BEAM MEASUREMENTS AT THE GSI HIGH CURRENT INJECTOR

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Abstract

The GSI UNILAC was upgraded as a high current injector for the heavy ion synchrotron SIS in 1999 [1]. During that time a versatile beam diagnostics test bench served for commissioning after each acceleration and transport section. After completion of the new linac, beam measurements have been carried out along the UNILAC at selected positions. The effects of high space charge forces could be analyzed. The beam emittance along the linac, the influence of the gas and foil strippers on beam quality, and emittance measurements at various beam energies (0.002 to 11.4 MeV/u) will be reported. Multi-particle simulations were performed and compared with beam measurements.

1 INTRODUCTION

The new High Current Injector (HSI) provides an increase of beam intensities filling the synchrotron up to its space charge limit for all ions – including uranium [2]. An increase of the accelerating gain by a factor of 2.5 was necessary to accelerate ion species up to maximum A/q-values of 65 ($^{130}Xe^{2+}$) within the given length of the former Wideröe injector. For a 15mA $^{238}U^{4+}$ beam out of the HSI $4\cdot10^{10}$ U^{73+} particles should be delivered to the SIS during 100 µs.

Two ion source terminals feed the HSI. The already existing LEBT was surveyed as basically useful for loss-free transport of high intense beams. The RFQ accelerates the ion beam from 2.2 keV/u up to 120 keV/u, matching to the IH-DTL is done with a very short adapter RFQ (SL). The final beam energy of IH1 is 0.743 MeV/u, while IH2 accelerates the ion beam to the full HSI-energy of 1.4 MeV/u. After stripping and charge state separation the beam of the HSI is matched to the Alvarez accelerator. The Alvarez accelerates the highly space charge dominated ion beams without any significant particle loss. The transfer channel to the synchrotron will be upgraded with a short charge state separator system, suited for the required transverse beam quality and a high particle transmission.

Table 1: Specified beam parameters at UNILAC and SIS injection, exemplary for a uranium beam.

	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 100 µs pulse	$2.6\cdot10^{12}$	$2.3\cdot10^{12}$	$2.8\cdot10^{11}$	$4.2\cdot10^{10}$
Energy [MeV/u]	0.0022	1.4	1.4	11.4
ΔW/W	-	$\pm4\cdot10^{-3}$	$\pm2\cdot10^{-3}$	$\pm2\cdot10^{-3}$
$\varepsilon_{n,x}$ [mm mrad]	0.3	0.5	0.75	0.8
$\varepsilon_{n,y}$ [mm mrad]	0.3	0.5	0.75	2.5

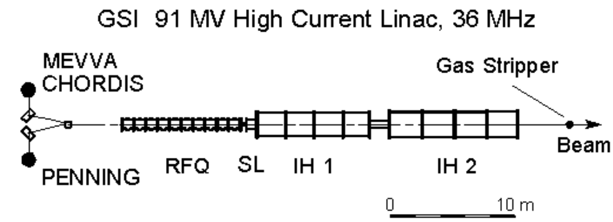

Fig. 1: Schematic view of the HSI.

2 BEAM DYNAMICS SIMULATION

2.1 Space charge forces

The strength of the space charge forces after the HSI is shown in Fig. 2. If as a worst case a 15 mA U^{4+} ion beam is stripped, U^{28+} should purely separated from the neighbouring charge states under extremely high space charge conditions (105 emA total pulse current) in the charge state separator. Due to the jump of the operation frequency to 108 MHz a drastical increase of the space charge forces is observed. In the 11.4 MeV/u stripper region of the transfer line to the synchrotron the space charge forces increases significantly [3].

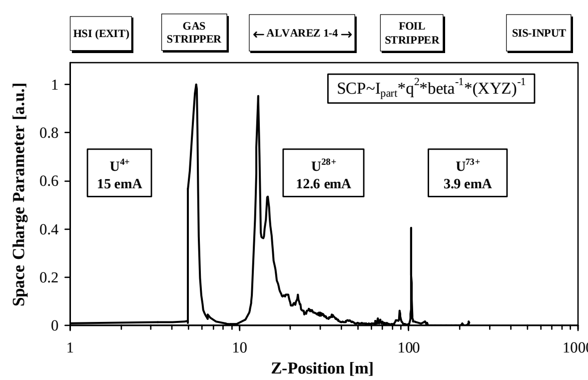

Fig. 2: The normalized space charge parameter SCP along the stripper section, Alvarez and transfer channel.

