UPGRADE OF THE UNILAC FOR FAIR

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Abstract

The UNIversal Linear Accelerator (UNILAC) at GSI has served as injector for all ion species from protons for uranium for the past four decades. Especially its 108 MHz Alvarez type DTL providing acceleration from 1.4 MeV/u to 11.4 MeV/u has suffered from material fatigue. The DTL will be replaced by a completely new section with almost the same design parameters, i.e. pulsed current of up to 15 mA of $^{238}U^{28+}$ at 11.4 MeV/u. However, operation will be restricted to low beam duty cycles as 200 µs at 10 Hz. Since preservation of beam quality is mandatory, a regular focusing lattice, as along an Alvarez section for instance, is aimed for. A new source terminal & LEBT dedicated to operation with $^{238}U^{4+}$ is under design. The uranium sources need to be upgraded in order to provide increased beam brilliances and for operation at 2.7 Hz. Revision of the subsequent 36 MHz RFQ electrode design has started as well as the layout activities of the section providing transition from the 36 MHz section to the 108 MHz DTL.

INTRODUCTION

GSI is currently constructing the Facility for Ion and Antiproton Research (FAIR). It aims at provision of 4×10^{11} uranium ions at 1.5 GeV/u [1]. As injector for FAIR serves the existing UNIversal Linear ACcelerator UNILAC (Fig. 1) together with the subsequent synchrotron SIS18. The UNI-

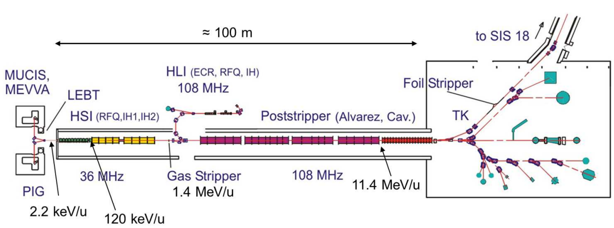

Figure 1: The UNIversal Linear ACcelerator (UNILAC) at GSI.

LAC comprises three ion source terminals. Two of them provide beams at 2.2 keV/u which are injected into an RFQ and are accelerated to 120 keV/u. It is followed by a MEBT comprising a doublet and a super lens, i.e. a 1m long RFQ that just provides longitudinal and transverse focusing without acceleration. The MEBT matches the beam into an IH-DTL. This DTL comprises 2 IH-cavities which apply the KONUS accelerating scheme [2], i.e. the design rf-phase slips from positive to negative phases. This technique allows for high effective shunt impedance and less transverse defocusing. But it provides less longitudinal focusing and requires very accurate longitudinal matching to the DTL entrance. Transverse focusing is provided through three internal triplets per cavity. The IH-cavities operate at 36 MHz and provide acceleration to 1.4 MeV/u. Alternatively, an ECR source followed by an RFQ and one IH-cavity operated at 108 MHz can provide ions with 1.4 MeV/u as well. The 36 MHz pre-stripper DTL is followed by a stripping section, where the ion beam is intercepted by a gaseous jet of nitrogen for increase of the charge state. For instance uranium is stripped from the charge state 4+ to the charge state 28+. The subsequent post-stripper DTL comprises five Alvarez type cavities for acceleration to 11.4 MeV/u being the injection energy required by the synchrotron SIS18. The UNILAC has a high flexibility in its 50 Hz operation. Several virtual accelerators can be operated, all differing wrt to the beam they deliver, i.e. ion species, energy, pulse length, and repetition rate.

This DTL was designed in the late 1960ies and it is in operation for 40 years now. The cavities suffered from considerable material fatigue. Sparking damaged the copper surface. Especially, fast changes of the rf-duty cycles and rf-amplitudes from switching between different virtual accelerators caused rf-sparking. As a consequence, the last years saw limitations in the rf-amplitudes that could be set to the tanks. This manifested in degradation of beam quality of heaviest ions as $^{238}U^{28+}$. Additionally, the beam dynamics design did not foresee provision of intense beams, which are prone to space charge effects. The beam design parameters of the UNILAC are listed in Table 1. The age of the

