TRANSPORT AND INJECTION OF HEAVY ION BEAMS WITH HIGH BRILLIANCE FOR THE GSI HIGH CURRENT INJECTOR

L. Dahl, W. Barth, Gesellschaft für Schwerionenforschung, D-64291 Darmstadt, Germany
S. Yaramishev, ITEP, Moscow, Russia

Abstract

The GSI High Current Injector (HSI) is in routine operation for more than two years and has reached its designed performance for light and medium ion species. During commissioning a high intense $^{40}Ar^{1+}$-beam from a MUCIS ion source was used to optimize the transport through the high voltage gap, the mass spectrometer and the low energy beam transport (LEBT) up to the HSI-RFQ. In the meantime an integrated solenoid lens between extraction system and post acceleration gap allowed for higher intensities, while the beam input parameters were changed. This implicated beam mismatch and losses in the LEBT and also in the RFQ-structure due to an extended emittance. For the desired U^{4+}-operation the design current of 15 emA is not yet available although the ion source can provide the desired current. This paper is focused on the transport from the ion source to the RFQ-injection of an U^{4+}-beam under realistic space charge conditions, especially in the dc acceleration gap (up to 80 emA total Uranium current). In order to optimize a modified complex transport system to the RFQ, multi-particle beam dynamic calculations were carried out on the basis of measured emittances behind the gap. Proposed improvements providing a higher overall acceptance are reported. Additionally, investigations of a modified RFQ rod design resulting in a higher acceptance and lower emittance growth for the operation with high intense heavy ion beams will be presented.

1 INTRODUCTION

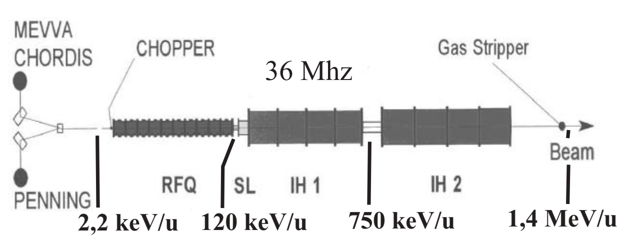

Fig. 1: High Current Injector HSI

To fill the heavy ion synchrotron SIS up to its space charge limit for all ion species, the GSI linear accelerator UNILAC underwent a renewal of its prestripper section to increase the ion beam intensities to $I = 0.25 \cdot A/q$ (emA) for mass over charge ratios of up to 65. The new high current injector (HSI) (Figure 1) consists of ion sources of MUCIS- or MEVVA-type installed on a high voltage platform, a low energy beam transport system (LEBT) including a mass spectrometer [1], an IH-type RFQ and two IH-DTLs. The main beam parameters are given in Table 1. The beam envelope of the LEBT based on the design input emittance is displayed in Figure 2.

Table 1: Designed and measured HSI beam parameters

output of:	Beam Energy (keV/u)	Design Emittance (mm*mrad)		Design Current (emA)		Measured Ar^{1+} Emittance 90% (mm*mrad)		Measured Current (emA)	
		$\varepsilon_{nx,ny}$	$\varepsilon_{x,y}$	U^{4+}	Ar^{1+}	ε_x	ε_y	U^{4+}	Ar^{1+}
DC gap	2.2	0.3	138	16.5	11.0	316	316	16.0	38.0
LEBT	2.2	0.3	138	16.5	11.0	176	154	8.0	18.0
RFQ	120.0	0.3	19	15.0	10.0	20	22	4.0	10.0
IH2-DTL	1400.0	0.5	9	15.0	10.0	-	-	4.0	8.5

