BEAM EMITTANCE STUDIES AT THE HEAVY ION LINAC UNILAC

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Abstract

New accelerating structures for the UNILAC at GSI were commissioned in the last two years [1, 2], and further machine upgrades are in preparation in order to meet the requirements for FAIR [3, 4]. Beam emittance is one of the key beam parameters that are essential for any beam dynamics calculation, for the design of new accelerators as well as verification or investigation of existing machines. Its measurement is intricate and often time consuming. Extensive emittance measurements went along with the commissionings and were conducted to provide a reliable basis for beam dynamics simulations. In addition to the 10 permanent transverse emittance measurement devices installed all over the UNILAC, two "mobile" devices had been built and mounted at four different sites in the UNILAC. This paper introduces the standard slit–grid device used for transverse beam emittance measurements and gives an overview of the activities and results. Amongst others, the following applications will be presented: Emittance growth of high current ion beams, stripping, and resonance effects in a DTL.

INTRODUCTION

The UNIversal Linear ACcelerator (UNILAC, Fig. 1) at GSI is a heavy ion linac, comprising the high current injector (HSI), a gas stripper section, the high charge injector (HLI), a drift tube linac (DTL) of Alvarez–type (Poststripper), and the transfer channel (TK) to the synchrotron (SIS 18) with a foil stripper. The experimental hall for coulomb barrier experiments like SHIP or TASCA is served by the UNILAC directly. The first complete commissioning took

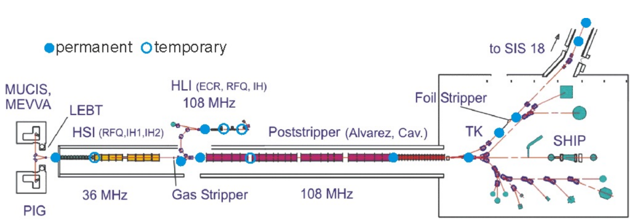

Figure 1: Overview of the UNILAC and the emittance measurement device positions.

place in 1975 [5]. Since then the UNILAC underwent major upgrades like the extension of the Alvarez DTL by two additional tanks and the replacement of the Wideroe injector by today's radio frequency quadrupole (RFQ) and interdigital H-structure (IH) accelerator at the HSI. Beam brilliance has risen several magnitudes. The original design of course could not anticipate this development. With FAIR (Facility for Antiproton and Ion Research) the requirements on beam parameters, especially intensity and emittance, became even more challenging, making further machine upgrades necessary. Optimizing the existing accelerator and the design of new accelerator components requires a profound knowledge and understanding of the machine behavior. Beam emittance measurements are an inevitable basis for this.

EMITTANCE MEASUREMENT DEVICES

Hardware

The device used for transverse beam emittance measurements consists of one slit and one multiwire beam profile monitor for each transverse plane. The slits are made from copper and have an aperture 0.1 to 0.5 mm. They are water cooled and their surface is undulated in order to withstand the high beam power (up to 1.5 MW_{peak} and 10 $kW_{\mathrm{avg.}}$). Slits are mounted on linear feedthroughs that allow for the precise movement necessary. The detectors have 16 to 64 wires with spacing between 0.8 and 1.5 mm. For precise measurements and very large beam sizes, the grids are also mounted on linear feedthroughs, while most of them are mounted on pneumatic drives. A "mobile" emittance measurement device (MEMD) was set up (Fig. 2) and used at different positions. Its installation length of 470 mm allows

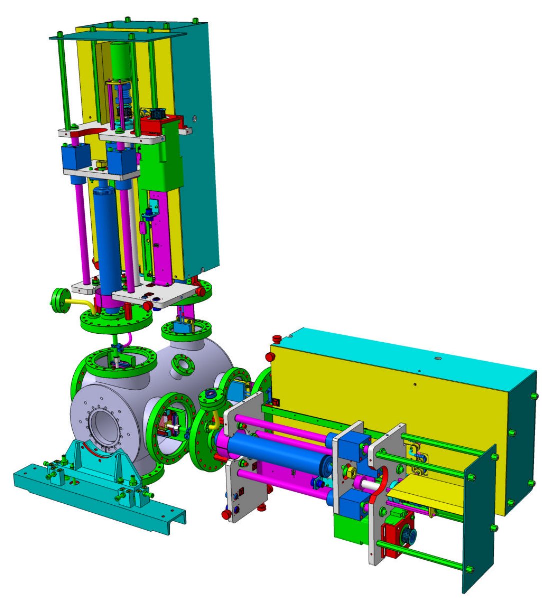

Figure 2: "Mobile" emittance measurement device.

