New Developments for the RFQ-Accelerator of the Heidelberg High Current Injector

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Abstract

At the Max-Planck-Institut für Kernphysik in Heidelberg a high current injector is under construction. It will consist in its first phase of a high current ion source for singly charged ions, two RFQ- and eight 7-gap-resonators. In this phase preferably Li- and Be-beams will be accelerated to an energy of 1.8 MeV/u with intensities up to 3 orders of magnitude higher than with the present tandem-postaccelerator-combination. All resonators will operate at a frequency of 108.48 MHz with a high duty cycle of 25% at a maximum power consumption of 80 kW per cavity. With the first RFQ-resonator high power tests and acceleration experiments have been carried out. A new numerical method to optimize a RFQ-design – based on random modifications of the design parameters – was developed and used for improvements of the RFQ-accelerator structure.

1 INTRODUCTION

Laser cooling experiments at the Heidelberg heavy ion cooler ring TSR with ultra cold beams [2] of $^{9}Be^{+}$ and $^{7}Li^{+}$ are limited by the low currents delivered from the tandem accelerator. A new injector will increase the beam currents for these two ion species by 3 orders of magnitude. The high current injector will consist in its first phase of a commercial CHORDIS ion source[5], two RFQs [4] and eight 7-gap resonators [3].

Also experiments with highly charged ions are frequently limited by low beam currents due to losses from stripping. Therefore an ECR- or EBIS- source can be added in a second phase to increase the currents for highly charged heavy ions.

In figure 1 the schematic layout of the new injector is shown. The accelerator will be placed parallel to the Tandem and the $^{7}Li^{+}$ - or a $^{9}Be^{+}$-beam will be injected directly into the postaccelerator acting as a transfer line. For a second phase stripping will be used behind the last seven gap resonator and the proper charge state will be selected by an achromatic separator consisting of four 60^{o}-magnets. Like the existing post accelerator the new injector operates at 108.48 MHz. The ion velocity of β= v/c = 6% after the high current injector is well adapted to the post accelerator and final energies higher than 5 MeV/u can be reached for all ion species in a pulsed mode operation with up to 25% duty cycle.

2 THE RFQ-RESONATORS

The second section of the high current injector consists of two 4-rod-RFQ resonators [4] operating at a charge to mass ratio Q/A $\geq$ 1/9 as required for Be^{+}. The two resonators operate at 80 kW rf power with 25% duty cycle. Sufficient cooling of the 3 m long electrodes is as important as the mechanical stability because more than 35% of the rf power has to be dissipated at the electrodes. However, the maximum diameter of the rods is limited by the capacity between the electrodes to preserve a high shunt impedance. A custom made hollow profile from a copper-tin alloy combines easy machining in the local workshops and high mechanical stability of the electrodes.

In 1995 the first RFQ-resonator was constructed and tested in full length. To provide optimal electrical conductivity the electrodes were copper plated at the GSI. The mechanical alignment of the 3 m long electrodes was performed successfully. The achieved mechanical tolerance (± 0.02 mm) of the electrodes measured after installation is satisfying.

For the low level rf-measurements at the resonator the perturbation method was applied. Segments of massive copper between the supports of the resonance structure were used to adjust the eigenfrequency and the voltage distribution along the electrodes. Fig. 2 shows the electrical field strength between the electrodes before and after installation of the copper plates.

Power tests up to 20 kW in cw mode were carried out without any problems. Weak ponderomotoric oscillations – which could be observed when operating at high power – could easily be suppressed by means of mechanical decoupling between the cryo-pumps and the resonator.

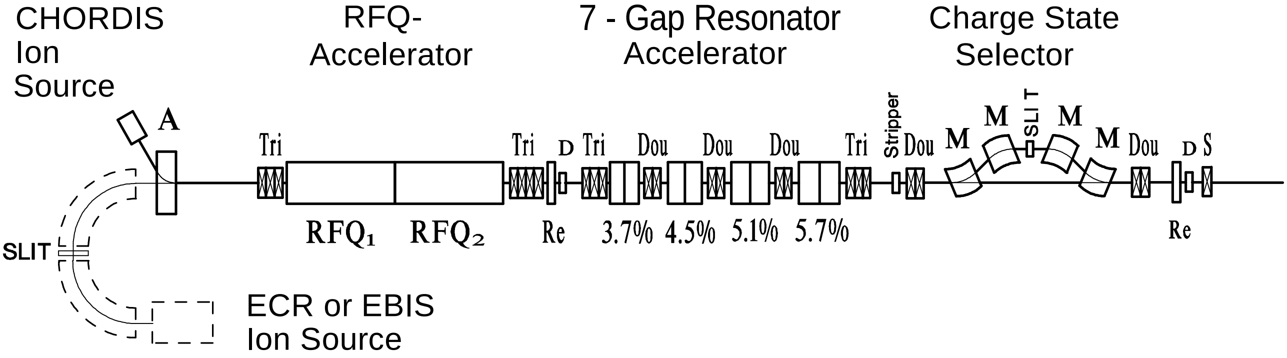

Figure 1: Schematic layout of the new high current injector. A, M, S, Dou, Tri: magn. dipoles and lenses, Re: rebuncher, D: beam diagostic. The ion source for highly charged ions (ECR or EBIS) and the charge state selector are planned for the second construction phase. The ion source will then be located one floor below.

