ACHIEVEMENTS OF THE HIGH CURRENT BEAM PERFORMANCE OF THE GSI UNILAC

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Abstract

The present GSI-accelerator complex is foreseen to serve the future synchrotron SIS 100 [1] as an injector for up to 10^{12} U^{28+} particles/sec. The High Current Injector (HSI) of the UNILAC was successfully commissioned five years ago. An increase of more than two orders of magnitude in particle number for the heaviest elements in the SIS 18 had to be gained. Since that time many different ion species were accelerated in routine operation. In 2001 a physics experiment used $2\cdot10^9$ Uranium ions per spill. In order to meet this request the MEVVA ion source provided for the first time in routine operation an Uranium beam with high intensity. The main purpose of the machine development program during the last two years was the enhancement of the intensity for Uranium beams. Different hardware measures and an extended investigation program in all UNILAC-sections resulted in an increase of the Uranium intensity by a factor of 5. The paper will focus on the measurements of beam quality, as beam emittance and bunch structure for Megawatt-Uranium beams. Additionally, the proposed medium- and long-term hardware measures will be described, which should result in the required Uranium intensity to fill the existing SIS 18 up to the space charge limit.

INTRODUCTION

For a 15 emA $^{238}U^{4+}$ (as a design ion) beam out of the HSI up to $4\cdot10^{10}$ U^{73+} particles should be delivered to the SIS 18 during 100 μs. The SIS 18 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. The UNILAC-HSI-front end consists of ion sources of MEVVA-, MUCIS- or Penning-type and a low energy beam transport system (LEBT) including a mass spectrometer to select isotopes for the injection into the RFQ. The 36 MHz IH-RFQ accelerates the ion beam from 2.2 keV/u to 120 keV/u. 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 [3]. Before injection into the Alvarez accelerator the HSI-beam is stripped and one charge state is selected (e.g. 28+ for Uranium beams). The Alvarez accelerates the high intensity HSI beam without any significant particle loss. In the transfer line to the SIS 18 at 11.4 MeV/u a foil stripper and another charge state separator system is in use. For the longitudinal matching to the SIS 18, the single gap resonators can partly be used, as well as a dedicated 36 MHz-rebuncher in the transfer line.

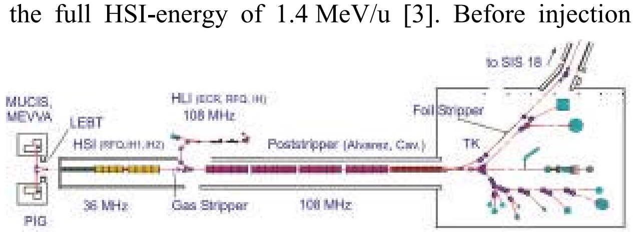

Fig. 1: Schematic overview of the GSI UNILAC.

Table 1: Specified beam parameters at UNILAC and SIS injection (for Uranium) [2].

	HSI entrance	HSI exit	Alvarez entrance	SIS injection	**Required for FAIR**
Ion species	$^{238}U^{4+}$	$^{238}U^{4+}$	$^{238}U^{28+}$	$^{238}U^{73+}$	$\mathbf{^{238}U^{28+}}$
El. Current [mA]	16.5	15	12.5	4.6	**15.0**
Part. per 100μs pulse	$2.6\cdot10^{12}$	$2.3\cdot10^{12}$	$2.8\cdot10^{11}$	$4.2\cdot10^{10}$	$\mathbf{3.3\cdot10^{11}}$
Energy [MeV/u]	0.0022	1.4	1.4	11.4	**11.4**
ΔW/W	-	$4\cdot10^{-3}$	$\pm1\cdot10^{-2}$	$\pm2\cdot10^{-3}$	$\mathbf{\pm2\cdot10^{-3}}$
$\varepsilon_{n,x}$ [mm mrad]	0.3	0.5	0.75	0.8	**0.8**
$\varepsilon_{n,y}$ [mm mrad]	0.3	0.5	0.75	2.5	**2.5**

UNILAC UPGRADE MEASURES

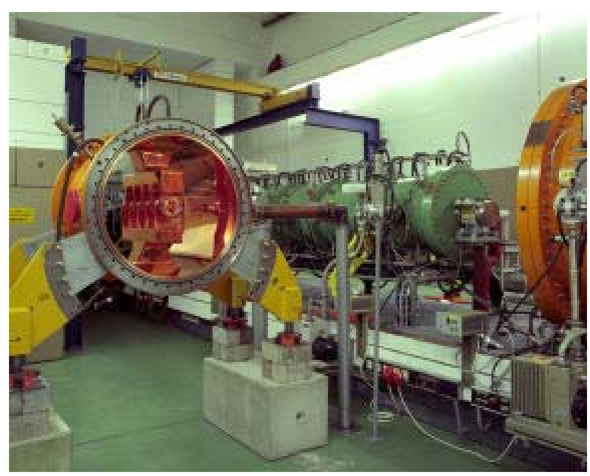

Fig. 2: The upgrade of the HSI-Super Lens in 2002.

