A NEW LEBT AND RFQ INPUT RADIAL MATCHER FOR THE UNILAC FRONT END*

L. Dahl, W. Barth, S. Yaramishev, GSI, D-64291 Darmstadt, Germany
S. Visotski, I. Vorobyov, ITEP, Moscow, Russia

Abstract

The UNILAC heavy ion accelerator will serve as a high current injector for the future FAIR accelerator complex of GSI. This requires to inject 3.3 $\cdot 10^{11}$ ions/100µs of U^{28+} into the existing synchrotron (SIS 18). Additionally, the UNILAC serves in multi-beam operation experiments with high duty factor beams of different species. To meet all future demands a dedicated upgrade program of the UNILAC is in progress. This paper focuses on front-end improvements. A new beam transport system will provide achromatic deflection and high mass resolution for the heavy ion beams from both existing ion source terminals. A third terminal for high current Uranium ion sources with a straight-line solenoid based beam channel will be added. E.g. U^{3+} and U^{4+} ions with a total beam current of 55 mA will be injected into the RFQ for a maximum intensity yield of U^{4+} beam at the exit. To optimize the total front-end beam transmission a redesigned input radial matcher of the RFQ is already implemented. It enables a smoother RFQ input matching of the high current beam resulting in smaller beam diameter and in lower particle losses. Beam measurements comparing old and new input radial matchers are presented.

INTRODUCTION

For the planned Facility for Antiproton and Ion Research (FAIR) [1] at Darmstadt the present GSI accelerator complex, consisting of the UNILAC (Universal Linear Accelerator) and the SIS18 (Heavy Ion Synchrotron), is foreseen to deliver high current ion beams [2]. As shown in Fig. 1 the UNILAC consists of a 36 MHz pre-stripper accelerator HSI (High Current Injector), a gas stripper section at energy of 1.4 MeV/u, and a 108 MHz Alvarez type post-stripper accelerator with a final energy of 11.4 MeV/u. A second injector HLI (High Charge State Injector) injects by the use of a kicking magnet directly into the Alvarez tanks. The transfer beam line to the synchrotron is equipped with an additional foil stripper to provide high charge states for highest SIS18 energies.

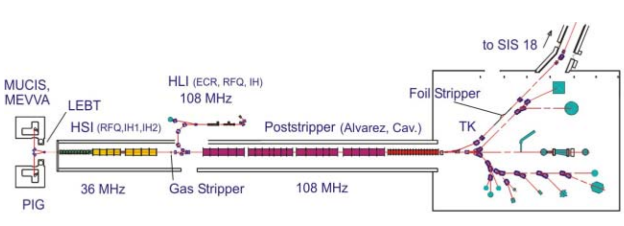

Figure 1: Scheme of the UNILAC.

*Work supported by the European Community INTAS Project Ref. no 03-54-3543

The HSI is fed by a PIG-ion source terminal offering a wide range of isotopes up to Uranium. A second terminal houses MUCIS- or MEVVA-type high current sources. Behind mass separation [3] a 50 Hz switching magnet enables a pulse selection between two different ion species to be injected into the subsequent RFQ accelerating the beam from 2.2 keV/u to 120 keV/u. A short matching section and two IH-structures perform the further acceleration to 1.4 MeV/u.

After commissioning of the HSI in 1999 from 16 mA of U^{4+} beam at the RFQ entrance only 8.3 mA were measured at the RFQ exit. The FAIR scenario requires 18 mA, corresponding to $3.3 \cdot 10^{11}$ ions/100µs of U^{28+} at SIS18 injection. Therefore a dedicated upgrade program concerning the UNILAC front-end is partly done and will be continued to reach this goal.

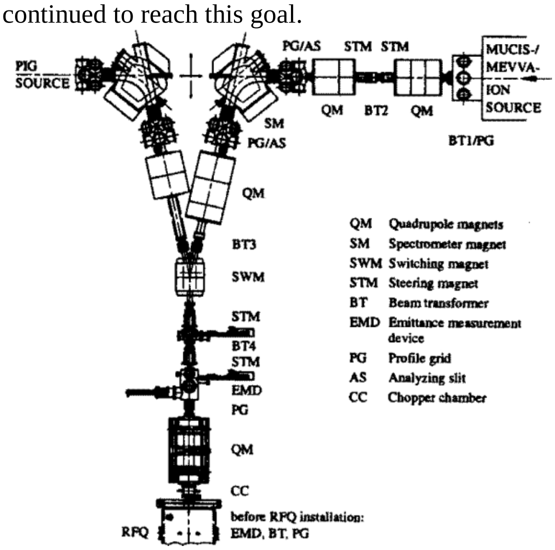

Figure 2: UNILAC low energy beam transport.

