

EXPERIMENTS WITH VIEWING TARGETS FOR ION BEAMS FROM ECRIS

P. Spädtke, R. Lang, J. Mäder, F. Maimone, J. Roßbach, K. Tinschert, GSI Darmstadt, Germany
J.W. Stetson, MSU Michigan, USA

Abstract

Electron Cyclotron Resonance Ion Sources (ECRIS) are increasingly used as ion source for different types of accelerators because of their high current densities for highly charged ions. To increase the available current densities further, the frequency for electron heating has to be increased as well as the magnetic flux density within the ion source to improve the plasma confinement. With increasing magnetic flux density the influence on the extracted ion beam becomes severe.

To investigate the ion beam quality, normally delivered to the RFQ of the high charge state injector at GSI, we had the chance to install a viewing target close to the position of ion beam injection into the RFQ. The profile visible on the viewing target could be recorded through a regular glass window by a video camera outside the vacuum.

At that beam line a CAPRICE type ECRIS with 14.5 GHz and about 1 T flux density in the extraction was used to deliver different Argon charge states for the measurements. The beam line consists of a solenoid, a quadrupole singlet, a 135°-dipole, a quadrupole triplet, and another solenoid for ion beam matching to the RFQ. Ramping single beam line elements and simultaneous observation of the beam shape on the viewing target can contribute to a better understanding of the process of ion beam generation. We have found a highly structured ion beam distribution at that position. These structures caused by the hexapolar field within the ion source have already been observed directly behind extraction. They are transported through the beam line without becoming homogeneous, which indicates a high degree of space charge compensation for that cw-beam.

If the beam line is mastered by the dipole, all charge states show similar ion beam distribution on the target for a given extraction voltage. This is also a hint, that the structures already have been produced inside the source.

INTRODUCTION

Matching of an ion beam extracted from an ECRIS to a quadrupole transport channel requires specific ion-optical elements, otherwise ion losses are to be expected. Horizontal and/or vertical slits are typically used in low energy beam lines to collimate the beam, however, for ECRIS beams such devices do not behave as expected. To diagnose this specific behavior, viewing targets were essential, even if their life time is rather limited with increasing power of the extracted beam. This power can easily reach several

100 W directly behind extraction, but it will drop already after the first solenoid due to different focusing strength for different mass to charge ration. The information which can be obtained from these viewing targets, especially if optical elements can be used to produce a so called BRF (beam response function) is worth their usage.

The symmetry given by an ECRIS, defined by the magnetic structure of two solenoids and a hexapole, has to be transformed to the symmetry requirements given by a quadrupole channel. One possible option is to transform the ECRIS beam into a round, azimuthally independent beam before alternate focusing is applied. A possible compensation device is shown in Fig. 4.

It has to be proven whether the influence of the magnetic field can be theoretically compensated. For example, the error given by the fact that the ions are generated within the plasma confined by a certain magnetic flux density the integral $\int \vec{B} ds$ will not vanish, its influence cannot be compensated; twisted trajectories are caused by this fact.

Viewing targets have shown clearly, that a 120°-symmetry exists inside the beam. This symmetry is given by the combination of hexapole and the radial field of both ion source solenoids:

$$B_{rad} = B_{rad,hex}(r, z, \phi) \pm B_{rad,sol}(r, z) \quad (1)$$

The sign in equation 1 indicates the difference of the magnetic flux density distribution between injection side and extraction side of the plasma chamber. Because the hexapolar field does not increase linearly with radius, this field component is a reason for emittance growth. To remove the influence of the hexapolar field, the transversal phase space projection of the beam has to have such a distribution, that the action of the magnetic field of the hexapole compensate the nonlinear behavior. With the focusing strength of the first solenoid and with the distance between the first solenoid and the hexapole matching of the beam to the correction element should be possible. All other than the required mass to charge state will be attenuated by that first solenoid [1]. The correction hexapole needs to be rotatable, to counteract the azimuthal movement of the ion beam caused by the solenoidal fields. The hexapole field for the correction should be able to reach 0.1 T at a radius of 10 cm with an effective length of 10 cm. Because the necessary diameter could be as small as 50 mm the device can be designed normal conducting. In the ideal case, the corrected beam should not show any aberrations any more.

MEASUREMENTS

The ion beam extracted from an ECRIS of CAPRICE type has been measured with viewing targets at different locations: directly behind extraction within the extraction box, behind the first solenoid, after the bending magnet in the plane of horizontal focusing, see Fig. 1. These results have been published elsewhere [2]. This time we measured the profile directly at the place of injection into the RFQ. The RFQ has been removed and replaced by a diagnostic chamber for this measurement.

