PROGRAM TO IMPROVE THE ION BEAM FORMATION AND TRANSMISSION AT JYFL

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Abstract

The increased requirements towards the use of higher ion beam intensities motivated us to initiate the project to improve the overall transmission efficiency of the K130 cyclotron facility at JYFL. A similar project has earlier been started at the NSCL/MSU (National Superconducting Cyclotron Laboratory/Michigan State University) where a remarkable improvement in the ion beam transmission has been obtained [1]. Since similar improvement plans were considered at the KVI (Kernfysisch Versneller Instituut) the natural choice was to carry out the common improvement work in collaboration between the afore-mentioned laboratories. In this article we present the beam transport efficiency of the JYFL cyclotron facility in different operation conditions, the experiments to discover the “bottle-necks” and plans to solve the problems. The objective of this program is to double the accelerated beam intensity of medium charge states. The Ar^{8+} ion beam is used as a benchmark, which at present the maximum intensity is about 8 μA after the cyclotron.

BEAM TRANSMISSION

Experimental set-up

The JYFL 14 GHz ECRIS is the main tool for the ion beam production required by the JYFL nuclear physics programme. The performance of the ion source is typically adequate but large beam emittance growth in the beam extraction from the ECRIS and in the beam injection line limits the usable beam intensity after the cyclotron. Figure 1 shows the layout of the beam line from the ion source to the emittance scanner located after the 90° analysing magnet. After the ion source extraction the beam is focused by two solenoids (SOLJ1, SOLJ2), collimated by a 20 mm (5/10/20) collimator and analyzed by a R500 dipole (DJ1). The gap of the dipole is 85 mm. After the dipole the ion beam is focused again through a 20 mm collimator and its intensity is measured by a Faraday cup. Ion beam can be focused by a solenoid (SOLJ3) into the Allison type 2D emittance scanner. After the dipole the beam shape can be analyzed with the KBr beam viewing plates. The beam profile in the vertical direction can be seen also with the aid of the emittance measurements.

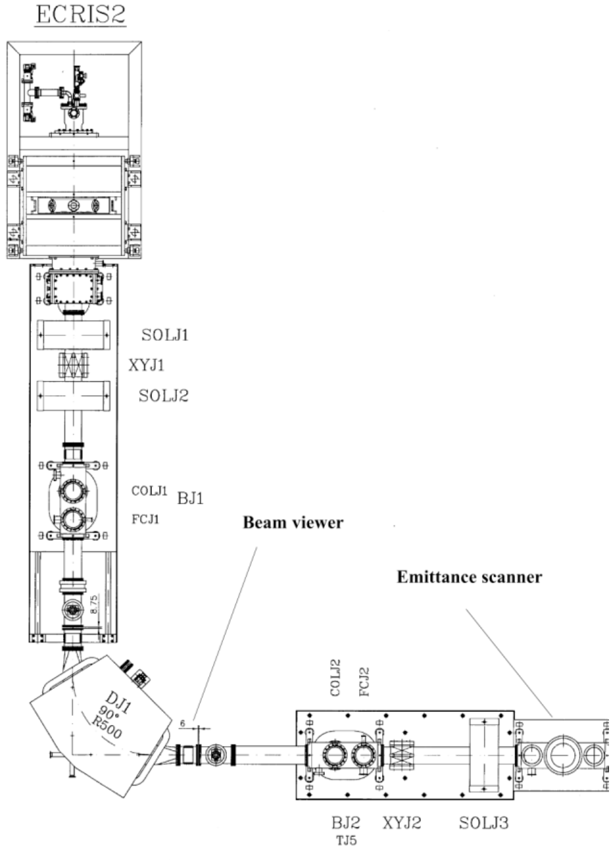

Figure 1: The layout of the JYFL 14 GHz ECRIS beam line.

Present beam transmission efficiency

According to the transmission experiments carried out at JYFL the beam transmission efficiency decreases with the beam intensity extracted from the JYFL 14 GHz ECRIS. Here the transmission efficiency is I_{PFC}/I_{FCJ2}, where I_{PFC} and I_{FCJ2} (see Fig. 1) are the beam intensities measured after the K130 cyclotron and after the ECRIS, respectively. Typical behaviour of the transmission efficiency of the JYFL cyclotron facility is shown in Fig. 2. It indicates that the beam quality decreases with the beam intensity. The degradation can take place during the beam formation and/or during the beam transmission in the beam line due to incorrect beam optical components. As a first step we have to determine the bottle-necks of our beam transmission system.