CURRENT FRONT-END PERFORMANCE

To understand the low beam transmission of the existing front-end, beam dynamic studies of the LEBT (Low Energy Beam Transport) and RFQ using the DYNAMION code were done on basis of a 16 mA U^{4+} beam and the according emittance, both measured in front of the matching quadrupole quartet. For realistic simulations also the measured magnetic field distribution of the quadrupole lenses, the geometry of the RFQ electrodes as fabricated, and measured misalignments of the ten RFQ sections were considered. External electrical fields in the IRM (Input Radial Matcher) as well as in the regular RFQ cells were precisely calculated solving the Laplace equation for the potential in the area formed by the surfaces of the electrodes and the tank. Behind the RFQ a beam current of 8.7 mA was calculated; the measured current was 8.3 mA. The low front-end transmission of 55% was caused by significant particle losses in the RFQ and a 50 % higher beam emittance compared to the design value. Tight matching conditions require strong beam convergence at the RFQ entrance leading to significant deformation of the 6D beam phase volume, a large diameter of the beam in the quadrupoles, and therefore remarkable particle losses.

New Input Radial Matcher Design

To improve the transition of LEBT and RFQ the IRM was redesigned. The aperture along the new and slightly extended IRM of 13 cells (10 cm) follows an advanced design rule [4] to provide for an improved smoother beam matching (Fig. 3).

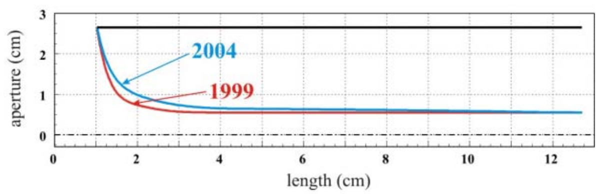

Figure 3: Apertures along the original and the redesigned IRM. The dashed line represents the RFQ axis.

Starting at the position of the emittance meter the beam was matched to the RFQ entrance with the existing four quadrupole lenses using the TRACE-3D code (Fig. 4). Finally the particle motions in the whole front-end system were simulated with the DYNAMION code. A 15 % higher transmission was predicted for the 16 mA U^{4+} beam, with respect to the original electrodes design.

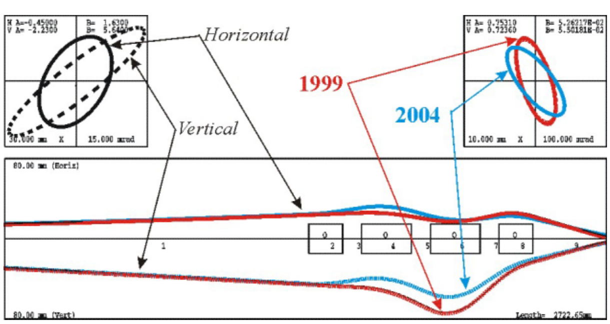

Figure 4: Beam envelopes and emittances in the LEBT for the original and for the redesigned IRM.

The HSI is in operation since 1999. For U^{4+} beams (V_{rf} = 125 kV), the RFQ rf-power was about a factor of two higher than calculated. The design inter-vane voltage of 137 kV for ions with a mass to charge ratio m/q = 65 was not reached. In an RFQ upgrade program in 2004 new electrodes were machined and copper plated [5] instead of polished to improve both, the maximum electrodes voltage with reduced dark currents and the overall transmission after redesign of the IRM.

RFQ Commissioning Results

Dark currents during high power operation were strongly reduced. The rf-power for the design electrodes voltage of 137 kV decreased from 650 kW to 380 kW.

Commissioning measurements of the improved RFQ for a high current Ar^{+} beam of 16 mA and an U^{4+} beam of 0.5 mA were carried out. A high current Uranium beam was not available at that time. For a low current U^{4+} beam 100 % transmission was reached compared to 85 % before. Fig. 5 shows the Ar^{1+} transmission before and after the upgrade depending on the inter-vane voltage. The calculated gain of up to 15 % is verified. From this an U^{4+} current of 9.5 mA can be scaled. This improvement is still not sufficient for the FAIR requirement but confirmed the reliability of the DYNAMION code to predict realistic results.

