Experiments with the High Current RFQ Prototype for GSI*

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Abstract

A new high current injector (HSI) for the UNILAC and the SIS synchrotron for all ions up to Uranium is planned at GSI [1],[2]. The Spiral-RFQ accelerator accepts low energy (2.2 keV/u), high current (25 mA) beams with low charge states (U^{2+}) at an operating frequency of 27 MHz. Results of particle dynamics calculations and structure development for the first crucial part of the HSI-RFQ, where all bunch forming is done, are presented together with results of rf measurements and first beam tests.

I. Introduction

The GSI upgrading program [3],[4] consists of the new 18 Tm heavy ion synchrotron SIS, the experimental storage ring ESR and the two new injectors HLI (Hochladungsinjektor) and HSI (Hochstrominjektor). With these new components and the UNILAC it is possible to accelerate all elements up to Uranium to energies above 1 GeV/u. The SIS and the ESR are now working for more than 2 years. The HLI for the nuclear physics research program at the UNILAC is also succesfully working since June 92. Figure 1 shows the plan view of the extended GSI accelerator facility.

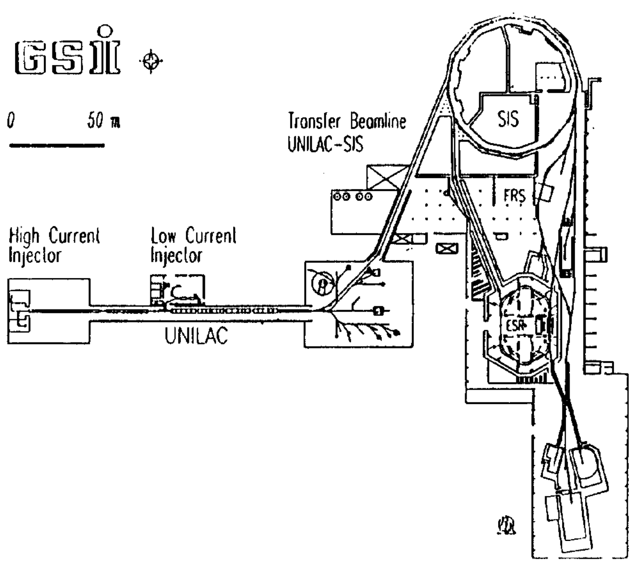

Figure 1 Plan view of the extended GSI accelerator facilities

The high charge injector HLI [5] consists of a combination of an ECR ion source, a 4 Rod-RFQ [6] and an IH-structure [7], both operating at a frequency of 108.5 MHz. The HLI enables direct injection of U^{28+} into the Alvarez part of the UNILAC at an energy of 1.4 MeV/u without stripping. This injector is designed for a beam current of 5 μA at a duty cycle up to 50 %.

The high current injector HSI is designed to fill the SIS up to the space charge limit and will accept e.g. U^{2+} beams with currents as high as 25 mA at low initial particle energies of 2.2 keV/u. The accelerator structure works at the Wideroe frequency of 27 MHz, which allows a beam transfer without frequency jump. A gas stripper at 216 keV/u produces a reasonable fraction of the necessary charge state of U^{10+} for acceleration in the second Wideroe part of the UNILAC. The second gas stripper at 1.4 MeV/u between the Wideroe and the Alvarez part provides the U^{28+} beam for postacceleration and injection into the SIS.

II. The Spiral-RFQ-Structure

A 4 Rod-RFQ with spiral shaped supports [8] is suitable for operation at the Wideroe frequency (27 MHz). The length of a spiral arm is 1180 mm, the height is 450 mm. Using the spiral stems for the RFQ-accelerator allows the application of a very compact vacuum chamber (e.g. with a diameter of only 600 mm). Figure 2 shows a scheme of the spiral structure.

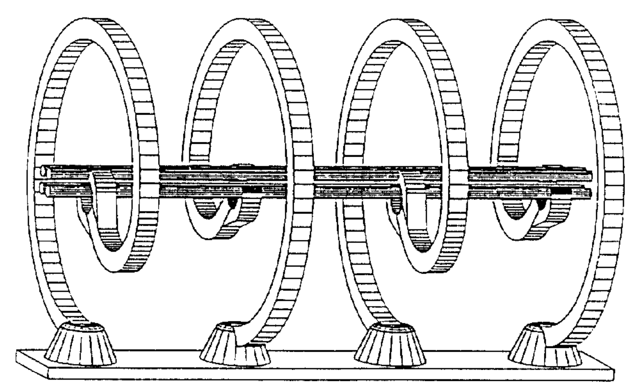

Figure 2 Scheme of the spiral structure

The whole HSI-RFQ will have an overall length of about 35 m to reach an ion velocity corresponding to an accelerator voltage of 26 MV. To achieve the space charge limit of 0.2 mA times the ratio mass over charge state the electrode voltage has to be 180 kV for U^{2+}. A short test resonator of 1 m length had been operated with even higher voltages [9].

