The High Current Injector at the MPI für Kernphysik in Heidelberg

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Abstract

At the Max-Planck-Institut für Kernphysik in Heidelberg the new High Current Injector is presently being put into operation. In its first phase the injector consist 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 operate at a frequency of 108.48 MHz with a high duty cycle up to 25% at a maximum power consumption of 80 kW per cavity. After the successful test of the 2 RFQ resonators in autumn 97, the injector has been completely installed and aligned. After a short conditioning period a 16 keV He-Beam was accelerated by the 2 RFQs up to 1.85 MeV with a transmission better than 90%. In a second phase an ECR source will be added to provide the full spectrum of highly charged ions up to uranium. In this paper the progress in the commissioning of the RFQs and first results of the conditioning phase of the complete injector will be reported.

1 INTRODUCTION

Laser cooling experiments at the Heidelberg heavy ion cooler ring TSR with ultra cold beams [2] of $^9Be^+$ and $^7Li^+$ 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 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 heavy ions are frequently limited by low beam currents due to beam reduction by at least 2 stripping processes. Therefore an ECR- or EBIS- source will be added in a second phase to increase also the currents for all heavy ions.

In figure 1 the schematic layout of the new injector is shown. The accelerator is mounted parallel to the Tandem and the $^9Be^+$-beam will be injected directly into the postaccelerator. In the 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 CHORDIS ION SOURCE

The first section of the new injector consists of a CHORDIS ion source, designed and optimized for the production of singly charged ions. In the sputter version to be used to produce Be^+ beams, a negatively biased sputter target is located around the extraction electrode. From scaling results a current of 4 mA is expected. For the production of Li^+-beams a sputtering of Li-alloy is used. Extracted ion currents of 2 mA have already been demonstrated. The following table 1 gives an overview of the ions produced up to now.

Ion	operation mode	U_{ex} [kV]	I [mA]
$^4He^+$	gas	17.5	2.5
$^7Li^+$	sputter	17.5	2.0
		28.0	2.3
$^9Be^+$	sputter$^\heartsuit$	30.0	0.21
$^{24}Mg^+$	sputter	20.0	1.1
$^{40}Ar^+$	gas	17.5	2.5
		30.0	9.0
	pulsed	36.0	7.0
$^{48}Ti^+$	sputter	30.0	0.7
$^{53}Cr^+$	sputter	30.0	0.17
$^{56}Fe^+$	sputter	30.0	0.46

Table 1: List of the produced ions with the achieved intensities. $^\heartsuit$Cu–alloy with 2% of Beryllium.

3 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 90 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 by the local workshops and high mechanical stability of the mini-vane-electrodes. Figure 2 shows a drawing of the stems with 4 rods. Due to the high preci-

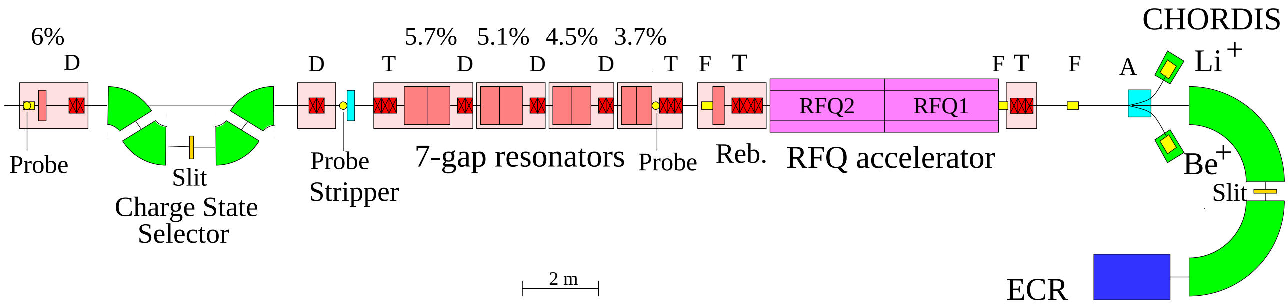

Figure 1: Schematic layout of the new high current injector. A, D, T: magn. dipoles and lenses, Re: rebuncher, F: faraday cup, probe: phase probe. The ion source for highly charged ions (ECR) and the charge state selector are planned for the second construction phase.

sion of the fabrication process no bellows or flexible tubings were neccessary to feed the cooling water from the stems to the rods, though minor corrections of the rod position during alignment still is possible.