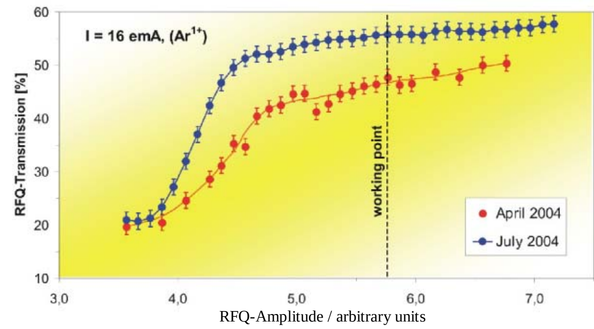

Figure 5: Measured transmission for a high current Argon beam before and after the upgrade of the RFQ. RFQ amplitude in arbitrary units.

FUTURE IMPROVEMENTS

The Uranium beam generated by the MEVVA ion source includes 37 mA of U^{4+} ions and 18 mA of U^{3+} ions. With the existing LEBT only 16 mA of the U^{4+} beam arrive at the entrance of the RFQ. Therefore an additional solenoid based straight-line beam channel to inject both beam components into the RFQ was considered. TRACE-3D (Fig. 6) calculations were performed on a basis of emittances measured directly behind the pre-acceleration gap of the ion source terminal [6]. Assuming fully compensated space charge no particle losses occur.

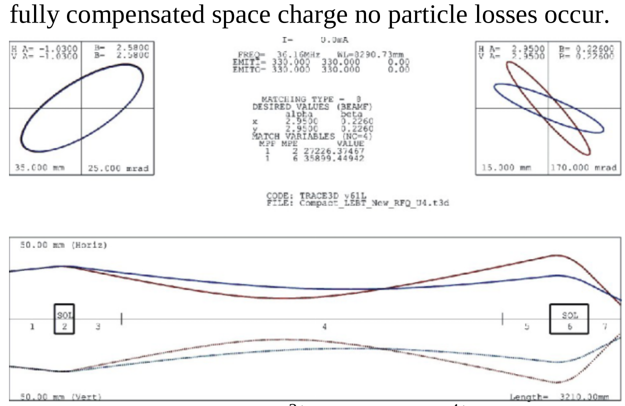

Figure 6: Envelopes for U^{3+} (blue) and U^{4+} (red) beam for a compact solenoid based straight-line LEBT.

Additionally, an advanced RFQ input radial matcher [7] and rod design following new modulation rules was investigated with the DYNAMION code considering an overall current of 55 mA of charge states 3+ and 4+. The optimum solution requires an extension of the RFQ tank of one additional tank section (1m). Fig. 7 illustrates the effects of the redesign on the acceleration parameters.

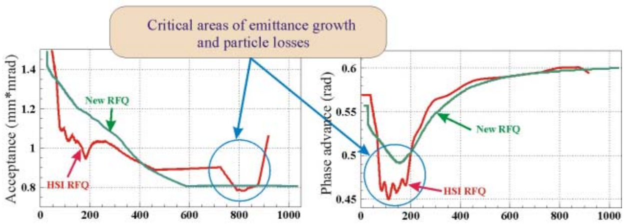

Figure 7: Normalized acceptance and phase advance of the existing and the new RFQ design along the axis.

Figure 8 shows the beam emittances measured directly behind the pre-acceleration gap including charge states 3+ and 4+, and the calculated emittances at the entrance and exit of the redesigned RFQ. Table 1 gives an overview of the output currents for different cases comparing present and future LEBT and RFQ.

