EXPERIENCES DURING OPERATION WITH HIGH CURRENT U^{4+} BEAMS IN THE NEW GSI HIGH CURRENT INJECTOR

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Abstract

The High Current Injector (HSI) of the GSI Universal Linear Accelerator UNILAC was installed and commissioned successfully in 1999. An increase of more than two orders of magnitude in particle number for the heaviest elements in the heavy ion synchrotron (SIS) had to be gained. Since that time many different ion species were accelerated in the UNILAC. In 2001 an experiment at the fragment separator used $2{\cdot}10^9$ uranium ions per spill, corresponding to an U^{73+} current of 0.2 emA at the injection into the SIS. In order to meet this request the MEVVA ion source was used for the first time in routine operation. The rf-field levels for uranium were achieved in the HSI due to simultaneous rf-conditioning during preceding experiments. The paper is focused on the first experiences with a MEVVA-beam during a long term beam operation. Maximum and average transmission through the HSI, the stripping area, the Alvarez accelerator, the single gap resonators and the transfer channel to the SIS are be presented. Additional results of measurements on beam quality, as beam emittance and bunch structure in the whole linac for the MEVVA-uranium beam are included.

1 INTRODUCTION

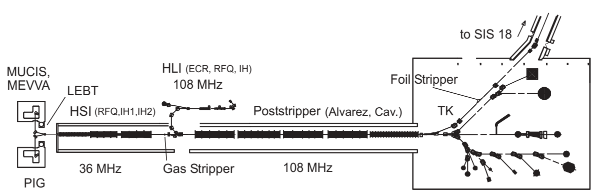

Fig. 1: Schematic overview of the GSI UNILAC.

For a 15 emA $^{238}U^{4+}$ beam out of the HSI up to $4{\cdot}10^{10}$ U^{73+} particles must be delivered to the SIS during 100 μs. The SIS space charge limit is reached by a 20 turn injection into the horizontal phase space. The required beam parameters (for the uranium case) are summarized in Table 1. In 1999 the UNILAC (see Figure 1) underwent a renewal of its prestripper section to increase the ion beam current to I = 0.25·A/q (emA) for mass over charge ratios of up to 65 [1]. The high current injector HSI consists of ion sources of MEVVA-, MUCIS or Penning-type installed on a high voltage platform, a mass spectrometer and a low energy beam transport system (LEBT). The 36 MHz IH-RFQ accelerates the ion beam from 2.2 keV/u to 120 keV/u. A voltage amplitude of 137 kV and a max. surface field of 28 MV/m is necessary to provide the required accelerating gain. The matching to the following IH-DTL is done with a short 11 cell adapter RFQ (Super Lens). The IH-DTL consists of two separate tanks accelerating the beam up to the full HSI-energy of 1.4 MeV/u [2]. Before injection into the Alvarez accelerator the HSI-beam is stripped - charge analysis is indispensable. It was confirmed by beam measurements with a high intensity argon beam that the Alvarez accelerates the HSI beam without any significant particle loss. In the transfer line to the synchrotron at 11.4 MeV/u a foil stripper and another charge state separator system is in use.

Table 1: Specified beam parameters at UNILAC and SIS injection (for uranium) [1].

	HSI entrance	HSI exit	Alvarez entrance	SIS injection
Ion species	$^{238}U^{4+}$	$^{238}U^{4+}$	$^{238}U^{28+}$	$^{238}U^{73+}$
El. Current [mA]	16.5	15	12.5	4.6
Part. per 100μs pulse	$2.6{\cdot}10^{12}$	$2.3{\cdot}10^{12}$	$2.8{\cdot}10^{11}$	$4.2{\cdot}10^{10}$
Energy [MeV/u]	0.0022	1.4	1.4	11.4
ΔW/W	-	$4{\cdot}10^{-3}$	$\pm1{\cdot}10^{-2}$	$\pm2{\cdot}10^{-3}$
$\varepsilon_{n,x}$ [mm mrad]	0.3	0.5	0.75	0.8
$\varepsilon_{n,y}$ [mm mrad]	0.3	0.5	0.75	2.5

2 IMPROVEMENT OF THE UNILAC PERFORMANCE

Especially for the requested operation with intense uranium beams the performance of the UNILAC was significantly improved. The MEVVA-ion source was renewed and improved [3]: Among other things the use of stabilized internal grids led to a long service life (typically 7 days) and a high ion source beam availability. The pulse to pulse stability was enhanced by increasing the arc current. With the additional application of a strong pulsed magnetic field an U^{4+} fraction of up to 67 % was reached. Enhancements of the extraction system resulted in a higher extraction voltage and accordingly in a higher total current density.

Table 2: Achieved rf-amplitudes for U^{4+}-operation

	Electrode Voltage (U^{4+})	**Dec. 01**	**July 02**
RFQ	125 kV	103 %	102 %
Super Lens	194 kV	92 %	110 %
IH1	1053 kV	105 %	100 %
IH2	961 kV	107 %	102 %

Due to the high rf surface field in the RFQ and in the Super Lens rf-conditioning has to be taken into account if low charged heavy ions must be accelerated in the HSI.

