

EXPERIMENTS WITH HEAVY-ION BEAMS AND RF-TESTS WITH THE 27 MHz HIGH-CURRENT SPIRAL-RFQ-PROTOTYPE *

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Abstract

A Spiral-RFQ has been built and operated with Ar^+ -beams up to 8 mA. In rf-tests very high electrode voltages were reached at design duty factor. The aim of the experiments was the test of the Spiral-RFQ for the High Current Injector (HSI), which is planned at GSI to fill the Heavy Ion Synchrotron (SIS) up to its space charge limit. This Spiral-RFQ, a prototype for the HSI-RFQ, covers the crucial matching and bunching section of the electrodes. It is capable to produce ion beams of high brilliance. The results of recent beam experiments with Ar^+ and rf-tests will be presented together with work for future plasma physics experiments.

Introduction

In 1990 the 18 Tm Heavy Ion Synchrotron SIS and the storage/cooler ring ESR went into operation. The linear accelerator UNILAC however, serving as injector for the SIS, had not been changed until then. To improve the UNILAC in a way of being able to fill the SIS up to its space charge limit several modification studies have been undertaken.

One possible solution is the combination of an ion source and a 27 MHz-Four-Rod-Spiral-RFQ with a length of 35 m, known as HSI (**H**ochstrom**i**njekt**o**r) replacing the first Wideroe section of the UNILAC [1]. This RFQ should be capable to accelerate heavy ion beams of 25 mA U^{2+} from particle energies of 2.2 keV/u up to 216 keV/u. The particle charge would then be increased to U^{10+} by a gas stripper, further acceleration by the remaining second UNILAC Wideroe section would follow. At 1.4 MeV/u the ion charge would again be increased to U^{28+} , and with postacceleration in the final UNILAC sections the beam would be ready for injection into the SIS.

Later studies deal with a layout for U^{4+} [2], where one stripper could be omitted. The RFQ-prototype could well be used for these ions, too. For even higher performance the rod-electrodes would simply have to be changed.

The Spiral-RFQ Prototype

A prototype for the U^{2+} -layout of the Spiral-RFQ has been built for both, rf-testing and beam experiments [3, 4]. It is only 4 m long but consists of the first 231 resonator cells, a third of the total HSI cell number. Nevertheless, the most

critical part of the electrodes where the beam is matched and bunched is totally covered.

The resonator structure is mounted in a rectangular vacuum chamber made of aluminium. The structure itself can be easily accessed by eight lids in the side wall of the chamber. It consists of 20 spirally shaped copper stems; onto these the electrodes are mounted. The electrode alignment is achieved by precisely milled washers, it has been checked via an opto-mechanical system and is as precise as ± 0.1 mm, less than 3 % of the aperture radius.

Table 1 gives an overview on the main parameters of the RFQ-prototype, Fig. 1 shows a schematic view of a 4-stem Four-Rod-Spiral-RFQ structure.

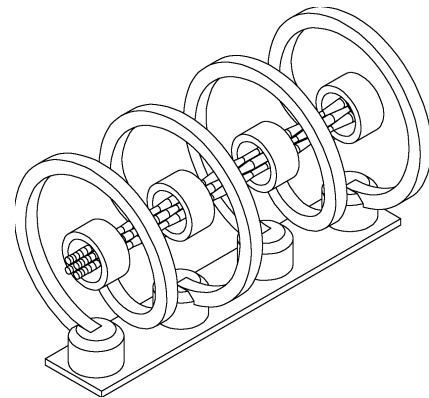


Fig. 1: Schematic view of a Four-Rod-Spiral-RFQ-Structure with four stems.