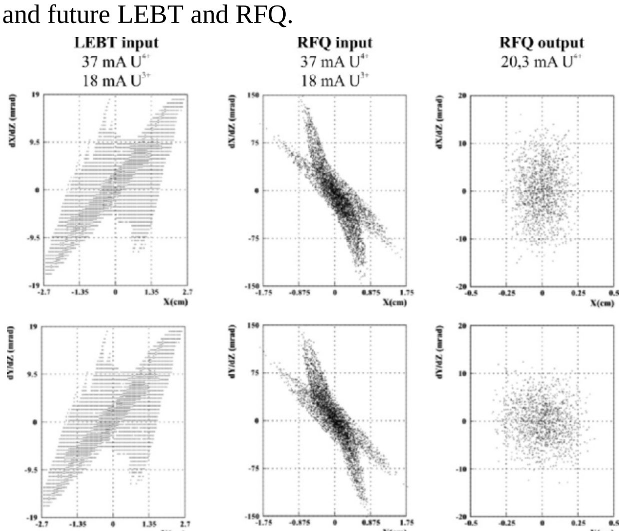

Figure 8: Particle distribution at LEBT entrance, RFQ entrance and exit. Top horizontal, bottom vertical planes.

Table 1: Beam Currents for Different Front-end Systems

	U^{4+} (mA)	U^{4+} (mA)	U^{3+} (mA)
	accelerated	*not accelerated*	
Existing LEBT + RFQ	11.8	1.3 (10%)	— —
Straight-Line LEBT + RFQ	15.1	2.8 (14%)	2.4 (12%)
Straight-Line LEBT + New RFQ	20.3	1.9 (8%)	1.5 (6%)

So far further upgrade measures to deliver 18 mA of U^{4+} beam are defined but not yet integrated into the front-end system. For this purpose the two LEBT branches with mass separators have to be widened to enable a switching magnet with enlarged aperture. Therewith a third, straight-line beam channel gets feasible as indicated in Fig. 9. A pair of solenoids prepares a double waist for the switching magnet. A pulseable magnetic quadrupole quartet provides for the focus at the RFQ entrance.

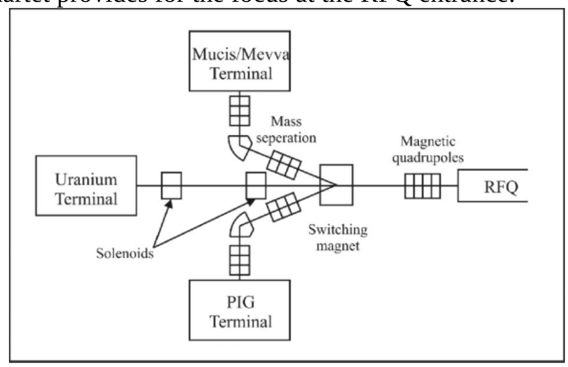

Figure 9: Scheme of the enhanced LEBT system connecting three ion source terminals with the RFQ.

CONCLUSION

For the requirements of the FAIR project additional improvements of the UNILAC front-end are necessary. The compatibility of ion source, dc pre-acceleration, LEBT, and RFQ, and hence the particle yield at the exit of the RFQ can be further improved by the installation of a straight-line Uranium LEBT and a redesigned and extended RFQ. The DYNAMION code turned out to predict results in good agreement with measurements. On that basis the simultaneous injection of charge states 3+ and 4+ into the RFQ ensures the required U^{4+} beam intensity of 18 mA. These measures are part of a mid term upgrade program for the UNILAC and SIS 18.

REFERENCES

[1] An International Accelerator Facility for Beams of Ions and Antiprotons (FAIR), GSI Darmstadt, Germany, Nov. 2001.
[2] W. Barth et al., Development of the UNILAC Towards a Megawatt Beam Injector, Linac2004, Luebeck, Germany, 2004.
[3] L. Dahl, et al., Transport and Injection of Heavy Ion Beams with High Brilliance for the GSI High Current Injector, LINAC 2002, Gyeongju, Korea, 2002.
[4] S. Yaramishev et al., Upgrade of the High Current Heavy Ion Front-End System of the GSI-UNILAC, XIX IWCPA, Alushta, Ukraine, 2005.
[5] S. Minaev et al., Matching of the capacity distribution of the new HSI-RFQ electrodes by individual copper plating, Preprint IAP no IAP-ACC-080604, Frankfurt, Germany, 2004.
[6] R. Hollinger et al., Beam Emittance measurements at the High Current Injector at GSI, Proc. of the 9th International Conference on Ion Sources, Oakland, California, USA, 2001.
[7] I. A. Vorobyov, et al., Development of LEBT and Beam Dynamics Study in Initial RFQ Part (Input Radial Matcher) for Heavy Ion High Current RFQ-GSI, XIX IWCPA, Alushta, Ukraine, 2005.