* supported by the BMFT and the GSI

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III. The Spiral-RFQ-Prototype

A. Layout

A 4 m prototype of the 4 Rod-Spiral-RFQ with 20 spiral supports has been built for both, rf and beam test purposes [10],[11]. The electrodes consist of the first 231 cells, one third of the HSI's total cell number. These 231 cells cover the crucial low-energy part of the HSI-RFQ, where the dc-beam is converted into a bunched beam. Therefore the 4 m prototype can give relevant information on beam properties e.g. emittance growth. Figure 3 shows the beam dynamics layout of the 4 m RFQ-Prototype. A survey over the main parameters of the RFQ-Prototype is given in table 1.

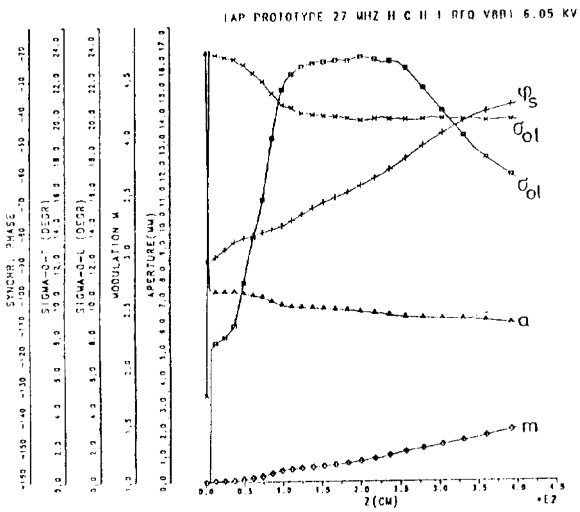

Figure 3 Beam dynamics layout

Table 1
Main Parameters of the RFQ

f	27.1 [MHz]	Q_0	5400
cells	231	Rp	520 [kΩm]
T_{in}	2.2 [keV/u]	T_{out}	17.6 [keV/u]
φ_s	-90 to - 39 [°]	a	7.0 - 6.02 [mm]
m	1 - 1.458	α_{synchr} (norm)	0.9 π [mm mrad]
ε_{in}	0.3 π [mm mrad]	length	3950 [mm]
U_{el}	1.51 A/ξ [kV]	spirals	20
I_{max}	0.23 A/ξ [mA]	A/ξ_{max}	130

B. Alignment of the RFQ

For the RFQ-Prototype a rectangular vacuum chamber made of aluminium has been chosen. Ten large lids simplify the mounting and adjustment of the RFQ structure. The structure has been aligned with an opto-mechanical system. For reasons of manufacturing each 4 m-electrode consists of 21 pieces. To achieve a high stability the electrodes are fixed and brazed on ten electrode carriers, each about 100 mm long. The electrodes are adjusted by washers with a precisely milled thickness. The precision of the electrode alignment is better than 0.12 mm, less than 3 % of the aperture radius.

C. Rf-Measurements

From low level measurements the quality factor of Q_0=5400 could be observed. The field distribution along the beam axis has a maximun deviation of less than 2 %. Rf-tests have been performed upto 35 kW pulsed input power (67 kV) and 7.2 kW in cw operation, no mechanical and cooling problems could be observed. From beam- and rf-measurements an Rp-value of 520 kΩm could be determined which has been checked with x-ray spectroscopy.

IV. Beam experiments with He^+

First beam experiments have been done at the Institut für Angewandte Physik. Due to the limited rf-power and extraction voltage light ions (He^+) have been used for the experiments. The corresponding electrode voltage and beam current are 6 kV and 0.8 mA, respectively. Figure 4 gives a view of the experimental setup .

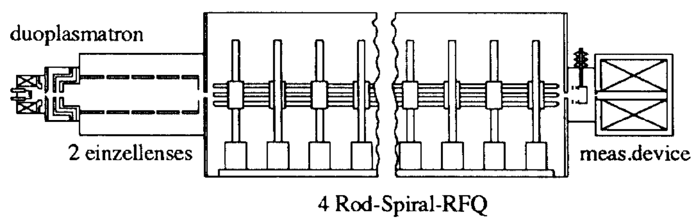

Figure 4 Scheme of the experimental setup

The beam was extracted from a duoplasmatron source and injected into the RFQ by two electrostatic einzellenses. For beam analysis an emittance-measurement-device, a fast Faraday-cup and an analyzing magnet had been installed.

Figure 5 shows the rf-signal of a pickup loop and beam bunches behind the RFQ recorded with a fast Faraday cup.