Table 1
 Parameters of the Spiral-RFQ-Prototype

Length	3.95 [m]
Operating frequency	27 [MHz]
Cell number	231
Input energy	2.2 [keV/u]
Output energy	17.6 [keV/u]
Synchronous phase	39 [°]
Aperture radius	6 [mm]
Max. electrode modulation	1.458
Normalized acceptance	0.9 [π -mm-mrad]
Electrode voltage	$1.51 \cdot A/\xi$ [kV]
Rf-power consumption	$0.018 \cdot A^2/\xi^2$ [kW]
Space charge limit	$0.2 \cdot A/\xi$ [mA] (i.e. 8 [mA] Ar^+)

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Beam Experiments

After having accelerated a He^+ -beam of $980 \mu\text{A}$ at the IAP Frankfurt (Institut für Angewandte Physik) – however, due to a mismatched injection, at twice the design rf-level – further beam tests with heavier ions were done at GSI. The ion beam was extracted from a CHORDIS (Cold or Hot Reflex Discharge Ion Source) and focused for RFQ injection by one magnetic quadrupole doublet lens and one magnetic quadrupole triplet lens. Therefore an optimized matching could be achieved. For beam measurement three beam transformers (behind the ion source, in front of and behind the RFQ), two fast Faraday cups as well as an emittance measurement device were available. Fig. 2 shows a photograph of the experimental setup.

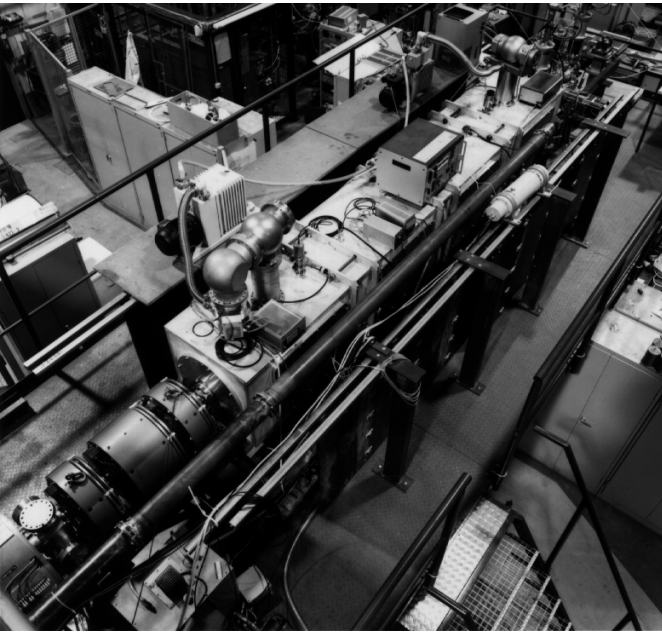


Fig. 2: Experimental setup.

The quadrupole parameters of the injection system were optimized with numerical methods. The actual input beam quality could be observed by mounting an emittance measurement device in place of the RFQ. The results confirmed the computer simulation well.

With Ar^+ -ions a maximum pulse beam current of 8 mA could be reached at design-rf-level; this is the space charge limit for the RFQ calculated with PARMTEQ (Phase and Radial Motion in Transverse Electric Quadrupoles) assuming ideal electric field distribution. The peak bunch current was 30 mA . Extrapolation to U^{2+} -ions would lead to a pulse beam current of 24 mA (i. e. a peak bunch current of 90 mA). Fig. 3 shows the pulse beam current at RFQ input (upper) and RFQ output (lower); the scale is 2 mA/div. vertically and 1 ms/div. horizontally. The peak bunch current is shown in Fig. 4; the scale is 10 mA/div. vertically and 10 ns/div. horizontally.

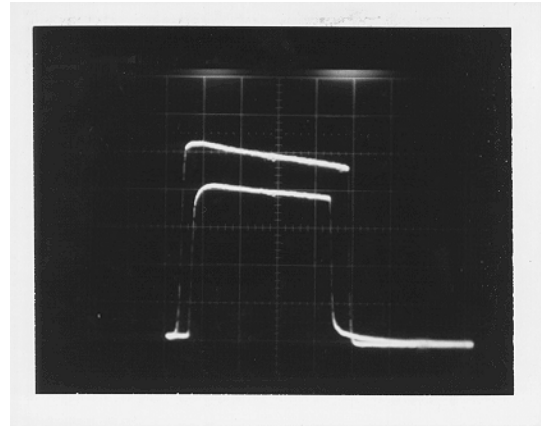


Fig. 3: Pulse beam current at RFQ input (upper) and RFQ output (lower). The scale is 2 mA/div. vertically and 1 ms/div. horizontally.

