INVESTIGATION OF THE BEAM MATCHING TO THE GSI-ALVAREZ DTL UNDER SPACE CHARGE CONDITIONS

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Abstract

The main part of the UNILAC consists of the 36 MHz high current RFQ/IH-injector, a gas stripper at an energy of 1.4 MeV/u and a 108 MHz Alvarez poststripper, accelerating ions up to 11.4 MeV/u. The design beam current for U^{28+} is 12.6 emA at full energy. After the stripping process the electrical beam current is increased by a factor of 7 for uranium. This leads to a significant beam emittance growth during the transport through the charge state separator and the matching section to the Alvarez DTL. This paper reports results of numerical studies and beam experiments focused on the matching of the high intensity beams to the Alvarez for different ion species. Possible improvements of the transverse focusing in the Alvarez linac are discussed and the total impact to the beam quality at the synchrotron injection is evaluated.

GSI UNILAC

The UNILAC [1] is designed to accelerate all ion species with mass over charge ratios of up to 8.5 and to fill the heavy ion synchrotron SIS up to its space charge limit. The main part of the UNILAC consists of the 36 MHz high current injector (HSI), a gas stripper section at energy of 1.4 MeV/u and a 108 MHz Alvarez type poststripper, accelerating ions up to 11.4 MeV/u (Fig.1).

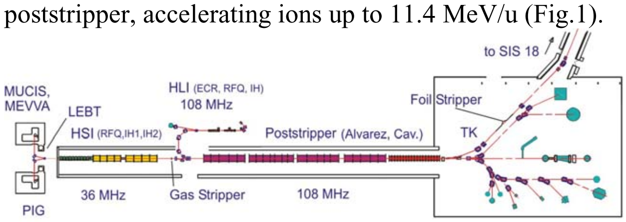

Figure 1: Schematic overview of the GSI UNILAC.

The prestripper section HSI [2] consists of two ion source terminals (PIG and MUCIS/MEVVA), the Low Energy Beam Transport (LEBT), a Radio Frequency Quadrupole accelerator (RFQ), a short matching section (superlens), and two IH (Interdigital H-structure) tanks.

The HSI has been in routine operation since 1999 and has achieved the design intensities for light and medium ions with a significant surplus of the primary beam current coming from the ion source. For heavy ions the achieved beam intensities behind HSI are about factor of two lower than the design values. Several measures were proposed and partially realized for the increase of the beam current and brilliance at the entrance of the synchrotron SIS 18 [3].

GAS STRIPPER SECTION

In the UNILAC gas stripper section [4] the charge states of incoming ions at energy of 1.4 Mev/u with a charge to mass ratio of A/q ≤ 65 are increased by stripping in a nitrogen gas jet to allow for further acceleration at A/q ≤ 8.5. The design U^{4+} beam current of 15 emA rises up to 7 times during stripping. The U^{28+} ions with design beam current of up to 12.6 emA have to be separated entirely from the neighbouring charge states.

Space charge parameter (SCP), calculated from the results of the uranium beam dynamics simulation in the UNILAC, is shown on Fig.2. As can be seen, the SCP is the highest in the stripper area, but it decreases rapidly with particle separation. Another significant peak at the entrance of the 1st Alvarez tank appears due to the small size of the beam in all three dimensions, as required for the beam matching.

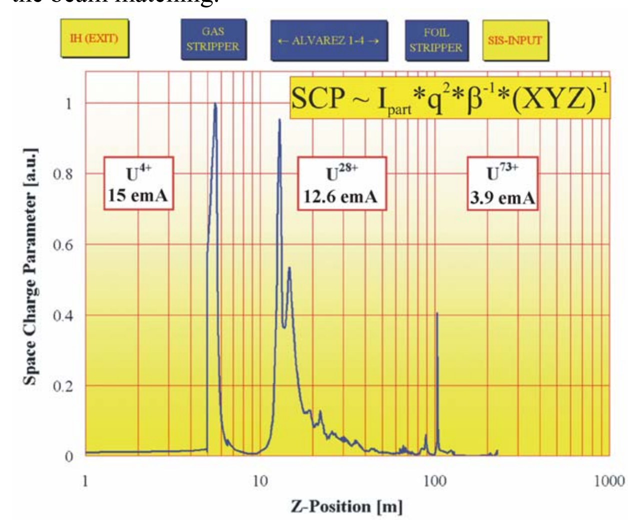

Figure 2: Space charge parameter along UNILAC.