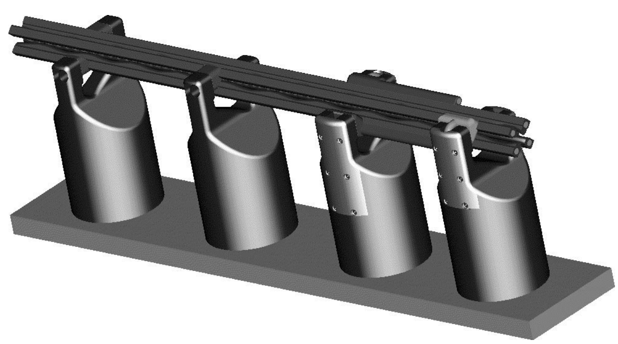

Figure 2: Drawing of the last 4 stems of the RFQ with the mini-vane-electrodes. The distance between the last two stems is decreased in order to get a flat voltage distribution.

First measurements with a 1 m long prototyp were carried out which resulted in a shuntimpedance of 100 kΩm. With the available power of 90 kW the design electrode voltage of 71 kV was not achievable. So a redesign was necessary where we followed two objectives. First to try to maintain the beam dynamic parameters at a lower achievable voltage and second to increase the shunt impedance of the RFQ by decreasing the capacity between the rods.

Significant progress was possible due to 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 for acceleration of ions with Q/A $\geq$ 1/9 providing almost the same final energy and the same high transmission of 90%. This new optimization method now also allows to design RFQs in a very compact form and to fulfill at the same time the so called LOS ALAMOS criteria for funcionally separated sections.

By reducing the electrode voltage the aperture has to be reduced to maintain the focussing force of the electrodes. This leads to higher capacities between the rods which in turn results in lower shuntimpedance. Therefore the electrode profile was improved with the 3-D code MAFIA to minimize the inner capacity without increasing higher order multipoles to critical values. 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 smaller diameter. This smaller radius increases multipole components. But the effect on the quadrupole field is equivalent to the effect caused by $\pm 0.2mm$ misalignment of the electrodes and is therefore tolerable.

A second important step was the rearrangment of the fabrication procedere of the electrodes. At first all brazing processes were done in order to maintain the high precision in the following CNC machining steps up to the finished rod. In a 3 m long carrier frame the milling of the modulation of the rod was done. Finally the supports which connect the electrode to the stems were milled with accurate reference to the beam axis. Therefore the adjustment of all rods was possible in a few days.

For the low level rf-measurements in the resonator the perturbation method was applied. Segmented plates of massive copper between the stems were used to adjust the eigenfrequency and the voltage distribution along the electrodes. For both resonators shuntimpedances and Q-values were found to be close to the expected ones. Low level shuntimpedances of 120 kΩm and Q-values of 4600 have been measured.

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

4 THE 7 GAP RESONATOR SECTION

With increasing ion velocity, RFQ acceleration becomes less efficient and other acceleration structures are superiour. The 7 gap resonators, developed at the MPI für Kernphysik are more efficient in converting the supplied power to accelerating voltage. Low power models - scaled 1:2.5 - of 7 gap resonators for ion velocities of 3.7, 4.5, 5.1, and 5.7% were built to optimize the voltage distribution and the shunt impedance of the resonators. After the optimization of the models all 8 power resonators were built. The resonator voltage - the sum over all gap voltages - of each resonator was determined by acceleration test with velocity adapted beams where the energy gain was measured by an analyzing magnet. The measured resonator voltages vary between 1.7 and 1.8 MV which correspond to shunt impedances from 75 MΩ/m to 95 MΩ/m. The Q-values are about 5000.

