viewing target VT1 is installed 25cm behind

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the extraction system, VT2 is located between the solenoid and the quadrupole singlet, and VT3 is placed behind the 135° spectrometer close to the position of the resolving slits. A pepper pot emittance meter has been installed directly behind the extraction system; a second device is located behind the spectrometer.

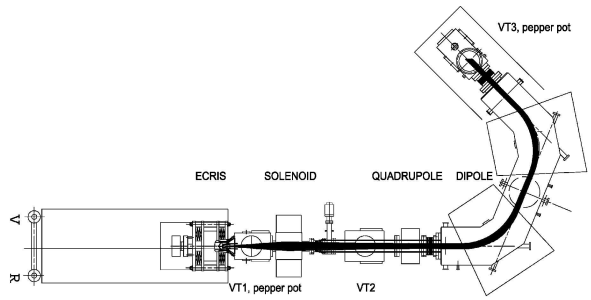

Fig. 1. EIS test bench with simulated 3D-beam envelope.

Instead of using the slit-grid method to measure emittance, the pepper pot method was preferred because the beam is not cylindrically symmetric and we wanted to investigate the full spatial and angular distribution. For the same reason we selected viewing targets instead of grids. Using grids leads to an integration along the wires, so that the information about the particle distribution of the beam in both real space and in phase space is lacking.

The pepper pot consists of an arrangement of 11 holes in horizontal direction and 11 holes in vertical direction and five holes in both diagonal directions. Each hole has a diameter of 0.2mm, separated 5mm from each other. 50mm behind the pepper pot a foil made from polyimid is exposed to the beamlets. This device has a limited resolution, but it is very easy to use. A new pepper pot device with higher resolution and CCD-readout is under development[4].

After performing the first pepper pot measurements behind the dipole magnet, shown in Fig. 2, it was decided to do corresponding measurements directly behind the extraction system, because the interpretation of the first measurements was not clear.

Again, an interpretation of the measurement (see Fig. 3) seemed to be impossible, and it was decided to record the profile at the same location. We started with a 20μm tantalum foil, clearly confirming that the beam is not of cylindrical symmetry (Fig. 4).

Due to the thermal conductivity the resolution of such foils is limited; therefore we replaced them by viewing targets made from BaF.

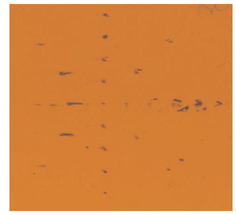

Fig. 2. Pepper pot figure of a He^+-beam behind the spectrometer.

Fig. 3. Central part of the pepper pot figure of a He^+-beam behind extraction. Extracted ion current 5mA.

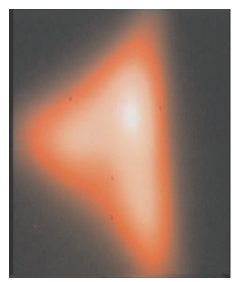

Fig. 4. Ion beam on a tantalum foil after extraction. Extracted ion current 5mA.

These targets gave excellent information and turned out to be very useful, even if life time and linearity are limited. The viewing target has an angle of 45 degree with respect to the beam in vertical direction to allow recording the front side of the target with a CCD camera. The step responses of the beam have been recorded while changing one selected source parameter (gas pressure, rf power, magnetic field settings), or extraction parameter (extraction voltage, extraction gap width, screening voltage). Beam response to ramping a selected beam line magnet was also recorded.

In Fig. 5 the argon gas pressure at the gas inlet has been changed from low pressure (10^{-7}mbar range) to higher pressure (several 10^{-6}mbar range). The other gas inlet, providing the helium working gas, was closed in this experiment. The extraction voltage with 15kV and the screening voltage with -2kV, as well as all other source parameters were kept constant. By changing the neutral gas density, plasma parameters like the charge state distribution and the total extracted current are influenced. However, in this experiment the influence of these parameters on the plasma boundary was shown to be important. Its shape should change from concave to convex with increasing plasma density: for two different plasma boundary conditions two triangles of different orientation can be observed. This could be explained by a lens effect of different focal lengths. These both objects, the triangle from the front side and the triangle from the back side will be focused at different places. It could also be explained in part by a sign change in the magnification.

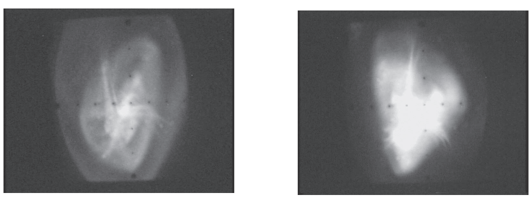

Fig. 5. Influence of gas pressure on the beam profile at the first VT1.

Fig. 6. Image on VT2 behind the solenoid, different charge states can be distinguished by different focusing.

