DEVELOPMENT AND PROGRESS IN THE UNILAC HIGH INTENSITY UPGRADE PROGRAM

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Abstract

In the framework of the beam intensity upgrade program of GSI the UNILAC - serving as an injector to the SIS - was upgraded. This contribution focuses on two aspects of the upgraded UNILAC. On the one hand it has to fill the synchrotron up to the space charge limit for heavy ions. That requires high intense, but short pulses (duty cycle typically 0.01 %) provided by the High Current Injector (HSI) [1]. So far beam intensities of up to 18 emA for Ar^{10+} in the UNILAC were achieved, demonstrating that the design intensities were met for ions of intermediate mass numbers. For uranium, the reference ion species, intensities of up to 0.5 emA were obtained in the charge state 73+ at SIS injection.

On the other hand UNILAC experiments demand high average particle intensities with a high duty factor of up to 30 %. Mostly the High Charge State Injector (HLI) met these requirements. To increase the intensity delivered to the experiments, the HLI has undergone a revision. For the super heavy element production setup (SHIP) two octupole magnets installed recently in the beam line allow the flattening of an initial Gaussian beam shape to a nearly rectangular transverse density distribution. This permits to increase the integrated on-target-intensity by a factor of three.

1 INTRODUCTION

The layout of the UNILAC is shown in Fig. 1. The HSI consisting of an RFQ and an IH-type DTL (two tanks) delivers low charge state ions at 1.4 MeV/u to the gas-stripper section. Tab. 1 summarizes the design data defined for the high intensity upgrade program. Highly charged ion beams from the ECR source are accelerated in the HLI (RFQ and IH) and are directly injected into the Alvarez DTL. Both injectors serve for the Alvarez as well as for the single-gap resonators in a time-sharing mode. Then the ion beam may either be injected into the SIS via a transfer channel or delivered to the UNILAC experimental hall. In order to achieve the highest ion beam energies in the synchrotron a second stripping process is required.

Table 1: Design parameters at UNILAC and SIS injection for the HSI, exemplary for an 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	12.6	4.6
Part. per 100μs 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

2 SHORT PULSE OPERATION

2.1 Studies with an Intense Argon Beam

Systematic studies with an intense argon beam have been carried out with special attention to the emittance growth behavior in the UNILAC. Measurements of the normalized transverse emittances (90% rms) for different beam energies together with the calculation for 100% values [2] are illustrated in Fig. 2.
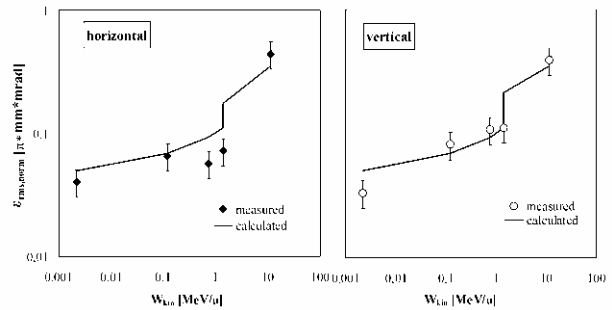
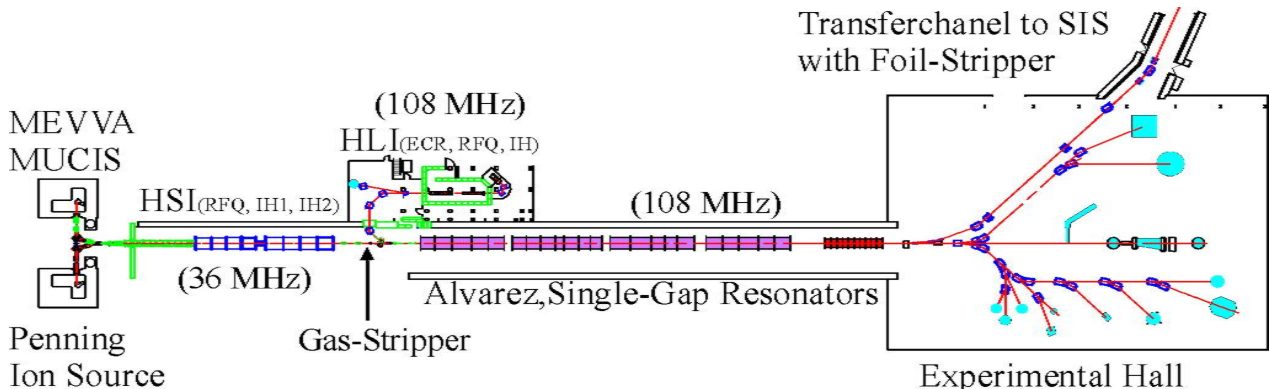**Figure 2:** Measured transverse emittances along the UNILAC. The solid line represents calculation (see text).