2.2 Beam Emittance along the UNILAC

For the simulation of beam dynamics in the different accelerator sections the PIC-codes PARMT, PARMTEQ, PARMILA, LORAS and DYNAMION were used, treating with specific requirements such as stripper effects, multi-charge beam dynamics, space charge influence [4]. A Gaussian particle distribution - representing a U^{4+}-beam - was injected directly into the RFQ. The beam was then transformed through the whole

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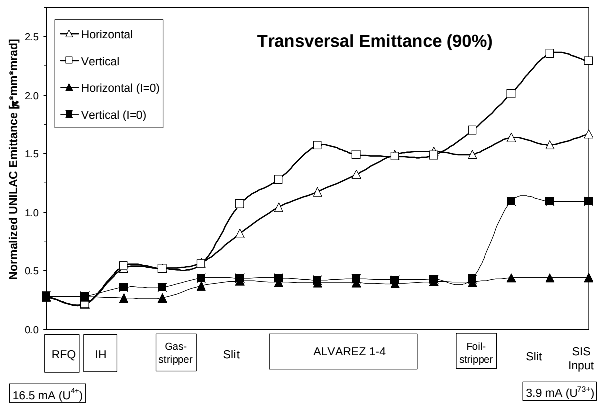

Fig. 3: Calculated transverse emittance growth in the UNILAC and transfer channel for high and low beam intensities.

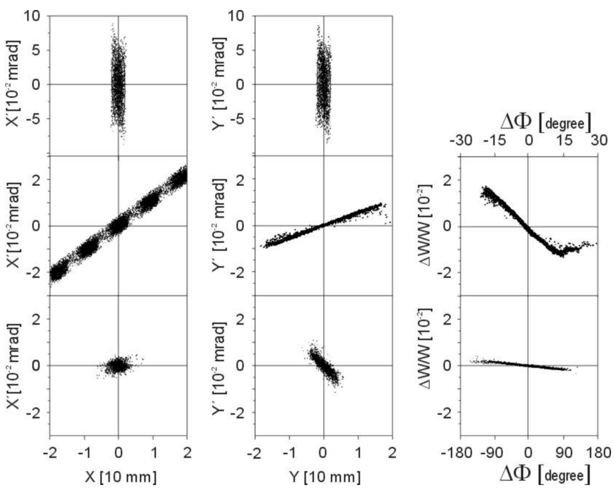

Fig 4: Calculated phase space distribution at RFQ entrance (up), in the gas stripper section (middle) and at the end of the transfer channel to the SIS (down).

UNILAC and transfer line without any discontinuity. The development of 90% emittance is shown in Fig. 3. Emittance growth is obvious in the IH-DTL, mainly in the vertical plane between gas stripper and charge separation – caused by a specific beam envelope and the space charge forces; in the adjacent matching section and the first Alvarez tanks resulting from the frequency jump and in the foil stripper only in the vertical plane. The growth factors from RFQ to SIS are 6.0 in the horizontal and 8.1 in the vertical plane, while the longitudinal emittance increases by a factor of 15. For low intensities only angular straggling in the foil stripper is responsible for vertical emittance growth. Fig. 4 represents the calculated phase space distribution at RFQ entrance, in the 1.4 MeV/u-charge state separator and at the end of the transfer channel.

3 MEASUREMENTS OF THE PHASE SPACE DISTRIBUTION

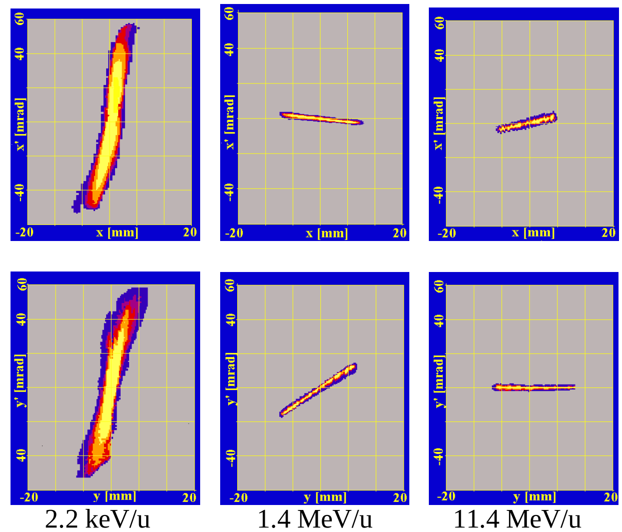

Fig 5: Measured horizontal (top) and vertical (bottom) emittance; 10 mA Ar^{1+} (2.2keV/u), 7 mA Ar^{10+} (1.4 MeV/u, after stripping and 11.4 MeV/u).

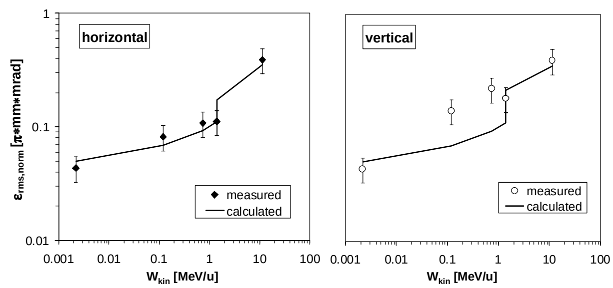

Fig.6: Measured transverse emittance for different beam energies (beam parameters as mentioned in Fig. 5).