With VT2 it is possible to investigate the profile for different charge states separately. Depending on the solenoid strength different structures were focused sequentially. This is shown in Fig. 6 and Fig. 7, where a small change in focusing results in a strong change of the beam shape. Each outer ring represents a different charge state. Higher charge states are over focused. The solenoid strength for different charge states is proportional to the square root of the mass to charge ratio of the extracted ions, as shown in Fig. 9. It should be pointed out, that the image of each charge state appears similar if they are focused properly.

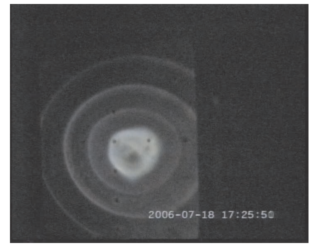

Fig. 7. Image on VT2, but different solenoid strength.

With VT3 the beam could be displayed after mass to charge separation by the magnetic dipole spectrometer, see Fig. 8. In this figure the influence of the screening electrode is shown: the voltage is set to zero (left) and to -2kV (right).

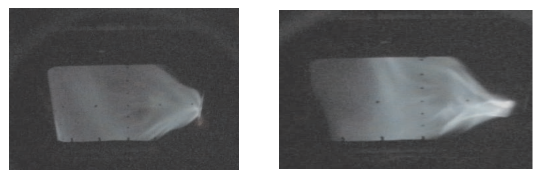

Fig. 8. Analyzed beam of one selected charge state on VT3. The screening voltage is set to zero in the left figure, and to -2kV in the right figure, respectively.

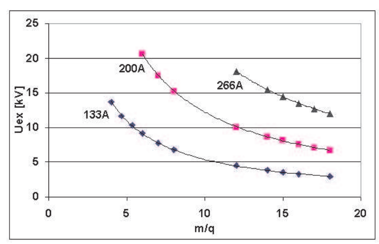

Fig. 9. Required extraction voltage for different m/q ratios. Three individual magnetic flux densities are shown.

Close to -700 volts, which is sufficient for the actual source parameters to screen electrons from backstreaming to the source, the beam profile changes: the structure becomes sharp when the space charge compensation is preserved.

There are clear indications that the extracted beam has a certain structure in beam intensity distribution on the viewing target. Depending on the optical properties of the beam line this structure might be transferred in a different sub space. Furthermore, some figures lead to the assumption, that the beam is extracted from a hollow volume. It seems that only ions from a certain shell surrounding the plasma are extracted. This assumption has been used successfully in the simulation, as shown in Fig. 11.

If the extraction voltage is not a free parameter, a moveable extraction gap is necessary to have the possibility to adjust the plasma boundary. The positive action of such a device which has been already demonstrated[1] can now be visualized.

With the information of the profile of the beam as shown in Fig. 8, the pepper pot emittance results shown in Fig. 2 can be interpreted. The left part of the beam in Fig. 8 is horizontally defocused, whereas the right part of the beam is focused.

3 Simulation

With the information obtained experimentally, it became clear that the full plasma chamber has to be taken into account for the simulation of the extraction system and following beam line. Ions are started everywhere in the plasma chamber as long as the condition $|B|\min<|B|<|B|\max$ is fulfilled (Some lines of constant flux density between 0.9T and 1T are plotted in Fig. 10). Inside the plasma chamber these ions are mainly guided by the magnetic flux density. The electric potential drops from plasma potential to source potential at the plasma boundary.

In the simulation it has been investigated from which places inside the plasma chamber ions could be extracted. Only these ions are plotted in the right column in Fig. 11. It is found that depending on the location within the plasma chamber different starting conditions are required to contribute to the extracted beam. We assume that the structures, found experimentally can be explained by this effect. This assumption would require either that the mean free path length is large compared to the plasma dimension or the ions are so as strongly magnetized, that collision effects can be largely neglected. If this assumption is correct, a flat plasma boundary would be favorable. Any other shape would produce a different object size for the ions coming from different regions, increasing the emittance.

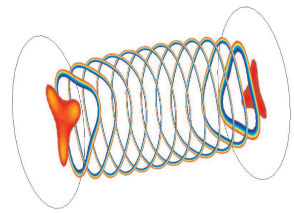

Fig. 10. The hollow volume from where ions are started in the simulation is colored.

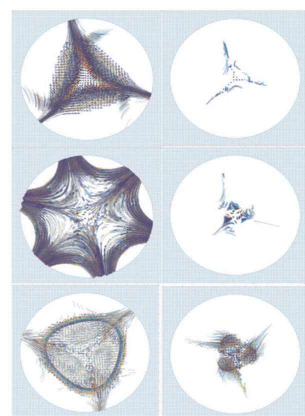

Fig. 11. Different cuts through the plasma chamber: injection side (top row), mid of plasma chamber (second row), extraction side (bottom row). The left column shows all trajectories, whereas the right column shows extracted ions only.

4 Conclusion

The extracted ion beam has a density structure reflecting the start distribution of the ions: two triangles could be observed simultaneously, indicating their origin. This fact has to be taken into account for the design of the beam line, as well as in particle tracking simulation.

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