Therefore the separation of the required ion species and the beam matching to the DTL structure are taking place under extremely high space charge influence.

A special optimization procedure, described below in detail, was proposed for the beam matching to the DTL and successfully implemented during machine experiments. It must be pointed out that the recently described procedure does not take into account the defocusing space charge forces. Nevertheless, for the maximum achieved beam current behind the stripper section for the U^{28+} (4 emA), the proposed method was implemented and transmission through the whole Alvarez section up to 100% was reached.

However, the design beam current behind the stripper section is about factor of three higher (12.6 emA for

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U^{28+}). The FAIR project [5] requires a uranium beam current even up to 15 emA. For these cases a much more complicated matching which also depends on the longitudinal structure of the beam is necessary.

The postaccelerator performance can also be improved by the optimization of the quadrupole settings in Alvarez DTL. It is most important in the 1st Alvarez tank [7], where increasing of the quadrupole strength leads to the higher phase advance of the focusing channel.

Due to the high mass to charge ratio of $^{238}U^{28+}$ ions, the maximum zero current phase advance σ_0 in the 1st Alvarez DTL is limited to 45° by the quadrupole power supplies. For a $^{40}Ar^{10+}$ beam mass to charge ratio is less, which allows the experimental study of the phase advance influence to the beam quality in the Alvarez accelerator. The space charge effects can be scaled from argon beam to uranium. To satisfy the requirements of the FAIR project, the intensities of Ar^{10+} beams up to 11 emA have been studied experimentally.

Accordingly, systematic numerical studies have already been started in collaboration with the several institutions over the world.

Matching Section

After the separation of the U^{28+} ions the beam must be matched to the periodic solution of the beta function of the 1st Alvarez DTL. The 6-D matching of the beam is carried out by a system consisting of the 36 MHz rebuncher, the quadrupole doublet, the quadrupole triplet and the 108 MHz rebuncher (Fig.3).

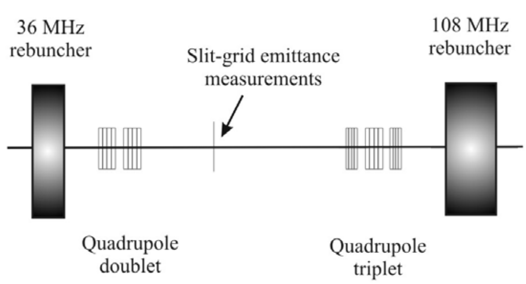

Figure 3: Matching section to the 1st Alvarez DTL.

Usually empirical matching can be done by a variation of the quadrupole settings preceding the DTL until a sufficient transmission through the Alvarez section of more than 90% is achieved. In order to increase the transmission close to 100%, a systematic matching procedure was proposed and realized during machine experiments. The method includes calculations of beam dynamics by means of MAD8 code in matching line to the 1st Alvarez tank and is based on the beam emittance measurements.

Emittance Measurements

The transverse phase space distribution (Fig.4) in front of the DTL is measured in both directions with a slit-grid device placed between quadrupole doublet and triplet (Fig.3). From the obtained data the beam Twiss parameters are extracted.