As illustrated in Table 2 permanent rf-conditioning with a low duty factor (approx. 0.3 %) in a time sharing mode with the regular beam time allows for the required rf-amplitudes. After the December 2001-run the Super Lens was completely demounted. In a upgrade scheme the rf-performance was significantly improved: the maximum field strength was slightly decreased, the surface quality was improved, a new plunger design is applied and the inductive power coupling is enhanced.

A constriction after the Alvarez section could be eliminated by the reduction of the number of the single gap resonators from 15 to 10 and by the application of longitudinal alternating phase focusing [4] – allowing for beam transport with smaller beta-function modulation and thus for better transmission. Additional steering- and beam diagnostics-devices facilitate the matching to the following beam transport section.

3 MEASUREMENTS WITH THE MEVVA-URANIUM BEAM

As shown in Fig. 2 the horizontal emittance ($\varepsilon_{x,90\%}$ = 190 mm·mrad) in the LEBT exceeds the RFQ acceptance of about 138 mm·mrad, while the vertical emittance

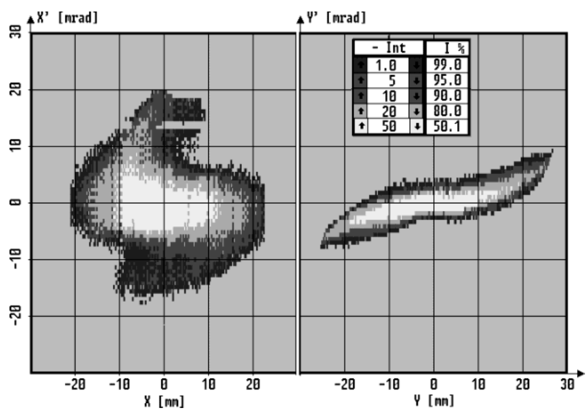

Fig. 2: Measured LEBT-emittance of a 4 emA U^{4+}.

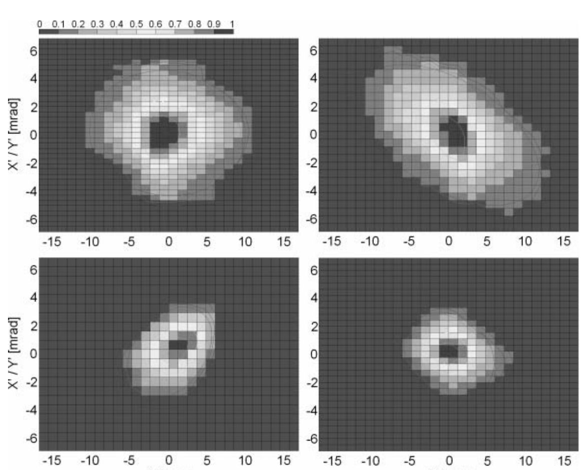

Fig. 3: Measured single shot-emittance before (top) and after (bottom) the poststripper accelerator.

(90 mm·mrad) fits well – the different transversal emittance data ensure from a optimisation with a big input phase space distribution. The particle transmission through the RFQ is close to 85 % - the particle loss of 10 % in the IH-section due to non-accelerated particles from the RFQ is predicted by simulations [5]. Further emittance measurements were performed in the whole UNILAC. The results are in good agreement to the calculation done with different multiparticle codes. For example, Fig. 3 shows the measured transverse emittance of a single macropulse (150 μs) before and after the Alvarez accelerator – the normalized emittance does not change significantly, while the velocity β increases by a factor of three.

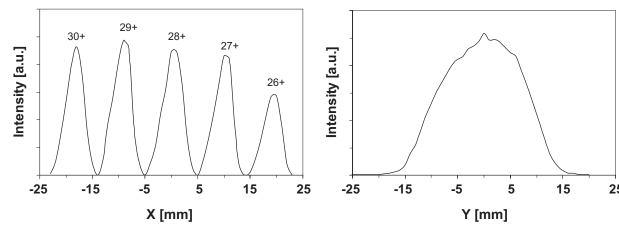

Fig. 4: Measured transverse profiles in the charge analysator after stripping a $^{238}U^{4+}$ beam (I = 2.5 emA).

The measured charge state spectrum after stripping of a uranium beam in a N_2-gasjet yields in a stripping efficiency of 13 % for the main charge state (28+). Fig. 4 epitomizes the measured transverse beam profiles (2.5 emA) after stripping and after transport to the analyzing slit. The dispersion in the spectrometer is high

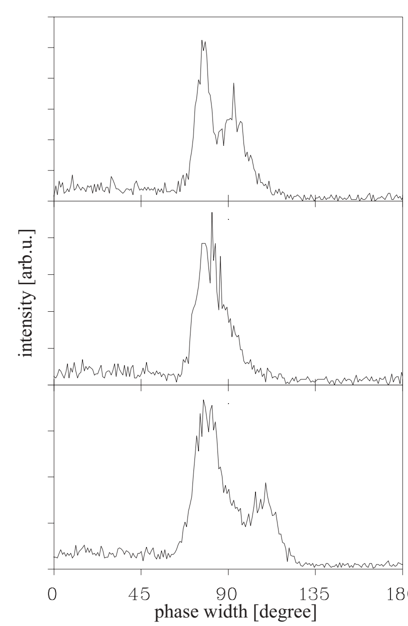

Fig. 5: Bunch shape measurements of the HSI beam with low intensity (top), higher intensity (middle) and with higher intensity including space charge effects during transport after the gas stripper (bottom).

enough to separate all charge states without scraping the main charge state. The vertical beam size is less than 30 mm, which is small enough to pass the spectrometer without any particle loss.