Figure 1: Layout of the UNILAC.

The calculation is based on intensities of 11 emA Ar^{1+} (2.2 keV/u) and 7 emA Ar^{10+} (≥1.4 MeV/u). Due to space charge effects these values represent the high current operation (scaled using the design data). As required for an optimal SIS injection, the horizontal emittances are slightly smaller than the vertical ones. Blow-up due to space charge effects after the stripping process contributes as a smaller effect to the emittance growth than expected from theoretical predictions [2]. On the other hand the emittance growth in the Alvarez section is much larger than calculated.

The transmission of Ar^{10+} beams from the gas stripper into the transfer channel was investigated at two different intensities (6 emA and 10 emA). A total transmission of up to 90% could be achieved. The values correspond to 12.6 emA U^{28+} (design limit see Tab. 1) resp. 21 emA, which is well above 15 emA required for the GSI Future Project [3].

2.2 Beam Operation with U^{4+}

In December 2001 the UNILAC had to deliver uranium with high intensities to meet the demand for high particle numbers after the SIS. During this run lasting two weeks, the MEVVA ion source delivered U^{4+} ions via HSI for experiments. Conditioning of the HSI rf structures with short, low rate pulses during preceding beam time made the U^{4+} operation possible.

The requirements were fulfilled by a beam intensity of 5.5 ± 1.1 emA U^{4+} in front of the RFQ [4] averaged over two weeks. A continues optimization of the UNILAC performance was not possible, but peak values of 8.5 emA and HSI transmissions of 75 % were already obtained.

Substantial transmission reduction was detected in different sections of the UNILAC. The following bottlenecks have been identified: beam transport from the ion source to the LEBT system of the HSI and matching to the RFQ, transmission through the RFQ and the single-gap resonator section. Emittance growth in the Alvarez, larger than expected, also contributed to the reduced transmission in the SIS acceptance.

2.3 Improvements

Efforts to improve the overall performance of the UNILAC are under way. The high current ion sources (MEVVA und MUCIS) provide high intensities at the expense of large emittances. A solenoid was already installed behind the ion source and the matching to the dc gap was improved. Hence a mismatch to the LEBT input appeared to result in transmission losses. A super conducting solenoid will be installed directly behind the dc gap to improve the matching.

Additionally an improvement of the LEBT section with larger apertures is proposed [5]. Design studies examine the possibilities to modify the RFQ by increasing its acceptance and by reducing the emittance growth therein.

The Alvarez section is the object of studies to increase the brilliance of the beam. First measurements with an intense argon beam show that a higher phase advance results in lower emittance growth, which is in good agreement to calculations [6]. Scaling the Alvarez quadrupole settings from argon to uranium, new power supplies turned out to be necessary.

So far, the bottleneck of the single-gap resonator region is 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 [7]. This allows beam transport with small beta-function modulation and thus full transmission. The resulting free space is used for additional steering magnets and beam diagnosis devices. This allows for easier matching to the following beam transport section.

3 LONG PULSE OPERATION

3.1 Beam Test in the HLI

Several changes at the HLI led to a significant gain in transmission of 40 %. A solenoid magnet behind the ECR permits better matching to the analyzing spectrometer magnet. The electrical field distribution in the IH structure was optimized by trimming the plungers. The improved longitudinal beam quality led to an almost loss-free beam transport through the 180º transport channel. The complete realignment of the HLI and beam transport lines contributed additionally to the better transmission.

3.2 Transverse Beam Shaping

The beam from the HLI is mainly delivered to the set-up for super heavy element production (SHIP). Typical beam energies are close to 5 MeV/u. Due to the peaked intensity distribution on center of the target, the high thermal stress limited the tolerable beam intensity. In order to accumulate the same deposited dose within reduced beam time a transition from a nearby Gaussian to a uniform distribution was demanded.