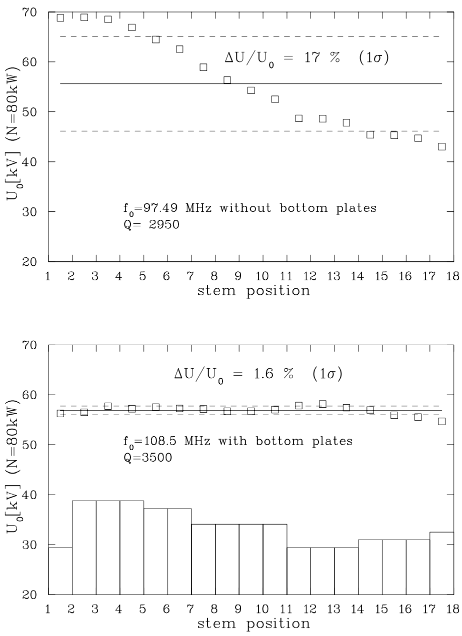

Figure 2: *Voltage distribution and eigenfrequency of the RFQ-resonator with and without tuning plates*

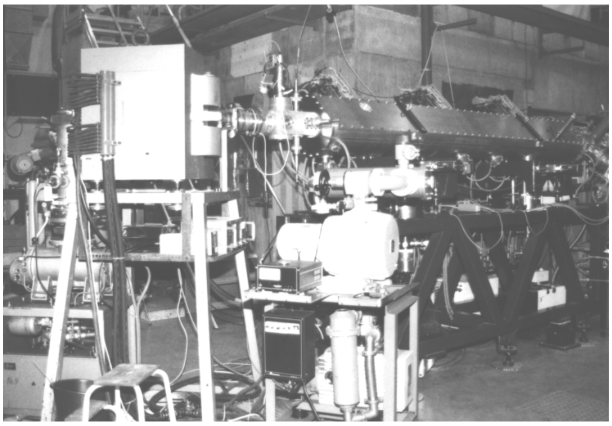

Figure 3: *Left side: analyzing magnet and diagnostics. Right side: the RFQ-resonator*

3 THE EXPERIMENTS

With an acceleration experiment the energy gain of an accelerated H_2^+-beam behind the RFQ-resonator was measured. The set up consists of a penning ion source with an electrostatic lens as used before at the RFQ-prototype [1] and an analyzing 90°- double focusing bending magnet with two diagnostic boxes. In fig. 3 a view on this section is shown.

First acceleration tests have been carried out and compared with the Monte-Carlo simulations at different rf-power levels. The measured and simulated energy spread of the beam at 7.4 kW is shown in fig. 4. The energy spread $\Delta E/E$ of the accelerated beam for different resonator voltages was investigated to determine the shuntimpedance of the resonator, seen in fig. 5. Because measuring the minimum in the energy spread in respect to the resonator power is more exact than determining the maximum energy (495 keV at an electrode voltage of 17.78 kV), the energy spread measurements were used to calculate the shunt impedance to 98.9 kΩm. With this shuntimpedance it is not possible to reach an electrode voltage of 71 kV (design value) with a maximum rf power of 80 kW. Therefore it was neccessary to redesign the electrodes at a lower voltage.

A significant progress was the development of a new numerical method to optimize the RFQ-design. It is based on random variations of the design parameters and governed by only two criteria: the length of the resonator for a fixed final energy and the calculated transmission. It was possible to optimize the RFQ-design for a reduced electrode voltage of 60 kV [see Fig. 6] required for Be^+-acceleration. New electrodes will be fabricated and aligned in the resonator.