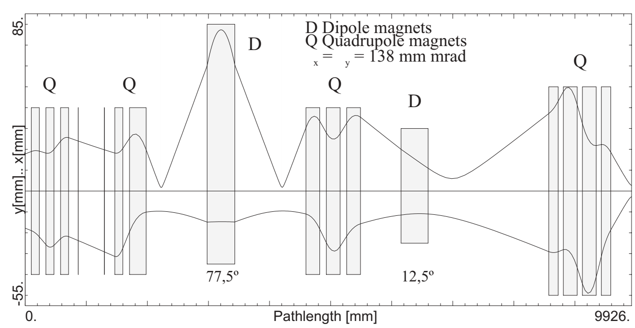

Fig. 2: Beam envelope of mass spectrometer and LEBT

The HSI is in routine operation since October 1999 and has achieved the design intensities for light and medium ions. Improvements of the beam transport system from the ion source via the dc acceleration gap to the LEBT to meet also the intensity demands on heavy ion beams were done. Thereby a multiaperture accel-decel extraction system, a solenoid lens in front of the high voltage gap, and a screening electrode between two ground electrodes in the dc-gap were investigated. Transverse emittance measurements [2] pointed out that the intensity enhancement results in a higher beam brilliance as well as emittance growth leading to a mismatch to the LEBT-system. The LEBT acceptance is completely filled while the RFQ acceptance is exceeded. In the following an analysis of the beam dynamics in the existing system of ion source terminal, LEBT, and RFQ and moderate modifications for increased transmission are presented.

2 MEASUREMENTS WITH INTENSE U^{4+}- AND AR^{1+}-BEAMS

During an Uranium run in December 2001 using the MEVVA-ion source a current of 24 emA was measured behind the dc acceleration gap. This value included a fraction of 67 % of U^{4+}-ions, corresponding to 16 emA, close to the design value in Table 1. Due to particle losses only 10 emA were measured after mass separation and 8 emA at RFQ injection [3,4]. Unfortunately the RFQ output intensity of 4 emA was not optimized. With respect to negligible space charge forces a current of 6 emA should be attainable after elaboratively tuning.

Comparable transmission was observed for an Ar^{1+}-beam from a MUCIS. 38 emA were measured behind the gap and 10 emA at the RFQ output. The aspired intensity in Table 1 was obtained due to an surplus of beam intensity from the ion source. There are no significant beam losses in the two IH structures.

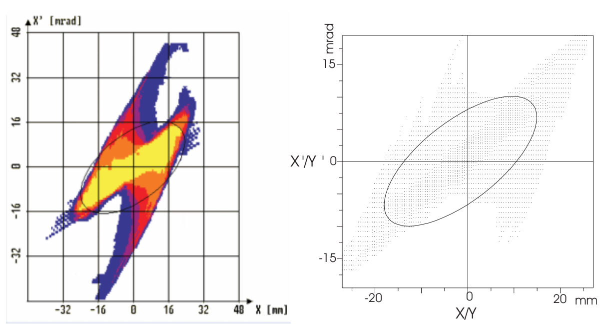

Fig.3: Left: measured emittance of an Ar^{1+} 38 emA beam at the LEBT input. Right: refined particle distribution for simulations and RFQ acceptance in solid line

3 MULTI-PARTICLE SIMULATIONS FOR THE PRESENT LEBT AND RFQ

All calculations were carried out for an Ar^{1+}-beam. The horizontal emittance of the radially symmetric beam was measured directly behind the dc acceleration gap. The macro particle distribution was refined by the introduction of 2,650 particles. These were linked randomly with an assumed similar vertical emittance to create the four dimensional transverse phase space distribution. Figure 3 shows the case of a 38 emA Ar^{1+}-beam with a 90% emittance of $\varepsilon_{x,y} = 316$ mm*mrad. Longitudinally a dc-beam without energy spread was supposed. Multi-particle simulations with the PARMTRA code considering higher order calculations of the spectrometer, fully space charge compensated beam, and best possible matching to the RFQ acceptance were carried out.

57 % of the particles arrived at the RFQ entrance, in agreement with measurements (Figure 4). The horizontal 90 %-emittance remained nearly constant, the vertical one shrunk to $\varepsilon_y = 190$ mm*mrad.