The use of octupoles in the beam transfer line to the experiment allows to generate a nearby rectangular beam shape. An octupole couples both planes following the equation for an ideal octupole:

$$B_x = G(y^3 - 3x^2y)$$
$$B_y = G(3xy^2 - x^3)$$

With $G = \pm B_0/r^3$, pole tip field B_0 and r aperture radius.

To transform the Gaussian beam shape into an almost rectangular one at the center of the beam must not be influenced but only the off-axis particles. Thus the transversal phase space distribution is tilted at the ends towards the center of the beam. This effect is displayed in Fig. 3.

To decouple the effects in the x- and y-planes two octupoles are used. The beam envelope must allow for a waist in one plane and for an expanded beam in the other plane. For the second octupole the envelope matching must be inverted.

The layout of octupoles was based on the specification that beams with highest rigidity have to be matched to the target size of the SHIP set-up. Due to the moderate power consumption, the magnets are air-cooled.
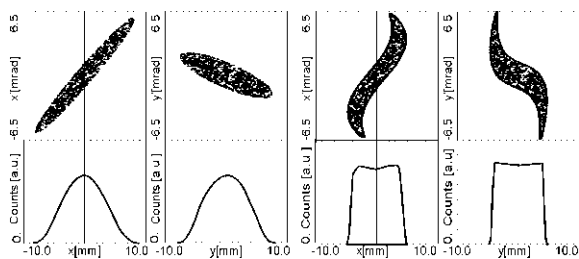

Figure 3: The horizontal and vertical phase space distributions at target position are shown on top, whereas the beam profile in the corresponding axes is displayed on the bottom (left: without octupoles; right: with octupoles).

The general beam transport line layout consists of two octupoles and several quadrupole duplets and triplets. The code MIRKO, which approximates the octupole by a small multipole lens (order of three), was used for a first layout of the modified beamline. The results were confirmed by the PIC-code DYNAMION [8]. This code applies a finite element method based on real magnetic fields. Due to the limited space in the beam line for SHIP, the new set-up is a compromise, placing the octupoles not exactly in the middle between the triplets. The resulting beam line set-up together with a beam envelope is shown in Fig. 4.
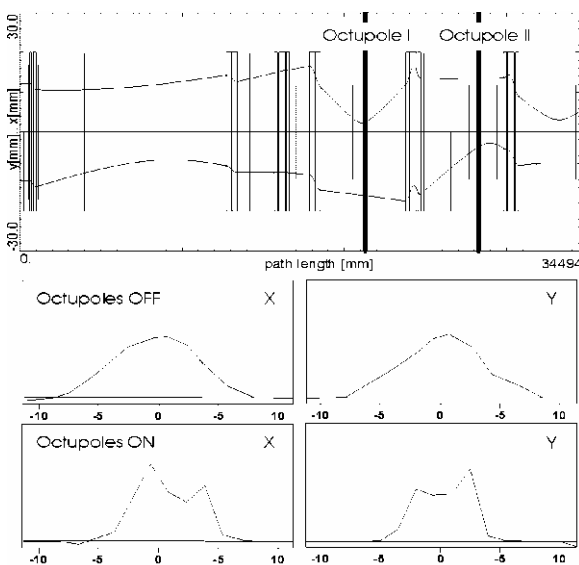

Figure 4: Beam envelope shown for a Zn^{10+} beam at an energy of 4.96 MeV/u (upper part). Measured profile grid at the target position (lower part).

To achieve the specified conditions at the position of the octupoles and the target, the operator is supported by an online version of MIRKO displaying the beam line from the entrance into the experimental hall up to the target. The initial emittance is calculated from profile grid measurements. For the final adjustment of the beam width on the target the profile grid measurement as shown in Fig. 4 is used.

Due to beam halo and relatively small quadrupole apertures – compared to those of the octupoles – a narrow beam envelope, as shown in Fig. 4, ensures a high transmission to the target resulting in very low background for the measurement. An optimal beam envelope is much wider at the position of the octupoles. To overcome the limitations the installation of quadrupoles with larger aperture is considered.

4 SUMMARY

The efficiency of both injectors was increased. The HSI can accelerate ion species of intermediate mass numbers up to the space charge limit. The envisaged pulse current for uranium has not been attained yet. The sections of beam losses are well identified and improvements are under way.

The HLI took full benefit of all its refinements. During a commissioning beam time at the end of 2001 the correct mode of operation of the octupoles was demonstrated. With the beginning of 2002 the octupoles are routinely employed.

5 REFERENCES

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