By reducing the electrode voltage the aperture is also reduced to maintain the focussing force of the electrodes. This leads to higher capacities between the rods which in turn results in lower shuntimpedances. Therefore the transverse electrode profile was improved with the 3-D code

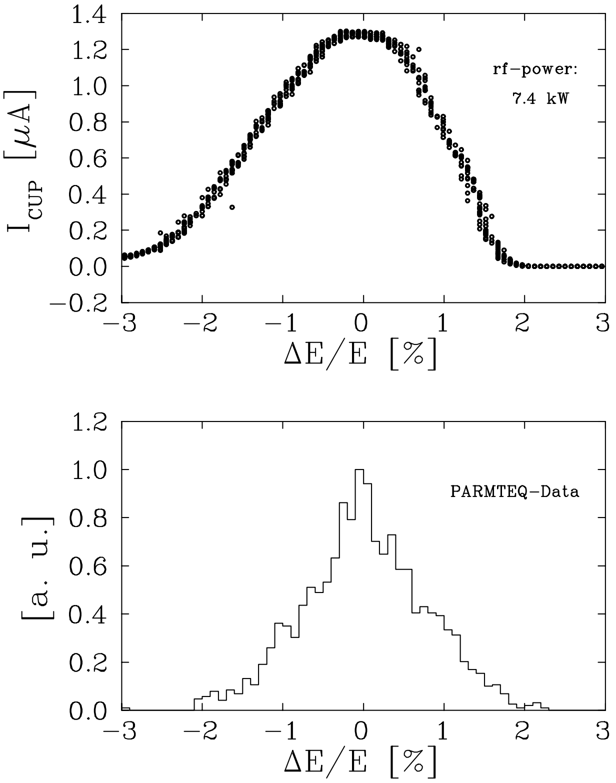

Figure 4: *Calculated (line) and measured (dots) energy distribution at an electrode voltage of 15.8 kV*

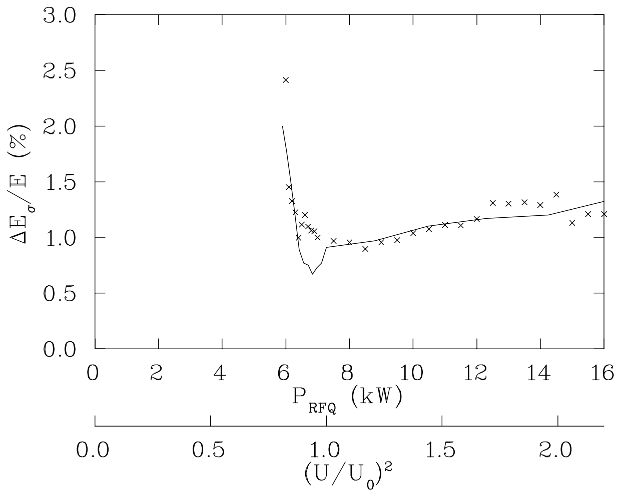

Figure 5: *Comparison between the calculated (solid line) and measured (dots) energy spread $\Delta E/E$ to determine the shunt impedance*

MAFIA to minimize the inner capacity without increasing higher order multipoles into critical regions. Furthermore, the influence of misaligned electrodes has been investigated. As a result the capacity can be decreased by about 10% by using a radius cutter with a much smaller diameter. This smaller radius increases multipole components. The effect on the quadrupole field created by the increase of the multipole components has the same order

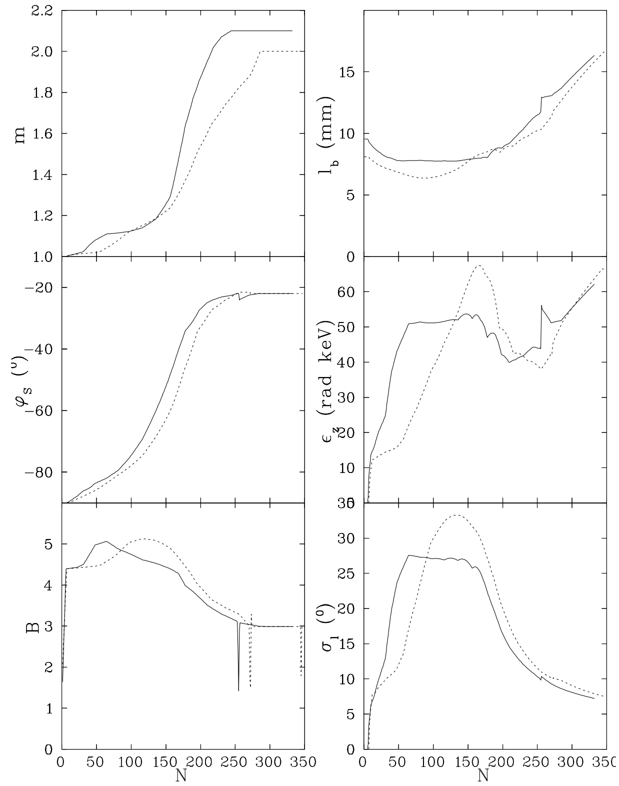

Figure 6: *Parameters of the re-designed electrodes: dashed line=old design, solid line=new design. m=modulation, ϕ=phase, B=focussing parameter, l_b =bunchlength, ϵ=emittance and σ=phase advance*

of magnitude as the effect caused by $\pm 0.2mm$ misaligned tolerances of the electrodes and is therefore tolerable.

4 ACKNOWLEDGEMENT

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