HIGH CURRENT BEAM DYNAMICS FOR THE UPGRADED UNILAC

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Abstract

The performance of the UNILAC as a high cur-rent, heavy ion injector into the SIS has been in-vestigated including the future RFQ-IH-type pre-stripper accelerator. The beam dynamics are in-fluenced by space charge forces in all sections of the accelerator, most severely after the the strippers at 1.4 MeV/u and 11.4 Mev/u. In previous studies a strong dependence of emittance growth on the initial intensity distribution and the envelope forming of the beam had been found. In order to obtain reliable beam parameters and to determine the consequences for the injection into the SIS, the beam behaviour was simulated through the complete system down to the SIS starting with Gaussian particle distributions after the ion source.

1 INTRODUCTION

Within the GSI high intensity progamme [1] the present Wideroe-DTL will be replaced by an RFQ [2] and two IH-structures [3] designed for the acceleration of high current, low charge state beams.

In Fig. 1 the future structure of the UNILAC is shown with some of the design parameters. The space charge forces, indicated by normalized numbers, are high in all sections due to the charge state jumps in the two strippers. The Alvarez DTL and the transfer channel to the SIS were originally not intended for high current operation. Previous studies of beam behaviour in the individual sections using artificial particle distributions have indicated tolerable emittance growth; however, the realistic transformation of a beam through the complete system could be done only recently.

2 UNILAC AND BEAM TRANSPORT LINES

It is under discussion to replace the existing LEBT line, equipped with a 77.5° bending magnet for mass analysis, by an alternative [4] which uses two 60° magnets with intermediate focus and dispersion compensation. These beam lines are

BEAM TRANSPORT SYSTEM BEFORE RFQ Dipole Magnets	Existing LEBT 77.5°	Optional LEBT 2 x 60°	Without LEBT
ION SOURCE			
Current	32 mA	20 mA	
90% rms-Emittance (norm)	0.010µm	0.010µm	
LEBT			
Space Charge Compensation	> 97%	> 70%	
SC-compensated Current	1 mA	6 mA	
RFQ INPUT			
Current	28 mA	20 mA	17 mA
90% rms-Emittance (norm)	0.11µm	0.043µm	0.03µm
Beam in RFQ-Acceptance	47%	75%	88%
RFQ OUTPUT (15mA)			
90% rms-Emittance (norm)	0.11µm	0.08µm	.056µm

Table 1: High current parameters for LEBT lines used in the simulations with uranium ions

very different in emittance growth, current limit and beam loss (Table 1). In order to achieve the design RFQ output current of 15emA U^{4+} also different requirements must be imposed on ion source current and space charge compensation.

The high current beam transport through the gas stripper section was investigated [5] with respect to various types of particle distributions; the advantage of

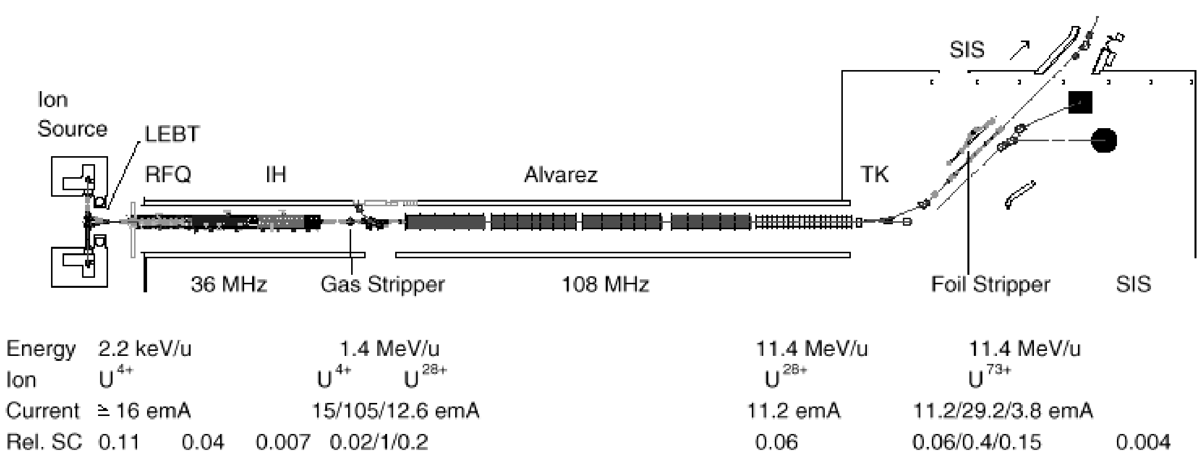

Figure 1: Unilac plan view and high current beam parameters (SC: space charge force)

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flat distributions was shown. It was found that even small changes of the beam envelopes may affect the emittance growth in the transverse phase planes. This section will be modified in order to improve the longitudinal matching to the Alvarez Linac.

In the Alvarez DTL the large transverse accep-tance of up to 10µm permits the low current operation at phase advances between 10^o and 100^o in a time share mode for different ions [6]. An already expanded beam with an rms emittance of 0.2µm may fill the drift tube aperture even at 50^0. The possibilities of time share operation will be restricted.

A foil stripper in the transfer line is used to achieve high SIS output energies. In high current operation the foil must be protected against dam-age and the beam should be saved from emittance growth by angular scattering and energy stragg-ling. The fast beam deflection system [7], now combined with a vertical charge separator, is included in the beam simulations. With a narrow upright beam spot on the foil the emittance growth in the horizontal plane will be minimized**,** while an increase of the vertical emittance is tolerated in view of the acceptance of the synchrotron.