Table 1: Beam Design Parameters for the Upgraded UNILAC

Ion A/q	≤8.5	
Beam Current (low duty cycle)	128·q/A	emA
Beam Current	≈500·q/A	eµA
Input Beam Energy	1.4	MeV/u
Output Beam Energy	11.4	MeV/u
Output Emit. (norm., tot.) hor/ver	0.8/2.5	mm mrad
Beam Pulse Length	≤5000	µs
Beam Repetition Rate	≤50	Hz
Rf Frequency	108.408	MHz

UNILAC together with the requirement to provide reliable and intense beams for the upcoming FAIR era calls for a revision of the UNILAC, especially its post-stripper DTL. The following section will describe the envisaged upgrade measures.

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SOURCE AND LEBT

FAIR will put special emphasis on uranium beams, which are presently provided together with other heavy ions by a VARIS or MEVVA source located in the northern source terminal. The existing LEBT includes two bends which impose dispersion and hexapolar fringe fields. Additionally, operation and handling of uranium comes along with restrictions from safety requirements. For this reasons a new and dedicated uranium branch is under design as shown in Fig. 2. It is a straight LEBT comprising two quadruplets

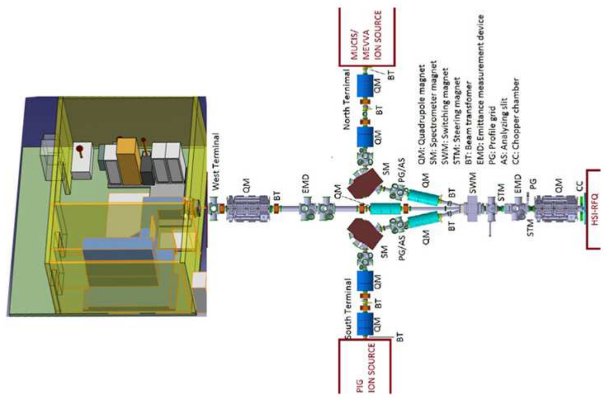

Figure 2: The existing north and south ion source terminals and LEBT branches together with the new uranium terminal (west).

and one triplet. The source will deliver several charge states of uranium but only $^{238}U^{4+}$ is accepted by the RFQ. The fractions of other charge states (mainly 3+) are reduced by chromaticity together with an circular iris located at a beam waist of the charge state 4+. Beam envelopes from simulations along the new LEBT are plotted in Fig. 3 together with phase space distributions at the entrance to the RFQ. Simulations were done for different assumptions wrt the amount on space charge compensation (95% - 100%). The results indicate that the beam brilliance (current/emittance) could be increased by a factor of about 2 compared to the present value. Finally, the repetition rate of the source needs to be increased from 1 Hz to 2.7 Hz. This increase has been reached for ions as gold, bismuth, and lead, but for uranium further systematic investigations especially on the cathode material are required.

RFQ

Also the RFQ suffered from sparking during operation with varying rf-duty cycles and rf-amplitudes. The attainable rf-voltages are about 10% below the required values for uranium. This leads to serious degradation of longitudinal beam quality from insufficient bunching. Additionally, the beam divergence at the RFQ exit is too large, triggering losses inside the subsequent super lens, which in consequence also has to be operated at lower voltages causing further degradation of beam quality. The design of the RFQ