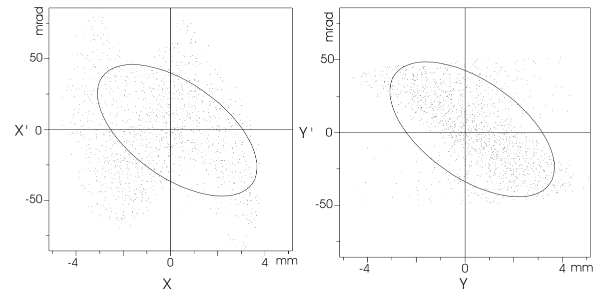

Fig. 4: Measured emittance transformed to the RFQ entrance and RFQ acceptance (solid line)

The six dimensional particle output coordinates served as input for the beam dynamics in the RFQ simulated by the DYNAMION code [5]. The matched twiss parameters at the RFQ-input for different beam currents were calculated assuming a KV distribution. Simulations of the RFQ were done with real geometry of the electrodes obtained from the tables for manufacturing.

Based on an input current from the ion source of 38 emA, 21.7 emA reached the RFQ input and 9.5 emA of accelerated Ar^{1+}-particles were calculated at the RFQ-output. The overall transmission from the dc gap to the RFQ-output amounts to 25 %.

4 MULTI-PARTICLE SIMULATIONS FOR A MODIFIED LEBT AND RFQ

The complete radially symmetric beam from the ion source can be captured by the substitution of the first quadrupole triplet by a superconducting solenoid with a magnetic field strength of 2.5 T within 100 mm length. For matched injection of the beam to the RFQ, the quadrupole quartet aperture in front of the RFQ entrance has to be extended to 150mm in diameter. Fig. 5 shows the LEBT with increased acceptance. PARMTRA simulations predict beam losses of only 6 % and values of $\varepsilon_x = 345$ mm*mrad and $\varepsilon_y = 473$ mm*mrad for the 90 %-emittance.

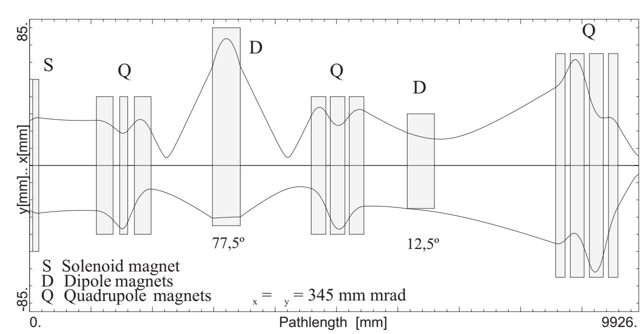

Fig. 5: Modified LEBT with increased acceptance

The particle distribution obtained from calculations of the modified LEBT was again pursued by the DYNAMION code for both, the existing RFQ structure, and a modified one to optimize the total yield.

In case of the existing RFQ the gain in current of 1 emA is rather small due to the emittance of the beam, which is significantly higher in the modified LEBT than the acceptance of the RFQ. Additionally, the fraction of not-accelerated particles amounts to 8 % of the number of input particles. This results in a total beam transmission of the accelerator front end of only 28 %.

For improvement moderate modifications of the RFQ electrodes were assumed. The length of the RFQ was increased by 1 meter corresponding to the length of one tank section. The extension of the radial matcher allows to decrease the effective emittance growth at the RFQ entrance to about 20 %. The dependence of modulation and synchronous phase along the RFQ were changed to minimize the beam emittance growth in the gentle buncher and to increase the particle capture efficiency. These measures result in a total transmission of 38 %. Figure 6a shows the transverse emittance growth related to the initial values and the transmission of all particles along the axis of the existing RFQ. Figure 6b gives the results for the upgraded RFQ.