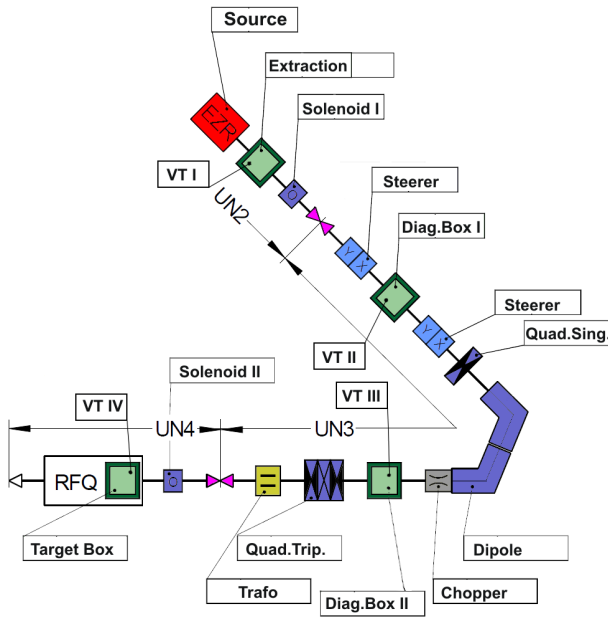


Figure 1: Existing beam line without any matching showing the location of the different viewing targets.

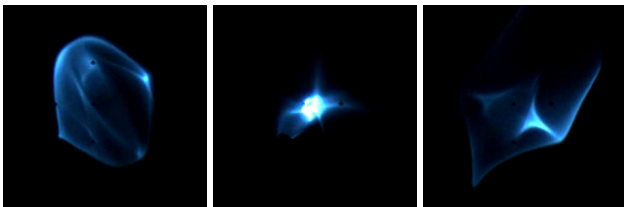


Figure 2: Ion beam profiles at the location of injection into the RFQ with increasing focusing strength of the second solenoid from left (-30%), center (optimum focusing), to right (+20%).

The structure of the ion beam at the place of injection shown in Fig. 2 is already known from earlier measurements at different locations, it has been originated already within the plasma chamber of the ion source [3]. This assumption is also supported by the fact that different charge states reveal similar behavior on the viewing target, when the ion source remains unchanged as shown in Fig. 3. Only

the beam line setting is modified according the selected charge state.

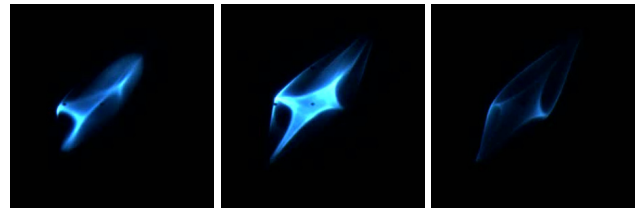


Figure 3: Ion beam profiles for different charge states: left Ar^{9+} , middle Ar^{7+} , and right Ar^{5+} . Ion source settings were not changed. The beam line magnets were scaled by the dipole setting. Extraction voltage was 20 kV.

Using the solenoid in front of the viewing target the following sequence is shown in Fig. 2: under focused, focused, over focused. The quality of the beam should be possible to improve if these structures could be removed from the beam.

HEXAPOLE COMPENSATION

The general scheme for compensation is to focus the divergent beam extracted from an ECRIS with a solenoid to create the correct phase space orientation at the location of the hexapole. The variable focusing strength of the first solenoid and the variable distance between first solenoid and hexapole can be used to control beam diameter and beam divergence angle separately within a certain range. To inject the corrected beam with increased divergence angles into a quadrupole channel, a second solenoid should be used to form a parallel beam again. A possible layout of such a compensation scheme is shown in Fig. 4. In addition, this second solenoid could be used to compensate the azimuthal rotation of the ion beam within the first solenoid by a reversed polarity of the second solenoid.

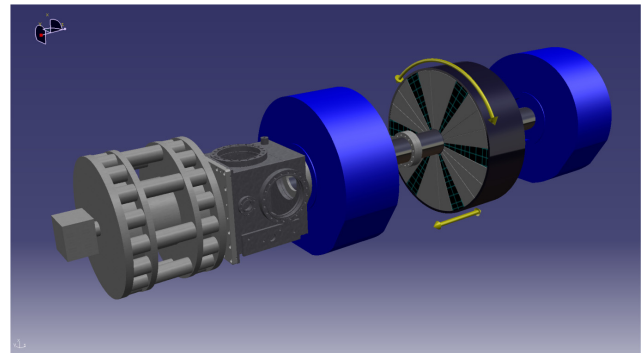


Figure 4: Beam line from left to right: The ion source (of CAPRICE type) is connected to the extraction box, solenoid, correction hexapole, solenoid.

To perform matching, suitable beam diagnostic is necessary. This beam diagnostic has to have full spatial resolution. No integration in any transverse direction is al-

lowed. This excludes wire harps, slits, or slit-grid devices as diagnostic, beam transformers and Faraday cups show the total current only. Viewing targets, μ -Faraday cups[4], and pepper pot devices are possible candidates to check the matching.

Assuming that a viewing target is available behind the second solenoid, the procedure would be as follows:

- Focus the beam with the first solenoid on the viewing target. The beam is convergent at the place of the hexapole. Choose focusing strength of the first solenoid and the distance from the solenoid to the hexapole, to set the ion beam radius and the orientation of the phase space ellipse at the location of the hexapole.
- Apply the correction to the beam by setting amplitude and azimuthal position of the hexapole.