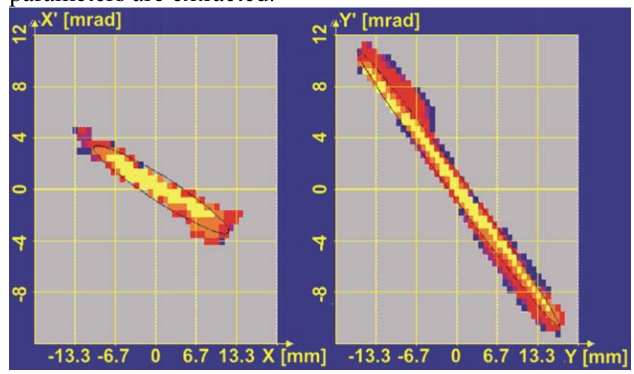

Figure 4: Data of emittance measurements at the matching section for 4 emA U^{28+} beam. Level of intensity is shown by the colour scale.

Optimization Procedure

Knowing the settings of the quadrupoles in the matching section, the measured Twiss parameters are transformed back to the entry of the matching section. The obtained Twiss parameters are used for the calculation of the horizontal and vertical beta-functions of the beam in the matching section and first cells of the 1st Alvarez tank (upper graph of Fig.5).

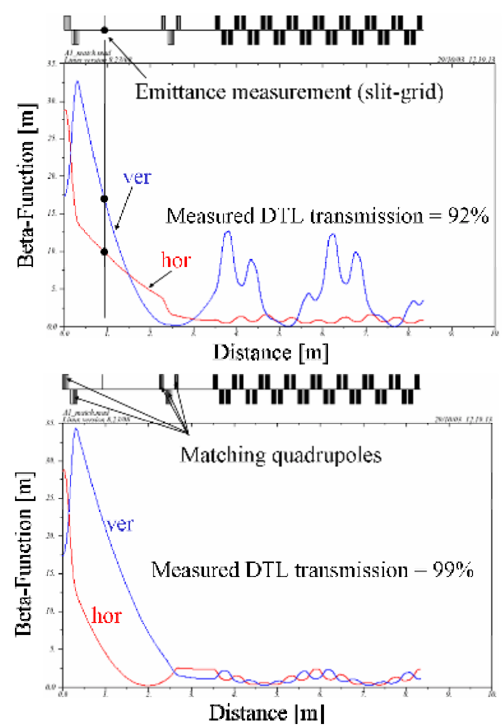

Figure 5: Horizontal and vertical beta-functions in the matching section and first cells of the 1st Alvarez tank with quadrupole setting before (upper graph) and after (lower graph) optimization.

In general the beam is mismatched with the DTL resulting in large beta function oscillations along the whole Alvarez accelerator, which may cause transmission losses and emittance growth.

Using the quadrupole settings in the first cells of the DTL the periodic solution for the 1st Alvarez tank is calculated. To match the periodic DTL solution, a fitting routine involving the five matching quadrupoles is applied. The optimized quadrupole settings provide the Twiss parameters, which are better matched to the DTL.

Applying these strengths the losses along the Alvarez section were reduced from 8% to less than 1%, being the resolution of the transmission measurement.

MULTI-PARTICLE BEAM DYNAMICS SIMULATIONS

Transmission in A1-A4 tanks as a function of beam current was measured during experiments by changing the gas pressure in the stripper and also was simulated by means of the DYNAMION code [6]. The measured transmission was about 90% and the simulated one is about 97% in range of beam current up to 4 mA of U^{28+} beam. The DYNAMION simulations were done from the position of the emittance measurements. The transversal input distribution of the particles was generated from the experimental data. The number of multi-particles in each bin is proportional to the measured beam intensity. The longitudinal distribution was obtained from the beam dynamics simulations in the IH tanks and stripper section with the codes LORASR and PARMTRA (Fig.6).

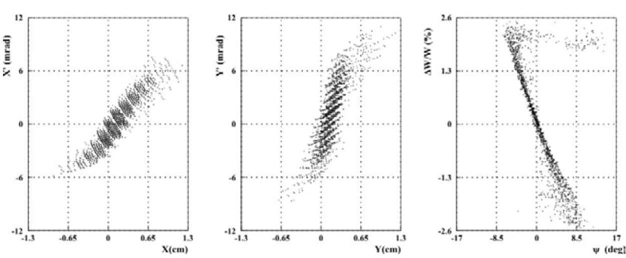

Figure 6: The particle distribution at the entrance of the 1st Alvarez tank simulated with the DYNAMION code from the position of emittance measurements.