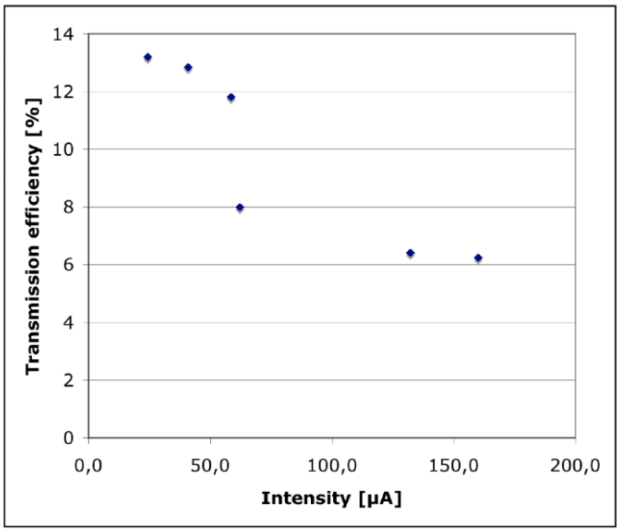

Figure 2: Typical Ar^{8+} ion beam transmission efficiency as a function of intensity extracted from the JYFL 14 GHz ECRIS.

Beam envelope

The beam behaviour in the beam line was studied using the DIMAD simulation code code [5]. No space-charge effect was included in the simulation. Figure 3 shows the Ar^{9+} beam phase space and shape at the location of beam viewer. According to the beam transport simulations the beam is asymmetric at the afore-mentioned point.

According to the simulations shown in Figure 3 the Twiss parameters differ significantly in the horizontal and the vertical directions which indicates that 2-D emittance can increase dramatically when the beam is focused for example by solenoids. Although the 2-D emittance variations are reversible, it is preferable to avoid them by having transverse emittances of similar sizes and similar Twiss parameters whenever possible for optimum beam transport [2]. With the aid of the simulations it was found that the asymmetric beam was generated by the double focusing dipole whose focusing strength in the bending plane and vertical plane are different. According to simulations the entrance/exit angle of dipole has to be decreased from 30° to 27° in order to maintain the symmetric beam shape.

The beam envelope was confirmed with the KBr beam viewing target installed after the dipole. Figure 4 shows that the beam shape was even more asymmetric than was expected from the simulations. The figure corresponds to Ar^{9+} ion beam extracted by the acceleration voltage of 12.14 kV. Because of two 20 mm collimators (COLJ1 and COLJ2) and inadequate focusing in SOLJ1, a significant fraction of the beam intensity was collimated before the beam viewer. This was done in order to have an evenly distributed beam profile. The distribution of beam intensity is fairly uniform although slightly higher beam density probably occurs in the edge of the beam spot.

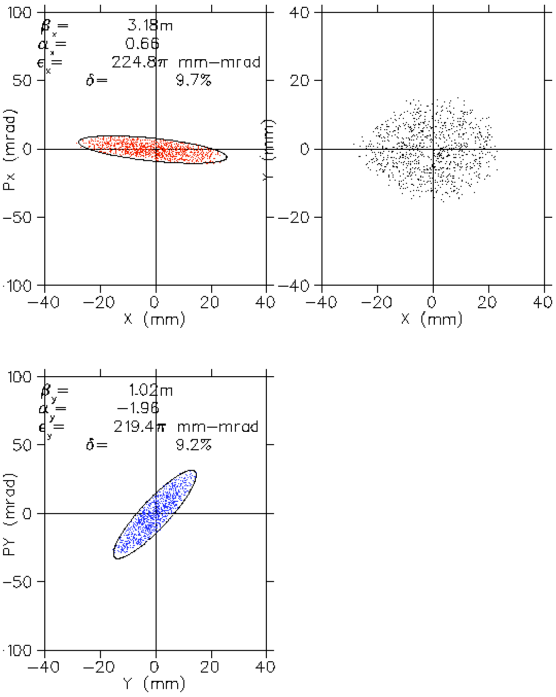

Figure 3: Simulated beam properties (vertical and horizontal emittance and the beam envelope) at the position of the beam viewer.

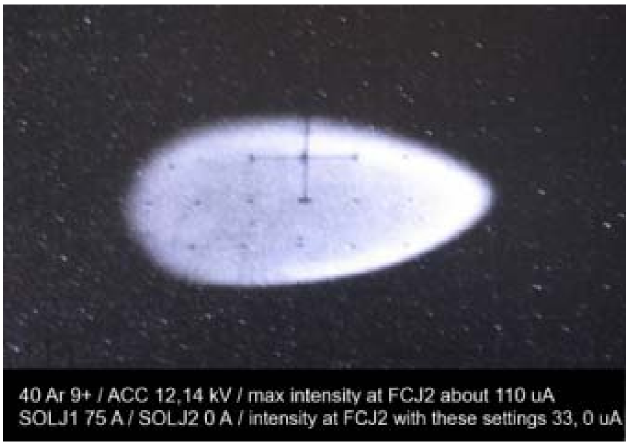

Figure 4: The beam envelope at the beam viewer located after DJ1 (see Fig. 1).