3 BEAM DYNAMICS SIMULATION

3.1 Simulation Procedure

For the simulation of beam dynamics in the different accelerator sections the PIC-codes PARMT, PARMTEQ, PARMILA, LORAS were used; the particle transfers between the codes had to be established. Extensions to the codes were implemented to treat stripper effects, multi-charge beam dynamics and emittance evaluations. The ion optical parameters were determined in advance using an envelope code (MIRKO); even so, iterative readjustments of matching lenses had to be made.

3.2 Input Beams

Three particle simulation runs will be compared. Basis of comparison are beams of 15emA U^{4+} behind the RFQ. They were obtained from a Gaussian particle distribution which was either injected directly into the RFQ or was first transformed through the existing or the optional LEBT lines using the parameters of Table 1. From the entrance of the RFQ on, the beams were transformed through the UNILAC and transfer line without any adjustments.

3.3 Emittance Growth

The development of 90% rms emittances is shown in Fig**.** 2. Emittance growth is obvious in the IH-DTL in both transverse planes, between gas stripper and charge separation predominantly horizontally - resulting from specific beam envel-opes, in the foil stripper only in the vertical plane. Disregarding the foil stripper, only slight emittance growth is seen after the gas stripper section. Growth factors from RFQ to SIS are about 6.5 in the horizontal and 9 in the vertical plane.

The longitudinal emittance, though growing by a factor of 15 can be shaped to satisfy the require-ment of $dp/p<10^{-3}$ at the SIS.

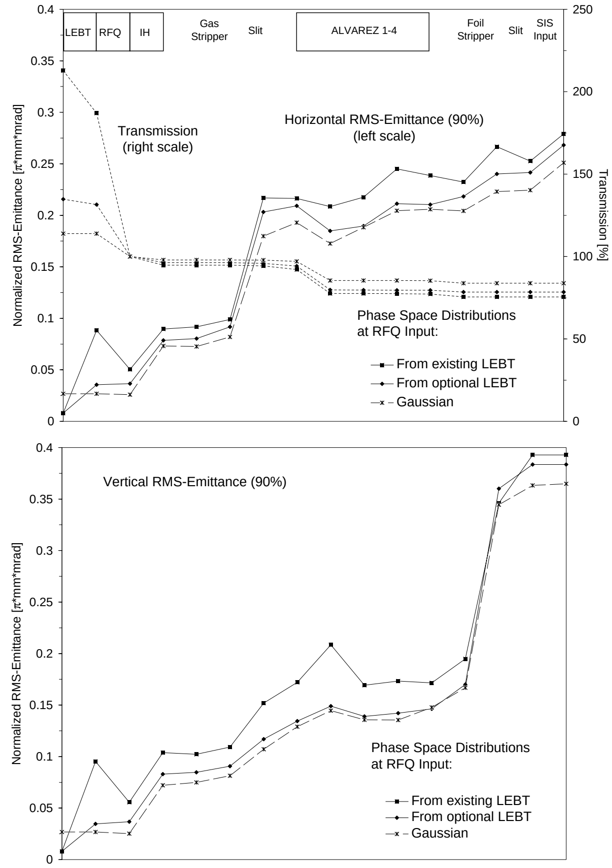

Figure: 2 Transverse rms emittances along the UNILAC for different input beams; Transmission (normalized to 100% at the RFQ exit)

3.4 Acceptance of SIS

The final full beam emittances do not fit into the acceptance of the SIS. The curves of Fig. 3 show the relations between partial beam intensity and occupied emittance. The vertical acceptance of the SIS (2.4µm) corresponds to the 70%-level of the design intensity and the horizontal one (0.8µm) to the 55%-level. The final acceptance numbers from the beam simulations are, referring to the design beam of 3.8emA U^{73+}:

beam from existing LEBT 44%
beam from optional LEBT 47%
beam from RFQ input 52%

Due to the emittance growth experienced by the beams the results do not depend significantly on the input particle distribution.

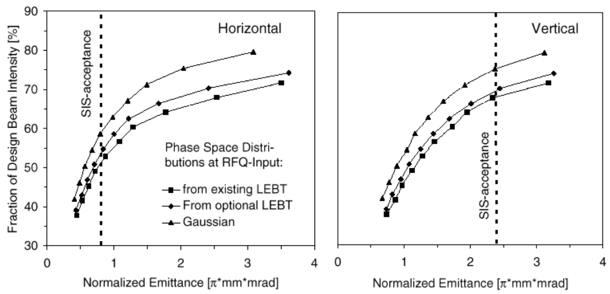

Figure: 3 Beam intensity within partial tansverse emittance at injection into the SIS. Intensity is normalized to the design current of 3.8emA U^{73+}

4 CONCLUSION

In the upgraded UNILAC the intended high currents will be delivered by the RFQ even from realistic, distorted input distributions, if the input current density is sufficiently increased. The required (LEBT-dependent) ion source currents are in a realistic regime (and have been produced with uranium).

The particle distributions obtained after the RFQ may be considered as realistic: after having lost their initially very different properties in the course of space charge dominated transformation through the RFQ they behave nearly identically furtheron.

From the consistent dynamics simulation of such a realistic particle ensemble over 250m of accel-eration and transport can be concluded that the transformation of the real beam through the UNILAC and transfer line will be possible without prohibiting beam losses.

However, emittance growth by space charge forces is of concern in all sections and emittance growth arising in the foil stripper can be minimized only in one phase space plane.

The final transverse emittances exceed the acceptance of the SIS. About 50% of the design beam intensity can be injected into 25 turns during 100µs, giving $2 \cdot 10^{10}$ particles of U^{73+} per pulse in the ring. This number corresponds to the space charge limit obtained from recent machine studies.

For ions lighter than uranium the space charge conditions are relaxed and a higher fraction of the beam intensity will be acceptable.

Some reduction of emittance growth may be expected from a redesign of the gas stripper section.

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