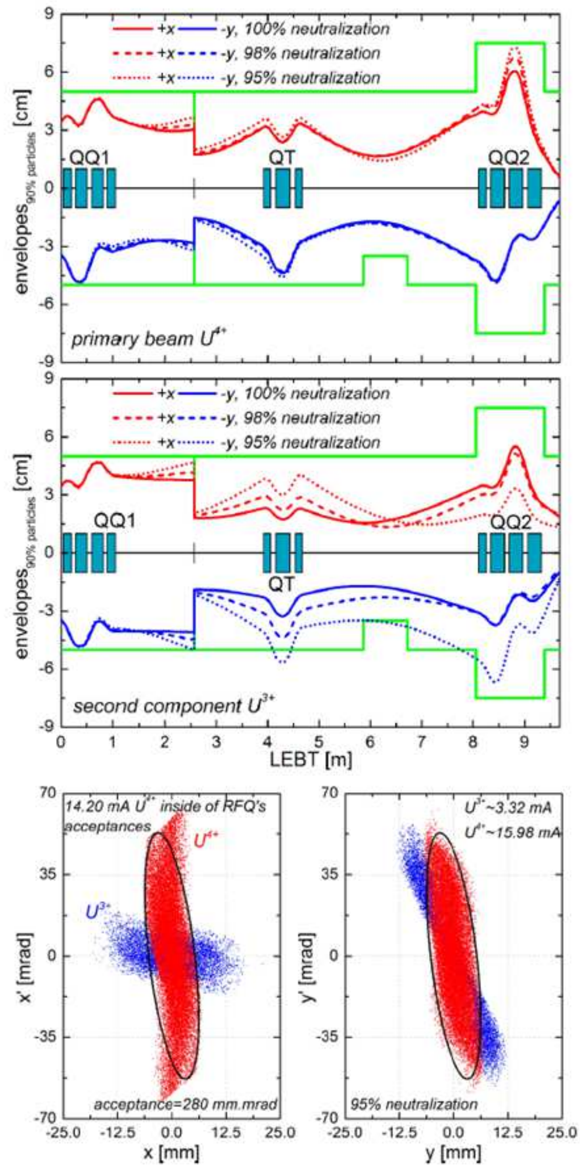

Figure 3: Simulated beam envelopes along the new LEBT: Design charge state 4+ (upper), charge state 3+ (centre), and phase space distributions (4+) at the RFQ entrance (lower).

will be revised such that lower surface fields are applied at the expense of reduced acceptance.

MEBT AND IH-DTL

The transverse and longitudinal focusing strengths of the super lens are coupled since it is an RFQ. In total the present MEBT offers just four knobs to tune its matching performance to the IH-DTL: two quadrupole gradients, one rf-amplitude, and one rf-phase. This limitation together with too low rf-amplitudes (from sparking) causes poor longitudinal matching to the KONUS IH-DTL. A new MEBT design [3] foresees two symmetric triplets and one buncher, i.e. six tuning knobs. The new MEBT layout and a compari-

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son of the longitudinal matching performances are shown in Fig. 4. However, the new design foresees additional 1.4 m in length. Accordingly, the subsequent IH-cavities have to be shifted and the stripper section has to be shortened by that distance. Simulations along the MEBT and IH-DTL

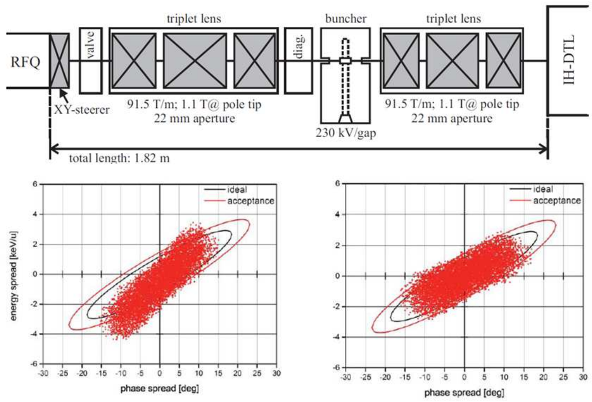

Figure 4: New layout of the MEBT (upper) and longitudinal matching performances (left: old design, right: new design).

indicate that the growth of emittance could be reduced from 57/93/320% (hor/ver/long, today's design) to 54/61/65% (new design) with simultaneous increase of the overall transmission from 86% to 100%.

ALVAREZ DTL

The beam parameters of the new post-stripper DTL are the same as for the existing one except the beam duty cycle. It will be limited to beam pulse length of 200 μs at a repetition rate of 10 Hz. The new UNILAC will serve just as an injector for the FAIR facility. Accordingly, the mixed operation between different rf-amplitudes and rf-pulse length, that caused damages at the cavity surface and limited the rf-amplitudes, will not be applied in the future.