All the presented measurements were carried out with an intense argon beam, while the HSI is working at the design space charge limit. The transverse emittance for the several energy steps of the HSI (and at 11.4 MeV/u) was measured exclusively with a slit-grid device for short pulses. Particularly the RFQ-matching condition of a double waist at a very small transverse beam diameter of 5 mm [5] was verified during the stepwise beam commissioning of the HSI. The emittance measurement device was implemented in a diagnostic test bench. For 120 keV/u, 750 keV/u and 1.4 MeV/u the beam is transported to a measurement device in the gas stripper region, another device is placed after the Alvarez. As an example Fig. 5 shows the measured transverse emittance for three different UNILAC energies. Fig. 6 summarises the measured emittance data for an Ar^{1+} beam with 10 mA at RFQ injection and 6.5 mA at the HSI exit. The Ar^{10+} current (after stripping and charge state analysis) was 7 mA. The measurements agree fairly well with the calculation, when a measuring error of about ±15 % is taken into account. The partly large emittance values for

120 keV/u and 750 keV/u result from space charge effects during operation with the gas stripper.

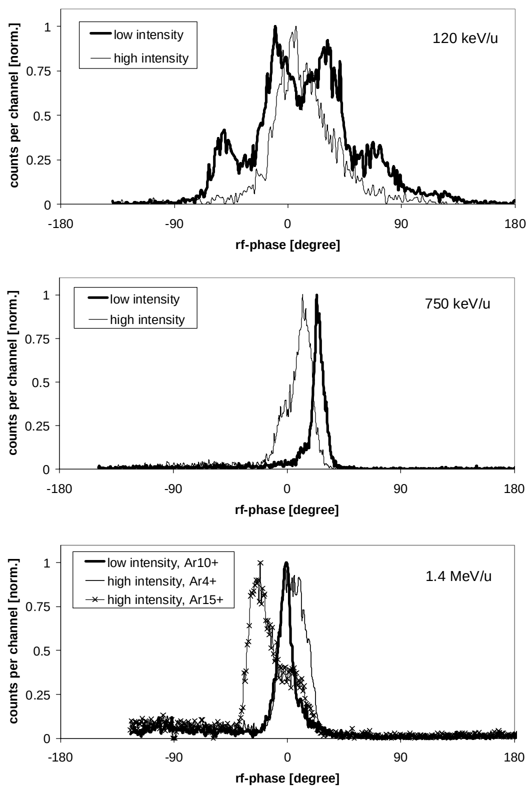

Fig. 7: Micro bunch structure for different HSI-energies.

Bunch shape measurements for different HSI-energies were done in the gas stripper region using a diamond detector, whereas the ion beam passes a thin Au-foil – the "Rutherford"-scattered particles hit the detector within a small angle [6]. The bunch shape is obtained by measuring the arrival time of the particles against a reference. It was even possible to observe the typical "zero current" phase space distribution in the longitudinal plane, leading to intensity peaks in the centre and at the beginning (resp. at the end) of the measured bunch shape. In the stripper region this effect is still present after accelerating the beam up to 120 keV/u (Fig. 7). Regardless the higher defocusing due to space charge forces in the high current case the bunch is shorter and without the significant "low current"-structure as predicted by simulations. At full HSI energy the beam is very well bunched for high and low intensities. Dependent on the charge state the different space charge forces after stripping has to be taken into account.

4 EMITTANCE GROWTH

As shown in Fig. 8 the emittance increases significantly as a function of the Ar^{10+}-intensity, but less than expected by calculation. At the design intensity of 6 mA an emittance growth of less than 10% was observed, in contrast to 40% as expected from calculations. If the intensity attenuation is performed by decreasing the stripper gas density only emittance blow up due to space charge effects in the HSI accelerator takes place. The emittance growth effects are mainly caused by the strong space charge forces after stripping. The different emittance values in the transverse planes are predicted by calculation (see Fig. 3).

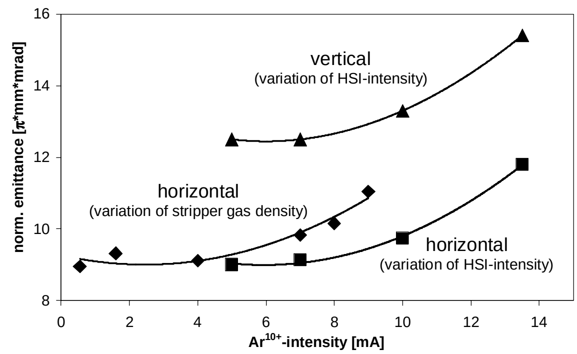

Fig. 8: Emittance growth as a function of beam intensity.

5 SUMMARY

The new High Current Injector was installed and successful commissioned in 1999. The performed and now implemented beam diagnostics devices to measure transverse phase space distributions and longitudinal bunch structure are well suited to investigate the beam properties up to the highest intensities. In general the beam quality is as good as expected. The "in advance" calculations were confirmed by the measurements done in the different sections, for different energies and intensities. The Measurements of the transverse emittances and bunch shape indicate a partial space charge compensation after the stripping process. The influence of space charge forces in the HSI itself is as expected.

6 REFERENCES

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