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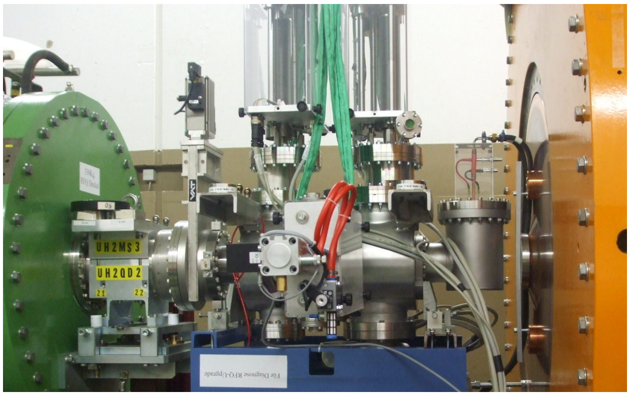

Figure 3: A buncher cavity had been removed to install the emittance device between the HSI RFQ (green, left) and IH1 (orange, right).

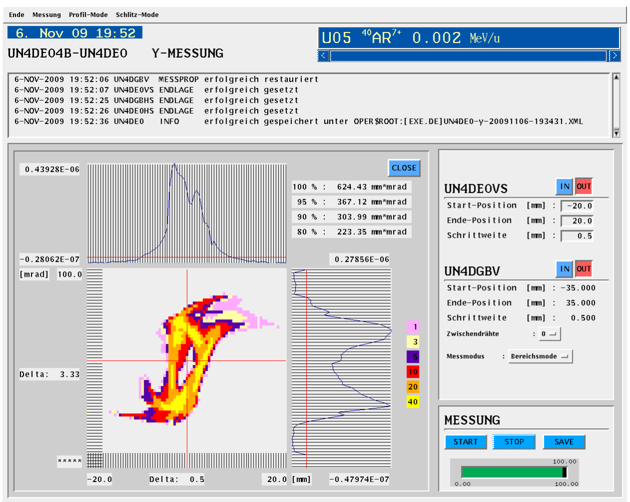

Figure 4: Screenshot of the emittance software DE.

for measurements where components have to be removed and space is limited (s. Fig. 3).

Software & Operation

The operation and data acquisition software DE (Fig. 4) was developed at GSI and is integrated into the VMS based UNILAC control system. Therefore, temporary installations of additional emittance measurement devices can be easily implemented and accessed via DE. This feature is increasingly used. The data are saved in XML-files and instantaneously presented as space-angle–plots. Four different measurement modes and resolution enhancement are implemented. The maximum spacial resolution is 0.1 mm, while the angular resolution can be increased to approx. 0.1 mrad by stepping the wire grid and doing multiple measurements. At high resolution, one transverse emittance scan takes about one hour.

For further analysis the software PROEMI is used. It provides comprehensive data manipulation and processing.

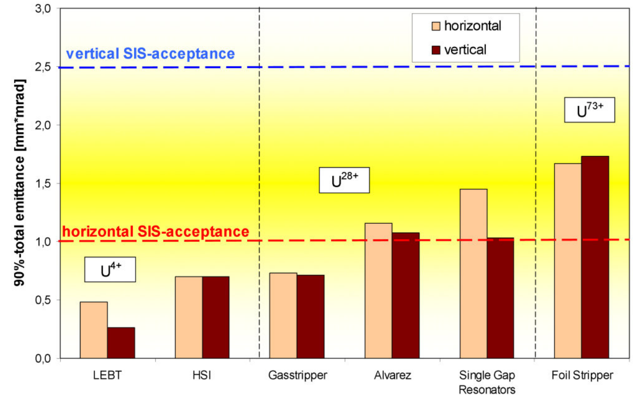

Figure 5: Emittance growth along the UNILAC for a ^{238}U beam. Indicated are the horizontal and vertical acceptance limits of the SIS 18 with respect to FAIR operation.

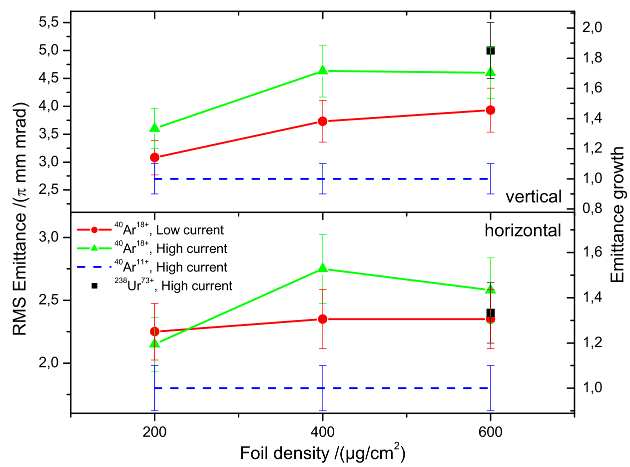

Figure 6: Effect of ion stripping by a carbon foil on the transverse emittance, measured for three different foil densities. The dashed line indicates the unstripped beam. Exemplary data points for ^{238}U are added.