With the focusing strength of the first solenoid and its distance to the hexapole the diameter of the beam and the orientation of the phase space ellipse can be controlled in a certain range. As a result an azimuthally homogeneous beam should be obtained on the viewing target.

The result of such an ideal correction will be not perfect because of different practical limitations: e.g. the correction should be as short as possible to stay with the 'thin lens' approximation, but there are still other limitations.

SIMULATION

The simulation problem 'extraction of an ion beam from an ECRIS and its beam improvement' requires full 3D modeling, KOBRA3-INP [5] has been used here. It turned out, that starting conditions of the ions at different locations within the plasma chamber are responsible for the structure obtained within the beam[6]. Typical emittance evaluation for that kind of programs present a projection of the full phase space into a 2D plane. That means that the horizontal emittance is determined by all particles, independent from its vertical position, and similarly for the vertical emittance in the perpendicular direction. This integration excludes the possibility of a spatial resolution. The structure of the beam becomes visible only when a viewing target is used or a pepper pot like diagnostic is applied. That means for simulation technique, that the projection for emittance has to be sensitive on the transverse spatial coordinate if a correlation exists. Using this feature of the program, the emittance becomes structured, shown in Fig. 5. The correct azimuth position of the proposed hexapole correction can be determined in simulation when the emittance is symmetric in the rotated coordinate system.

REFERENCES

- [1] J. Mäder, J. Roßbach, R. Lang, F. Maimone, P. Spädtke, K. Tinschert, GSI Darmstadt, L. Sun, Y. Cao, H. Zhao, IMP Lanzhou, Ion Beam Measurements at the Superconducting ECR Ion Source SECRA, GSI report 2009-03.

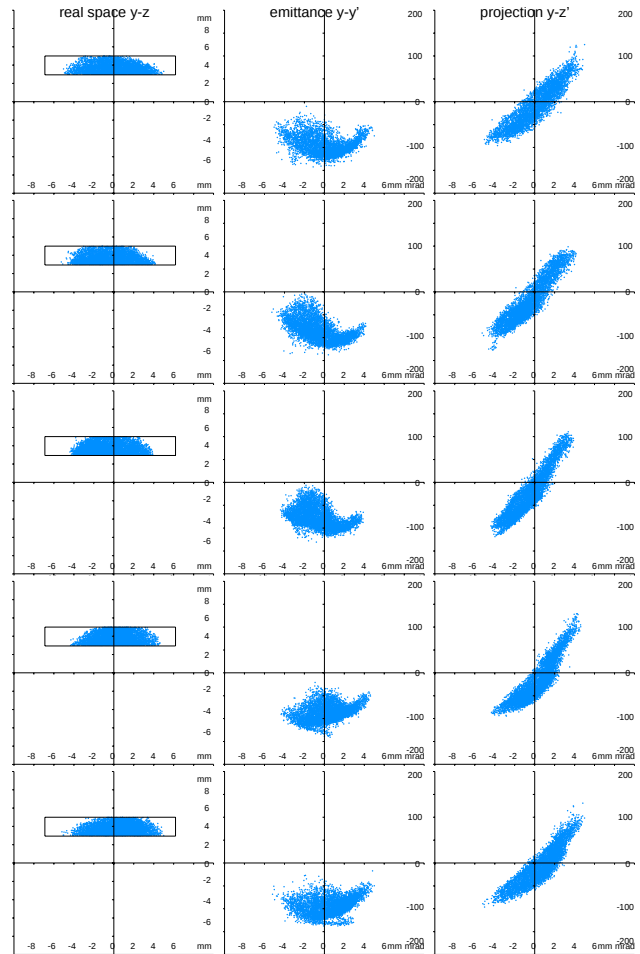


Figure 5: Different projections of phase space (real space $y-z$, emittance $y-y'$, mixed phase space $y-z'$) with transverse resolution, given with an open aperture from $z=3$ mm to $z=5$ mm. Beam direction is in x . The coordinate system is rotated in 20° -steps from 0° to 80° from top to bottom.

- [2] P. Spädtke, K. Tinschert, R. Lang, J. Mäder, J. Roßbach, GSI Darmstadt, J.W. Stetson, MSU Michigan, L. Celona, INFN Catania, Prospects of Ion Beam Extraction and Transport Simulations, Proceedings of the 12th International Conference on Ion Sources, Review of Scientific Instruments, Vol. **79** No 2, 2008.
- [3] P. Spädtke, The Physics of Ion Beam Extraction from an Electron Cyclotron Resonance Ion Source, IEEE Transactions on Plasma Science, Vol. **36**, No 4, August 2008.
- [4] L. Panitzsch, M. Stalder, R.F. Wimmer-Schweingruber, Direct high-resolution ion beam-profile imaging using a position-sensitive Faraday cup array, Review of Scientific Instruments, Vol. **80**, 113302, 2009.
- [5] KOBRA3-INP, Junkernstr. 99, 65205 Wiesbaden, Germany.
- [6] P. Spädtke, Model for the description of an ion beam extraction from electron resonance ion sources, Proceedings of the 13th International Conference on Ion Sources, Review of Scientific Instruments, Vol. **81** No 2, 2010.