For the type of DTL two options were initially considered: an Alvarez type and an IH type DTL. GSI has operational experience with both types. IH-DTLs offer high effective shunt impedances. This may allow to provide within the existing linac tunnel of GSI final ion energies of about 50 MeV/u (at a later upgrade stage). Such an energy opens the path to bypassing the existing synchrotron SIS18 and to inject directly into the synchrotron SIS100, which provides the final beam energy required by the FAIR users. Additionally, IH-DTLs require much less quadrupoles leading to reduction in cost. Alvarez-DTLs in turn proved to be reliable working horse accelerators. The related beam dynamics is fully understood even if considerable space charge is included. Periodic beam 3d-envelope solutions are properly defined as well as the procedure to match the incoming beam to that solution. For IH-DTLs for time being we did not find a procedure to assure matched beam transport and acceleration [4], that provides maximum mitigation of beam emittance growth from space charge.

As beam quality is of uttermost relevance for a low duty cycle injector, GSI currently plans to replace the existing post-stripper DTL with another Alvarez type DTL. The design works are at the beginning. The layout of the new cavities aims at optimization of the ratio of shunt-impedance to electric surface field. The latter shall be limited to 1.0 Kilpatrick. A new shape of drift tube plates has been found that provides 10% increase of impedance at the same surface field strength (Fig. 5). The curve does not include straight

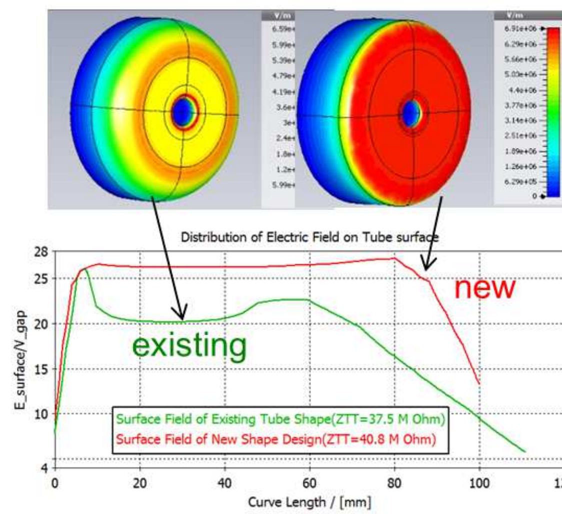

Figure 5: Comparison of the present (upper left) and new (upper right) drift tube design.

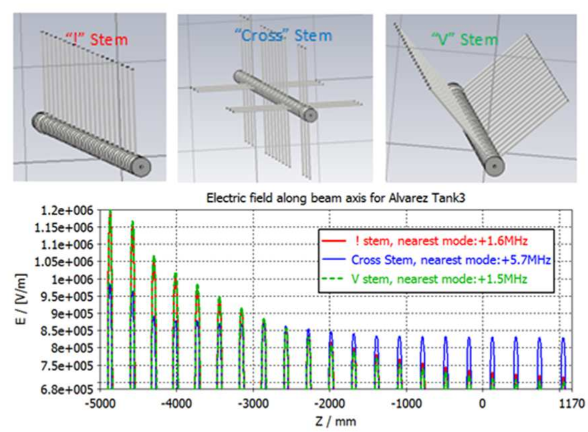

Figure 6: Several schemes of orientations of the DTL stems and their effect on the field stabilization.

sections and is defined through about 200 fixed points. This approach provides a smooth surface field distribution and should lower the multipacting rate. It does not cause significant extra cost for production nor it imposes restrictions wrt the achievable tolerances. Each drift tube along one tank will have the same end plate shape. The rf-frequency tuning of each cell is done through adoption of the drift tube length.

Stability of the accelerating field is done through well-considered orientation of the stems that keep the drift tubes.

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As the drift tubes have to be provided with cooling water and electrical current for the quadrupoles, each tube is kept by two stems. It turned out that the orientation of the two stems plays a significant role in the suppression of parasitic modes as illustrated in Fig. 6. The new DTL will comprise five tanks. For each tank a maximum rf-power of 1.8 MW is available of which 0.3 MW are beam power.

Special care will be taken for proper beam envelope matching along the four inter-tank sections. These sections impose interruptions of the periodicity of the lattice inside each tank. If not being well-designed they will trigger emittance growth from mismatch. Finally, the transverse phase advance has to be increased by about 15% wrt the present layout in order to compensate for tune depression from space charge.

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