Hollow beam structure

Beam distribution and beam profile has been studied using the beam viewer and the emittance scanner, both located after the DJ1 dipole (see fig. 1). The beam shape was first studied with argon ion beams using the extraction voltage of 12.14 kV. This is the normal acceleration voltage used for the cyclotron for the Ar^{9+} ion beam. Figure 5 shows the evolution of the beam envelope as a function of the focusing power (SOLJ1). The ECRIS parameters were kept constant but the beam intensity measured from FCJ2 varied between 33 μA and 110 μA due to the collimation of the beam by COLJ1. The beam was focused through the collimator using the solenoid current of 90 – 95 A.

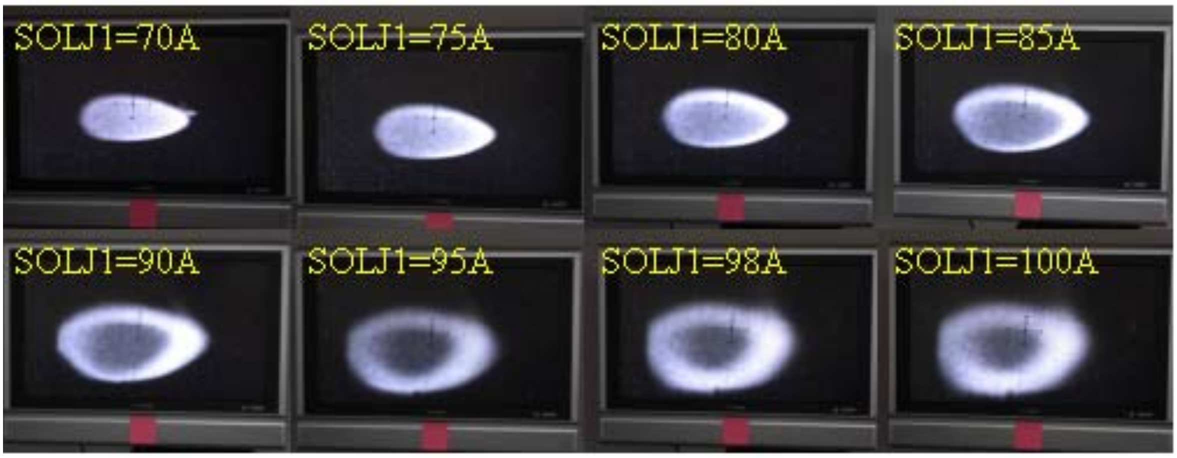

Figure 5: The shape of Ar^{9+} ion beam on the target when different focusing strengths have been used.

As Figure 5 shows, the beam distribution is quite uniform when the current of 70 A is used in SOLJ1 (I[SOLJ2] = 0). At this point the vertical emittance was measured to be about 200 π mm mrad. With SOLJ1 ≈ 80 A, there are some evidence of space charge effects (can be also other effect) on the Ar^{9+} beam from the higher charge state, since the beam image shows a slight hollow shape.

With SOLJ1 >85 A, although the beam intensity increases along the solenoid, the beam shape on the beam viewer changes dramatically. Not only the vertical emittance grows to about 400 π mm mrad, most importantly, it creates a hollow beam. The emittance increase originates from the collimation effect and possibly due to the hollow beam. At this situation, the beam intensity within the cyclotron acceptance actually reduces when SOLJ1 increased, limiting the injection efficiency. The current operation point for the K130 injection is at I[SOLJ1]=95A, which corresponds to the maximum intensity. It is clearly not the best operating point regarding the space charge effects.

There are two possible explanations for the hollow beam structure. The higher charge state has a focus point earlier in the beam line where it forms a strong local charge density. As a result of this an electric field is formed which is perpendicular to the direction of original ion beam velocity. This causes a perpendicular acceleration to ions. It has also been reported that the hollow beam structure can be formed already in the ECRIS plasma [3].

Experiments also show that the hollow beam structure decreases as a function of charge states. For example, the ion beam distribution is quite uniform in the case of Ar^{11+} when the mixing gas is not used. In the case of the JYFL 14 GHZ ECRIS this is the highest charge state, which still has a considerably high beam intensity. Similar behavior has been reported by the NSCL ion source group [4].

Improvement plan

As was described earlier, two separate problems occur concerning the beam transmission and the beam injection into the K130 cyclotron: asymmetric beam shape and hollow beam structure. The optimum solution may require a new double focusing dipole with the correct entrance/exit angle. However, as a first step the quadrupole will be tested in order to form a symmetric beam. Possibly the shimming of the dipole magnet will also be considered. The hollow beam structure phenomena will be studied in more detail. It is possible that the electrostatic focusing has to be used in order to minimize the problem.

Acknowledgements

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