The DYNAMION simulations of the beam dynamics in the 1st Alvarez tank show high transmission, but also oscillation of transverse beam envelopes and remarkable emittance growth, which leads to the particle losses in the following part of the UNILAC.

OPTIMIZATION OF THE DTL

The procedure, described above, was implemented to the matching of 6 emA argon beam (corresponding to a 12.6 emA uranium beam) to the 1st Alvarez tank with different values of the phase advance σ_0.

The transmission rises with the increasing of the phase advance up to 50° and then comes to the saturation level. Measurements of the beam emittance have been done with a slit-grid device behind the whole Alvarez section. The beam brilliance in dependence of the phase advance in the 1st Alvarez tank is shown in Fig.7. As can be seen, a phase advance σ_0>50° is required to increase the beam brilliance.

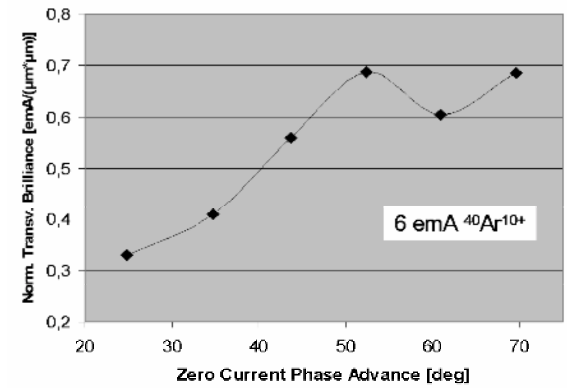

Figure 7: Brilliance of an Ar^{10+} beam behind the Alvarez section as a function of the transverse phase advance σ_0.

CONCLUSION

An efficient method for beam matching to the Alvarez section of the UNILAC was proposed and successfully realized for the beams with medium intensities. The matching of the required for FAIR space charge dominated beam needs more complicated procedures. Numerical studies of the problem have already been started. It is shown that the beam brilliance behind the Alvarez accelerator can be improved. The plans are to upgrade part of the power supplies for the quadrupoles of the 1st Alvarez tank, resulting in a higher phase advance σ_0 for the uranium case. These measures should lead to higher transmission, less emittance growth in the DTL and a significantly improved quality of the beam injected into the synchrotron. We acknowledge the support of the European Community-Research Infrastructure Activity under the FP6 “Structuring the European Research Area” programme (CARE, contract number RII3-CT-2003-506395) and under INTAS project 03-54-3543.

REFERENCES

[1] W. Barth et al., Development of the UNILAC towards a Megawatt Beam Injector// these proceedings.

[2] W. Barth et al., Commissioning of the 1.4 MeV/u High Current Heavy Ion Linac at GSI// Proc. LINAC-2000, Monterey, USA, 2000.

[3] W. Barth et al., Achievements of the High Current Beam Performance of the GSI UNILAC// EPAC-04, Lucerne, 2004.

[4] W. Barth et al., The New Gas Stripper and Charge State Separator of the GSI High Current Injector// Proc. LINAC-2000, Monterey, USA, 2000.

[5] W. Henning, An International Accelerator Facility for Research with Ions and Antiprotons// EPAC-04, Lucerne, 2004.

[6] A. Kolomiets et al., DYNAMION - The Code for Beam Dynamics Simulation in High Current Ion Linac// Proc. EPAC-98, Stockholm, Sweden, 1998.

[7] L. Groening et al., Measurements and Simulations on the Beam Brilliance in the Universal Linear Accelerator UNILAC at GSI// Proc. LINAC-02, Kuongjui, Korea, 2002.