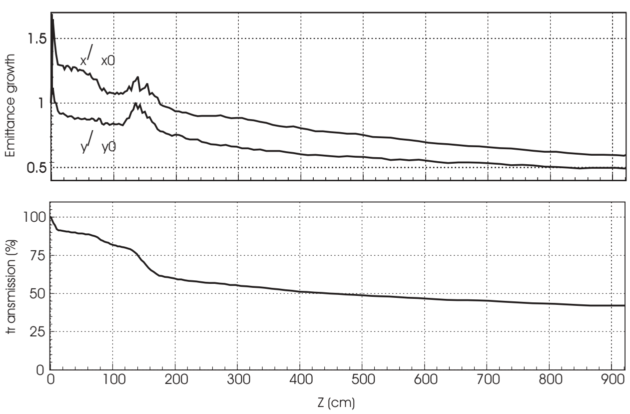

Fig. 6a: Emittance growth and transmission of all particles along the axis of the existing RFQ

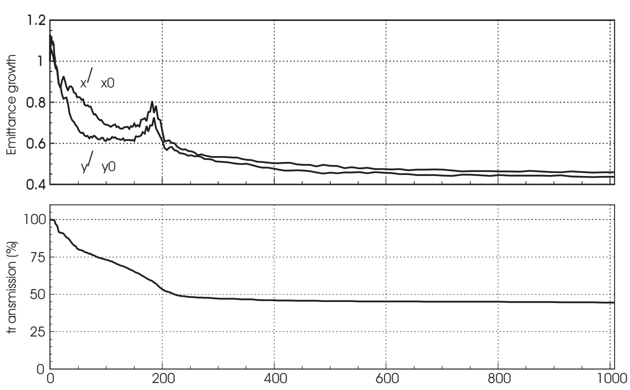

Fig. 6b: Emittance growth and transmission of all particles along the axis of an upgraded RFQ

Table 2 presents an overwiew of the three investigated front end system variants. Solely an upgrade of the LEBT improves the front end transmission only by 11 %. An additional extension of the RFQ length and a modified rod design increases the particle yield by 52 % compared to the existing accelerator front end.

Table 2: Parameters of different LEBT and RFQ designs

Ar^{1+}	Existing LEBT Existing RFQ	New LEBT Existing RFQ	New LEBT New RFQ
Ion source current	38 emA	38 emA	38 emA
RFQ input current	21.7 emA	35.7 emA	35.7 emA
Emittance $\varepsilon_x/\varepsilon_y$ (90%)	316/190 mm* mrad	345/473 mm* mrad	345/473 mm* mrad
RFQ length	9m	9m	10m
RFQ radial matcher	4 cells	4 cells	11 cells
RFQ transmission: accelerated particles (all particles)	44% (60%)	30% (38%)	41% (45%)
RFQ output current	9.5 emA	10.5 emA	14.5 emA
Total transmission	25%	28%	38%

5 CONCLUSION

At present the compatibility of high voltage dc-gap, LEBT, and RFQ at the UNILAC high current injector HSI is deficiently. The reasons are modifications of the ion sources and the pre-acceleration system for increased beam intensity.

Nevertheless, the HSI provides the designed beam currents of $I = 0.25 \cdot A/q$ (emA) for light and medium ion species due to a surplus of the ion source beam offer.

For U^{4+}-ions this surplus is presently not available. The MEVVA ion source delivers up to 16 emA, corresponding to the HSI design current. A moderately upgraded LEBT and RFQ allows to increase the present U^{4+}-current of 6 emA to only 9 emA.

To reach the aim of 15 emA of U^{4+} the brilliance actually obtained from the ion source has to be sustained up to the RFQ entrance. Fur this purpose a sophisticated correction of the space charge dependend emittance aberrations caused by the high voltage pre-acceleration gap is necessary. The application of an achromatic mass spectrometer with compensation of the higher order distortions might be helpful to avoid emittance growth in the LEBT. Finally a new RFQ rod design to provide an increased transverse acceptance has to be investigated.

6 REFERENCES

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