Results of the measurements done with a bunch shape monitor [6], placed after the gas stripper, are resumed in Fig. 5. Without any space charge effects in the HSI a typical bunch width from the RFQ is observed. A higher beam current in the HSI results in smaller bunch shape. If stripping and transport under space charge conditions is done the bunch width increases by a factor of 2.

The substantial measurements done with a MEVVA-uranium beam are summarized in Table 3.

Table 3: Summary of the U^{4+} - beam measurements

max. beam intensity (RFQ input)	8.5 emA ($^{238}U^{4+}$)
max. RFQ-transmission	85 % *(3 emA/RFQ input)*
beam emittance (LEBT)	190 mm·mrad (hor.) 90 mm·mrad (vert.)
max. HSI-transmission	75 %
beam loading for 3 emA (RFQ, IH1, IH2)	25 kW, 100 kW, 100 kW
bunch length (4m after the gas stripper)	± 24° (0.1 emA ± 32° (2.5 emA)
reproducibility of the transverse emittance (stand. dev./10 pulses)	± 9 % (Alvarez input) ± 12 % (Alvarez output)
max. beam intensity, $^{238}U^{28+}$, 11.4 MeV/u	2.5 emA (Alvarez input) 2.0 emA (Alvarez output) 1.2 emA (transfer line)
max. beam intensity, $^{238}U^{73+}$, 11.4 MeV/u *max. number of ions per 100 µs pulse*	0.5 emA $4.3 \cdot 10^9$

4 BEAM OPERATION

In 2001 [7] and in 2002 the UNILAC had to deliver an uranium beam with high intensities to meet the demand for high particle numbers after the heavy ion synchrotron SIS (up to $2 \cdot 10^9$ particles per spill). During these runs, lasting two and three weeks, the MEVVA ion source delivered U^{4+} ions for the HSI. The averaged beam intensity in December 01 was 5.5 ± 1.1 emA in front of the RFQ. A continuous optimization of the UNILAC performance was not done – therefore, the improved beam intensity at the end of the run did not lead to significant higher particle numbers at the SIS injection. An averaged RFQ-transmission of 56 % (± 7%) was achieved - in the whole HSI 51 % (± 7 %). At the end of the transfer line in average 0.15 emA U^{73+} were injected into the synchrotron ($1.3 \cdot 10^9$ particles per 100 µs pulse).

In Fig. 6. the typical particle transmission measured during the 2001- and the 2002-run along the whole UNILAC is illustrated. The beam intensity at the entrance of the RFQ was 4.5 emA (2002) instead of 7 emA (2001), while the particle transmission in the HSI was increased by an optimized matching to the RFQ. Hardware modifications in the stripper device were done resulting in a better stripping efficiency. Therefore the particle number in the 2002-run was up to 30% higher. Nevertheless a significant increase of the particle loss along the whole machine is observed, leading to the necessity of frequent machine tuning.

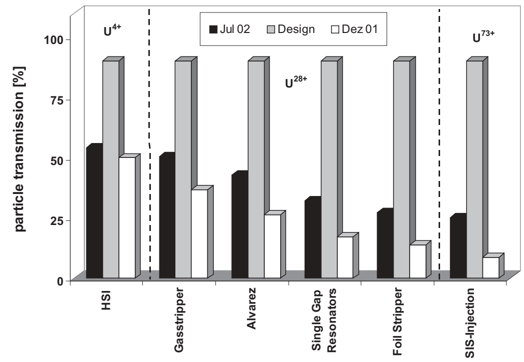

Fig. 6: Typical UNILAC-transmission during the 2001- and 2002-run; the design transmission is included.

5 CONCLUSION

In a medium term perspective up to 1 emA U^{73+} (10^{10} particles per 100 µs pulse) may be reached, if the offer of primary beam intensity in the LEBT could be close to 8 emA. In addition, the matching to the poststripper accelerator and the beam transport in the transfer line has to be improved. A full particle transmission was observed in this area for up to 10 emA Ar^{10+}, with a beam coming from the MUCIS ion source. The SIS space charge limit for medium masses was already reached. In long term range the UNILAC has to serve for the SIS with up to $4 \cdot 10^{10}$ U^{73+}-particles per 100 µs. R&D work is planned for a complete upgrade of the HSI front end and smooth modifications in the Alvarez and the transfer line to the SIS, what may result in an increase of the number of particles inside the SIS-acceptance.

6 REFERENCES

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