BEAM EMITTANCE STUDIES

Emittance Growth

Future operation of FAIR requires high beam brilliances. With seven emittance devices permanently installed along the UNILAC, emittance growth along the accelerator can be monitored. Such investigations have been carried out repeatedly. As the latest results in Fig. 5 show, the horizontal emittance needs to be further improved. Matching the 108 MHz main DTL and foil stripping have been identified as main sources of emittance growth.

The latter process was studied experimentally for different foil densities, beam intensities and ion species [6]. Some results are shown in Fig. 6. The dependence on the foil density is reproduced, the difference for high and low current operation is visible.

The preservation of beam quality of high current beams along the Alvarez DTL is a major concern. In order to de-

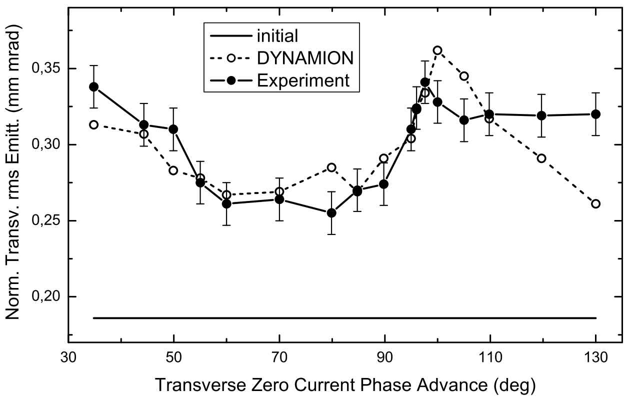

Figure 7: High current transverse emittance growth along the Alvarez DTL as a function of the (zero current) transverse phase advance: Simulated ○ and experimental ● data. The straight line indicates the reference emittance at the DTL entrance.

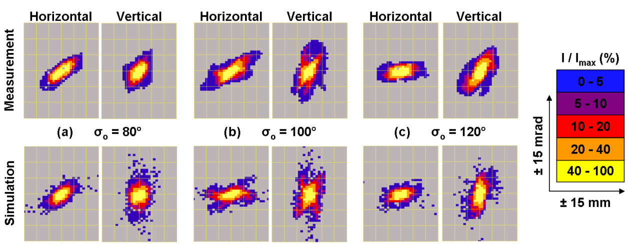

Figure 8: Experimental (top) and simulated (bottom) transverse emittances behind Alvarez I tank for a 7.1 mA $^{40}Ar^{10+}$ beam. At 100° phase advance the fourfold symmetry in the phase space distribution is clearly visible.

velop a detailed understanding, beam dynamics simulation codes were benchmarked together with systematic emittance measurements [7]. Good agreement between theory and experiment was confirmed (Fig. 7), ensuring that future upgrades can be based on these simulations. The emittance growth was already reduced significantly by applying a matching routine based on measurements in front of the DTL [7].

Resonance Phenomena

In a particle accelerator with a periodic structure beam space charge force may excite resonant beam emittance growth if the particles transverse phase advance approaches 90°. The first Alvarez tank of the UNILAC opened the unique opportunity to observe this fourth order resonance experimentally in a linac [8]. The predicted behavior could be observed at a zero current phase advance near 100° (Fig. 8). The resonant emittance growth can also be seen in Fig. 7.

New Components & Others

Recommissioning of the HSI RFQ The electrodes of the RFQ accelerator of the HSI were replaced in 2009 [1]. A new, enhanced design for the electrodes was implemented to increase beam transmission following the requirements for FAIR. During the commissioning the MEMD was installed directly behind the RFQ, complementing the permanent device in front of the RFQ. The measurements were used for verification of the design, and simulations of the beam matching to the RFQ based on these data have been started in preparation of upgrades of the low energy beam transport (LEBT).

New cw-RFQ & ECR beam studies The RFQ of the HLI was replaced in 2009/10 [2]. The new accelerator provides cw operation capability, besides enhanced beam quality and intensity. Since there is no permanent device, the MEMD was installed successively at the entrance and exit of the RFQ. By means of two beamtimes, the performance of the new tank was verified. During the first beam time, extensive beam studies of the ECR beam were carried out. More than 160 emittance measurements were conducted in five days with different ions and source settings. Simulations have been carried out, work is still in progress.

CONCLUSION

In the last years, transverse beam emittance measurements became a reliable and indispensable tool in a wide range of machine studies. Verification of recently implemented components and machine investigations for high current operation have been conducted successfully. Upgrades of the emittance measurement devices in the LEBT are in progress.

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