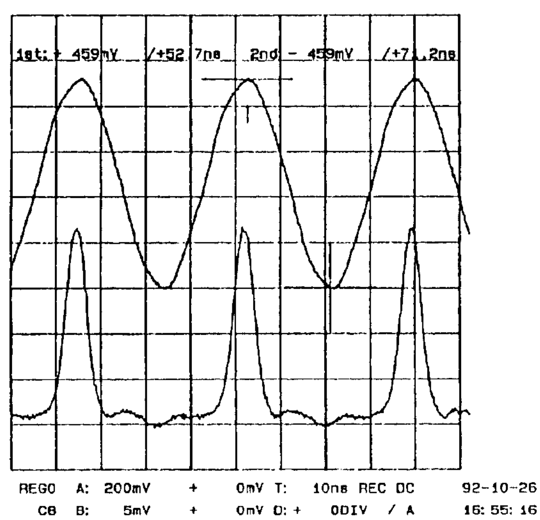

Figure 5 Measured rf-signal and beam bunch behind the RFQ.

Corresponding to the synchronous phase of 42° - 38° in the final part of the prototype, the proper output energy is reached at about 70 % of the design electrode voltage, as can be seen in Figure 6. Measurements and calculations are in good agreement.

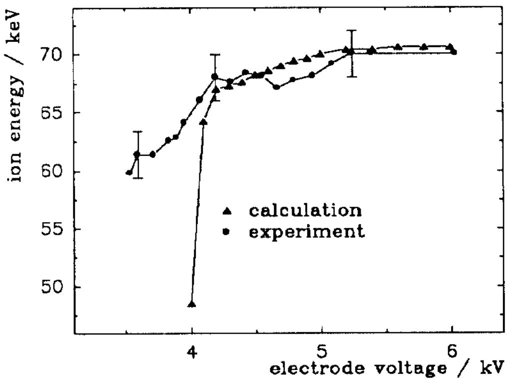

Figure 6 Ion energy vs. electrode voltage.

The maximum transmitted beam current was 980 μA, but due to the input emittance with the typical aberrations of einzellenses as shown in Figure 7 the transmission at design voltage has been less than 40 %. PARMTEQ calculations with this input emittance delivered transmission curves which are in good agreement with the measurements [12]. Figure 8 shows the calculated transmission curves vs. electrode voltage for the design input emittance (ε_{norm}=0.3 π mm mrad, α_x=0.8, β_x=0.1 mm/mrad), the emittance with the aberrations of the einzellenses (ε=0.5 π mm mrad, α_x=-0.8, β_x=0.04 mm/mrad) and the measured transmission. N^+ in the beam, caused by a leaky valve in front of the ion source, is responsable for the tail of the measured transmission curve. The calculated transport of N^+ is also shown in Figure 8.

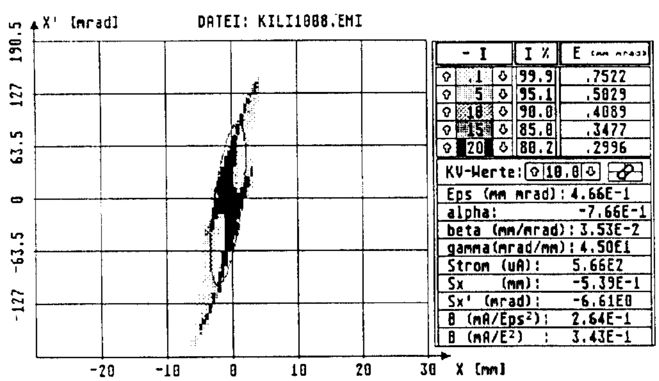

Figure 7 Measured Emittance at RFQ input.

V. Status and Schedule

The He^+ experiments in the institute have been successfully finished. Next plans are to operate the prototype at the high current injector test stand at GSI with heavy ions to check the full specifications.

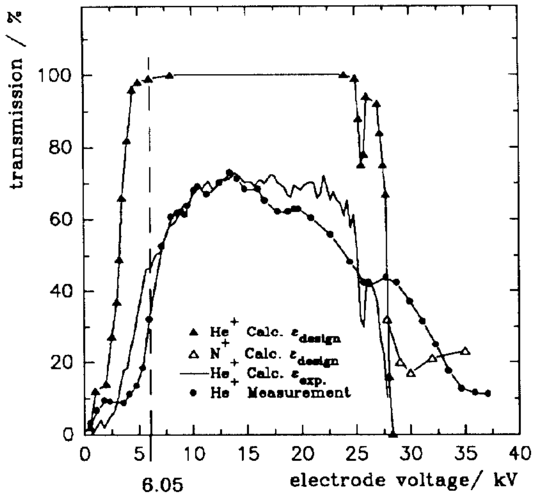

Figure 8 Calculated and measured transmission curves.

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