5 THE FIRST BEAM

After the alignment of the whole high current injector the RFQs were put into operation. With a 4 keV/u He^+-beam delivered from the CHORDIS, the shuntimpedances of both RFQs could be determined by varying the input power versus the measured maximum energy. For the first RFQ a shuntimpedance of 125 kΩm was measured (RFQ2 without power) which corresponds to 15.5 kW input power for a He^+-beam. In order to improve in this measurement the transmission through RFQ2, the latter was run with 14 kW input power and a detuned rf phase of 180^o with regard to RFQ1. With a transmission better than 80% we measured for RFQ1 an output energy of 0.23 MeV/u and an energy spread of 0.44%, see Figure 3. RFQ2 was only transporting the beam with good transmission and energy spread.

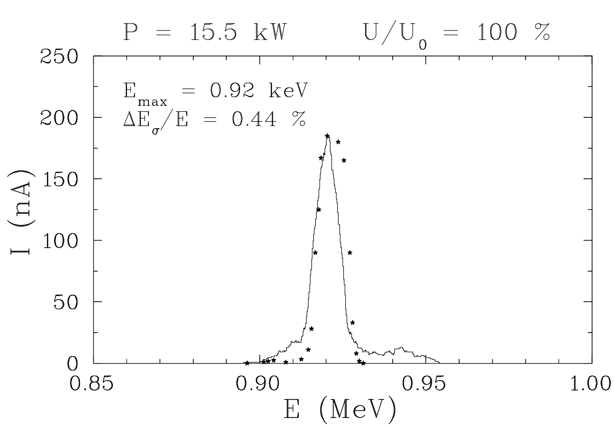

Figure 3: Spectrum of intensity versus energy of a $^4He^+$ beam to determine the energy spread of the beam accelerated in the first RFQ and to demonstrate the ability of the second RFQ to transport the beam by detuning the phase in respect to the first RFQ almost without transmission or energy spread deterioration. (solid line: theoretical values by PARMTEQ, dots: measurement)

With a fixed input power for RFQ1 the shuntimpedance of RFQ2 was determined to be 135 kΩm by varying again the input power versus the measured maximum energy, see Figure 4. The maximum energy of 1.915 MeV corresponds very well with the design value of the RFQs of 0.48 MeV/u. The transmission was better than 90% with the two directly coupled RFQs.

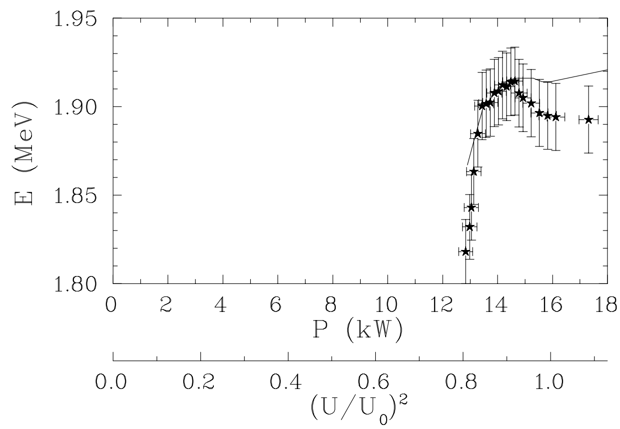

Figure 4: *Comparison between the calculated (solid line) and measured energy to determine the shunt impedance of RFQ 2*

6 ACKNOWLEDGEMENT

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7 REFERENCES

[1] annual report MPI-H (1994), p. 249

[2] R. W. Hasse, I. Hofmann and D. Liesen, Proc. Workshop on Crystalline Ion Beams, Wertheim, FRG, Oct 4-7, 1988, GSI-89-10, Darmstadt, 1989

[3] M. Grieser, PhD-thesis, Heidelberg, 1986

[4] C.-M. Kleffner, An RFQ-accelerator for the High Current Injector of the TSR, EPAC 92, Berlin, 1992

[5] R. Keller, B. R. Nielsen and B. Torp, Nucl. Inst. and Meth. B37/38(1989)74

[6] R. von Hahn, M. Grieser, D. Habs, E. Jaeschke, C.-M. Kleffner, J. Liebmann, S. Papureanu, R. Repnow, D. Schwalm and M. Stampfer, Nucl. Inst. and Meth. A328(1993)270-274