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 [4]. The use of stabilized internal grids led to a long service life (typically 7 days) and 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. 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. 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. In 2002 the Super Lens was completely dismounted. In an upgrade scheme the rf-performance was significantly improved: the maximum field strength was slightly decreased, the surface quality was improved, a new plunger design was applied [5]. Since the end of May 2004 a comparable upgrade measure for the RFQ has been in progress. A bottle neck after the Alvarez section was eliminated by the reduction of the number of the single gap resonators from 15 to 10 [6] – allowing beam transport with smaller beta-function modulation and thus for better transmission. Adjustments along all sections were performed additionally with high accuracy.

HIGH CURRENT BEAM DIAGNOSTICS

If the HSI delivers highly intense Uranium beams, the power stored in one pulse (100 µs) can easily destroy any conventional destructive diagnostics element. Either the beam intensity has to be reduced to perform the measurements, or dedicated non-destructive measurement devices have to be used [7]. At the UNILAC both paths are followed: non-destructive devices such as current transformers as well as residual gas fluorescence monitors [8] for profile measurements are installed. An online surveillance system automatically reduces the frequency and the length of the beam pulses, keeping the deposited power well below any destruction threshold.

The rf-bunch pick-ups are 4-segmented probes, which allow for deriving the beam position by digitizing the power of the 6th harmonic of the rf-frequency. Besides to this function, the online transmission surveillance system is also based on the use of current transformers. This surveillance system is directly linked to the control system. If a significant beam loss is detected, an interlock signal is generated that cuts off the beam pulse within less than 10 µs. The capacitive pick-ups measure the beam energy by a time-of-flight technique; the sampled signal of up to two pick-ups can be displayed on a video screen. Using this visualization it is possible to evaluate the shape and stability of the macro-pulse.

Measurements of the transverse emittance along the whole UNILAC were performed at eight different places exclusively with a slit-grid device for short pulses. For high current operation a pepper-pot system capable of measuring the transverse emittance within one macro-pulse is used. The set-up for an online measurement of longitudinal emittances for the different UNILAC output-energies installed in the transfer line to the SIS 18 comprises an iris, magnetic bends, a vertical rf-chopper at 108 MHz, and a beam profile screen. The method is based on the transformation of the longitudinal particle coordinates into transverse coordinates. With the dispersion after bending magnets the particles energy deviation is transformed at first order into the horizontal position. If the bunch passes a vertical rf-chopper the particles longitudinal phase is transformed into a vertical kick, being a vertical offset after a subsequent drift. Additional bunch shape measurements at 1.4 MeV/u are capable of using diamond detectors; the ion beam passes a thin Au-foil – the "Rutherford"-scattered particles hit the detector at a small angle. The bunch shape is obtained by measuring the arrival time of the particles against a reference.

HIGH CURRENT MACHINE INVESTIGATIONS

Multi particle simulations were carried out for a high current (38 emA) Ar^{1+}-beam. The horizontal emittance was measured directly behind the dc acceleration gap and a macro particle distribution was refined. Longitudinally a dc-beam without energy spread was supposed. Simulations with the PARMTRA code taking into account higher order calculations of the spectrometer, a fully space charge compensated beam, and optimized matching to the RFQ acceptance were carried out. 57 % of the particles arrived at the RFQ, in agreement with measurements. The horizontal 90 %-emittance remained nearly constant, the vertical one was shrunken. The six dimensional particle output coordinates served as input for the beam dynamics simulations in the RFQ. The overall transmission from the dc gap to the RFQ-output amounts to 25 %. It can be concluded, that a moderately upgraded LEBT (with increased apertures) and RFQ makes it possible to increase the present U^{4+}-current of 6 emA by 50 %. [9]

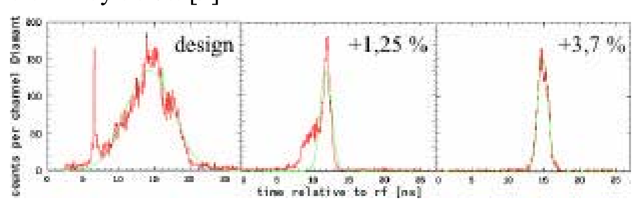

Fig. 3 Bunch structure measurements for an intense Uranium beam after the HSI for different rf-amplitudes of the IH2-structure.