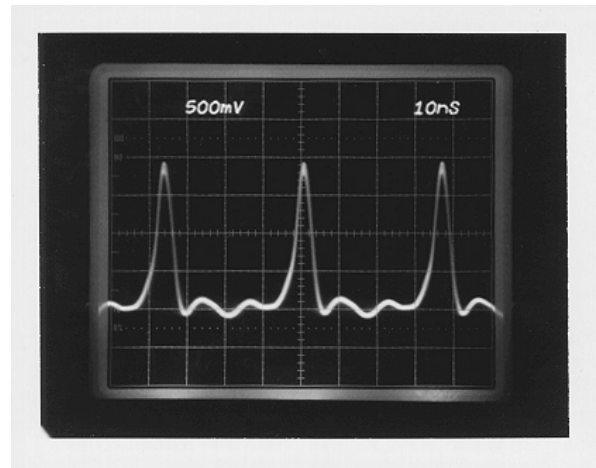


Fig. 4: Bunch current at RFQ output. The scale is 10 mA/div. vertically and 10 ns/div. horizontally.

The measured transverse emittance was $50 \pi\text{-mm-mrad}$, the energy spread was $\pm 1.5 \%$, again well-corresponding to computer simulations. Fig. 5 shows the output emittance after 530 mm drift in the xx' -plane (left) and the yy' -plane (right).

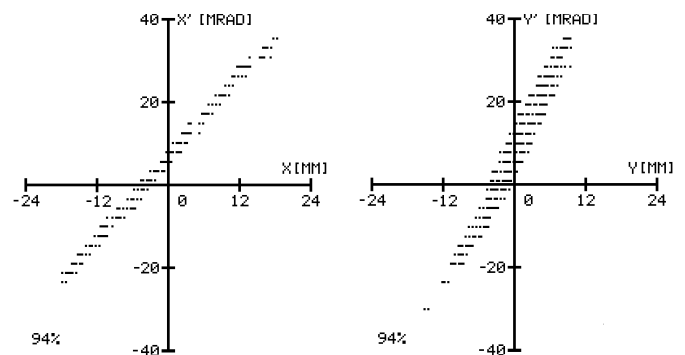


Fig. 5: xx' - and yy' -emittance behind the RFQ and a drift of 530 mm .

Rf-Experiments

For accelerating ions with yet a higher mass-to-charge ratio higher electrode voltages (and so rf-levels) are required. The ability of the RFQ to operate under such conditions has been tested. After a considerable time of conditioning the maximum applied rf-power was as high as 260 kW at a duty-cycle of 0.4 % / 50 Hz. The electrode voltage, measured with an rf-pickup probe calibrated with Ar⁺-beam, was 185 kV. This leads to a very high maximum field gradient of 340 kV/cm, corresponding to a Kilpatrick value of about 3. The Rp -value (= shunt impedance) is 520 k Ω -m, which confirms previous low-level measurements [3]. The RFQ behaved stable, no excessive sparking and no ponderomotive effects could be observed. Adequate cooling of the RFQ-structure ensured that the resonance frequency showed no drift. Higher rf-levels could not be applied due to the limited rf-amplifier power.

Forthcoming Plasma Experiments

Further use of the 27 MHz-Spiral-RFQ-Prototype will be providing a high-current He⁺-beam (0.8 mA) for experiments in plasma physics. The beam will be fed onto a luminescent target, allowing the bunch structure being observed with high time-resolution by a streak-camera. Another planned experiment is the interaction of the ion beam with thin plasmas for space charge neutralisation purposes.

The ion beam will be extracted from a CHORDIS source and will be injected into the Spiral-RFQ via two solenoid lenses. The final focus will be achieved by a magnetic quadrupole triplet lens. For beam current and bunch structure observation there are beam transformers and Faraday cups installed.

The work for setup of the experiment is almost completed so that first beam measurements are scheduled for September 1996.

Conclusions

The objective of the recent experiments, proving the capability of the Four-Rod-Spiral-RFQ serving as an injector providing highly brilliant high-current heavy-ion beams, could be fully achieved. Beam current as well as the rf-parameters were in very good correspondence to PARMTEQ simulations. Therefore the Spiral-RFQ-prototype can supply high-current ion-beams for experiments in plasma physics as well as working as a compact implanter for singly charged heavy ions like O⁺, P⁺, As⁺, up to Kr⁺.

References

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