Results of the measurements done with a bunch shape monitor are resumed in Fig. 3. It is shown that the longitudinal beam quality depends strongly on the rf-settings of the HSI-structures. After the optimization of the rf-settings, the transmission in the poststripper- and single gap resonator- section was increased, as well as the longitudinal matching to the synchrotron.

^{238}U-BEAMS FOR SIS 18-INJECTION

Fig. 4 shows the increase of the Uranium beam intensities along the UNILAC and transfer line during 2002 and 2003. Mainly the increased primary beam intensity from the MEVVA ion source, the higher beam stability and availability allowed machine tuning with

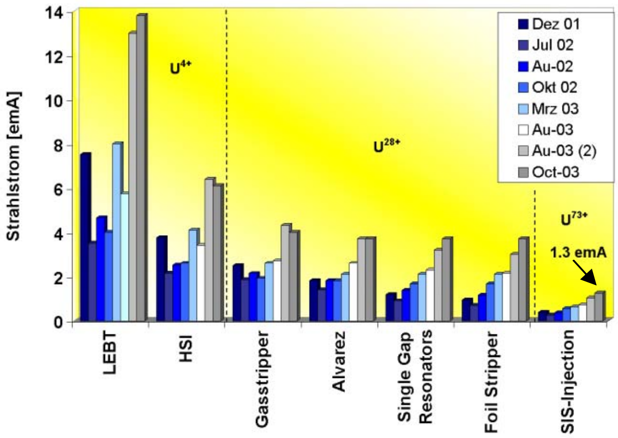

Fig. 4: Improvement of Uranium beam intensities along the UNILAC during the last two years. [10]

space charge dominated Uranium beams. In 2003 a maximum U^{73+}-intensity of $1.1 \cdot 10^{10}$ particles per 100 µs ($8.0 \cdot 10^{10}$ particles per 100 µs, U^{28+}) was obtained. For the high current Uranium stripper operation it is obvious to reduce the thermal stress for the carbon stripping foil. In order to cope with the potentially disastrous beam load, the established magnetic beam sweeping system is in use to save the foil and limit the beam quality deteriorations caused by the stripping process as well. Results of the emittance measurement of a high current Uranium beam after stripping to charge state 73+ are shown in Fig. 5. The normalized vertical emittance of 2.4 mm·mrad is as required (see Tab. 1). In the horizontal plane the emittance budget, defined by the SIS 18-acceptance, is exceeded by nearly a factor of two ($\varepsilon_{n,x} = 1.9$ mm·mrad). The momentum spread at the SIS 18-injection was minimized by using one of the single gap resonators and the 36 MHz-rebuncher cavity in the transfer line. A phase probe pick up at the end of the transfer line is sufficient for the optimization; fine tuning is performed by the use of Schottky beam diagnostics in the SIS 18.

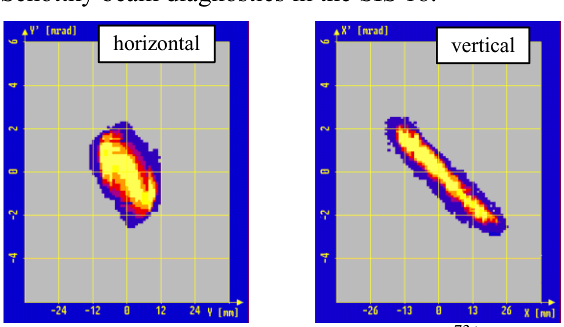

Fig. 5: Results of high current (1.3 emA) U^{73+}-emittance measurements in the transfer line to the SIS 18.

FURTHER UPGRADE PROGRAM

In a medium term perspective up to 2 emA U^{73+} ($2 \cdot 10^{10}$ particles per 100 µs pulse) may be reached, if the offer of primary beam intensity in the LEBT could be close to 16.5 emA. It is planned to investigate the beam forming process (after the ion source) during post acceleration with a dedicated test bench. Presently the main bottle neck regarding transmission loss under space charge conditions is the HSI-front end system, which does not fit to the delivered beam quality in the LEBT. The results of beam dynamics studies were already presented; an extended investigation program resulting in a proposal for a new high current Uranium front end system is still in progress. In addition, the space charge dominated beam matching to the poststripper accelerator and the beam brilliance in the transfer line has to be improved. It is planned to substitute part of the power supplies of the Alvarez-quads resulting in a higher phase advance and less emittance growth in the DTL. For charge state separation of high intensity heavy ion beams at 11.4 MeV/u a compact charge state separator [11] is foreseen. This device has already been designed and is ready for order. Moreover an upgrade program for additional non destructive beam diagnostics [12], sufficient for high current operation, is still in progress.

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