Status of the High Curren t Injector Project

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Abstract

Man y experiments at the Test Storage Ring TSR are limited by weak ion beam intensities [1], delivered from a tandem–postaccelerator com bination. A new high current injector, consisting of a CHORDIS ion source, 2 RFQ and 8 seven–gap resonators, will deliver 1–3 orders of magnitude higher intensities of singly charged ions. The final energy of 1.8 MeV/u is w ell adapted to the acceptance of the postaccelerator. By adding an ECR–source in a second phase the system will be able to deliver heavy ion beams up to uranium with energies above the coulomb barrier of the heaviest elements. The CHORDIS is already operating in cw–mode, in sputter mode the pulsed in tensity has still to be optimized. By means of an optimizing algorithm it was possible to lower the electrode voltage of the RFQ–accelerator from 71 kV to 60 kV main taining a particle transmission of about 80% with ion curren ts of 10 mA. All of the 8 seven–gap resonators have been power tested successfully and performed as expected. This paper describes the status of the project.

Introduction

In its first phase the high current injector consists of a commercial CHORDIS ion source [4], 2 RFQ–accelerators [3] and eight 7–gap resonators [2] delivering $^{7}Li^{+}$ or $^{9}Be^{+}$ ion beams with 1–3 order of magnitude higher in tensities. In a second phase an ECR– or EBIS–source will be added to increase the currents for highly charged heavy ions because some experimen ts are frequently limited by low beam currents due to stripping losses. In fig. 1 the schematic layout

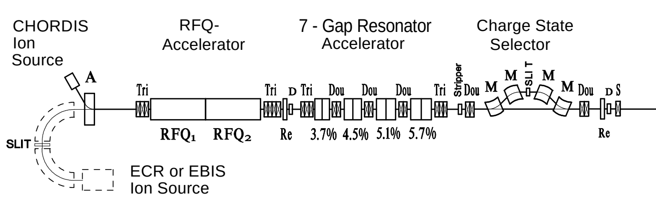

Figure 1: *Schematic layout of the new high current injector. A, M, Dou, Tri: magn. dipoles and lenses, Re: rebuncher, D: beam diagostic.*

of the new injector is shown. The accelerator will be placed parallel to the Tandem. 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 v elocity 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 reac hed for all ion species in a pulsed mode operation with up to 25% duty cycle.

The ion source

For the production of high currents of Li^{+} and Be^{+} with low duty factor (5 Hz, 500μs) the commercial ion source CHORDIS [4] is used. The construction of the ion source section consisting of the source on a platform, a 60°–magnet for isotope selection and a quadrupole triplet to match the beam to the RFQ section has been finished. The CHORDIS ion source has been in operation on its test–bench for several hundred hours [see Table 1]. The design

ion type	regime	U_{ex}[kV]	I [mA]
$^{4}He^{+}$	gas	17.5	2.5
$^{7}Li^{+}$	sputter	17.5	2.0
		28.0	2.3
$^{9}Be^{+}$	sputter	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 ion species and current intensities already produced with the CHORDIS source.*

value of 2 mA was achieved with Li^{+} in stable operating conditions. Higher currents were reached and could be stably produced by using an additional cooling equipment of the sputter cathodes. For the Be^{+}–source an alloy with a Beryllium contents of only 2% was used with which an intensity of 0.2 mA was satisfactory for all tests. Higher currents can then be achieved with cathodes made from pure Beryllium. Improvements were made with respect to diagnostic methods for source operation and particle beam optimization. The pulsed mode operation has been established for the gas version, however, some improvements are still necessary in the sputter mode. The emittance of the CHORDIS of 35 π mm mrad has been measured to be within specifications.

The RFQ–Resonators

The second section of the high current injector consists of two 4–rod–RFQ resonators [3] operating at an eigenfrequency of 108.48 MHz. With a rf–power of 80 kW (25% duty cycle) an electrode voltage of 71 kV should be reached in order to accelerate ions with a charge to mass ratio $q/a \geq 1/9$ as required for $^9Be^+$. The electrodes with 3 m length are milled out of a hollow profile from a copper–tin alloy to provide sufficient cooling (35% of the rf power is dissipated at the electrodes) as well as mechanical stability. However, the maximum diameter of the rods is limited by the capacity between the electrodes to preserve a high shunt impedance [3]. To provide optimal electrical conductivity the electrodes were copper plated at the GSI. The first RFQ–resonator was constructed and tested in full length this year. The mechanical alignment of the electrodes was performed successfully and the achieved tolerance ($\pm$0.02 mm) measured after installation is satisfying. Massive copper plates were installed between the stems to adjust the eigenfrequency to 108.48 MHz. The resonator has a Q–factor of 3800. Power tests up to 20 kW in cw–mode were carried out without any problems. Weak ponderomotoric oscillations – which could be observed in pulsed high power operation – could easily be eliminated by means of mechanical decoupling between the cryo–pumps and the resonator–tank. Moreover, a mechanical stabilization was used at the long ends of the electrodes to suppress

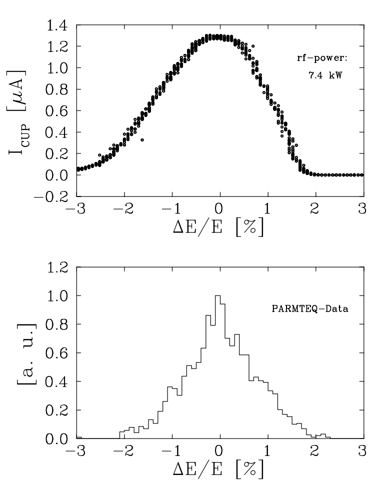

Figure 2: *Calculated (line) and measured (dots) energy distribution at an electrode voltage of 15.8 kV*

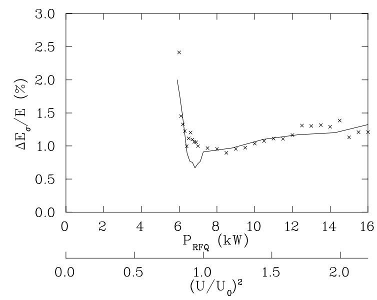

Figure 3: *Comparison between the calculated (solid line) and measured (dots) energy spread $\Delta E/E$ to determine the shunt impedance. U_0=15.8 kV, design voltage for an H_2^+–beam.*

mechanical oszillations.
In order to determine the shunt impedance R_S of the structure the energy gain of an accelerated H_2^+–beam behind the first RFQ–resonator was measured. The set up consists of a penning ion source with electrostatic lenses and an analyzing 90°–double focusing bending magnet with two diagnostic boxes. First acceleration tests have been carried out and compared with PARMTEQ–calculations [6] at different rf–power levels. The measured and simulated energy spread of the beam at 7.4 kWis shown in fig. 2. The comparison between between calculated and measured energy spread, fig. 3, leads to a shunt impedance R_S = 101 kΩm. With this shunt impedance it is not possible to reach an electrode voltage of 71 kV (design value) with a rf power of 80 kW. Therefore the electrodes are redesigned with a lower voltage of 60 kV by means of an optimizing algo-

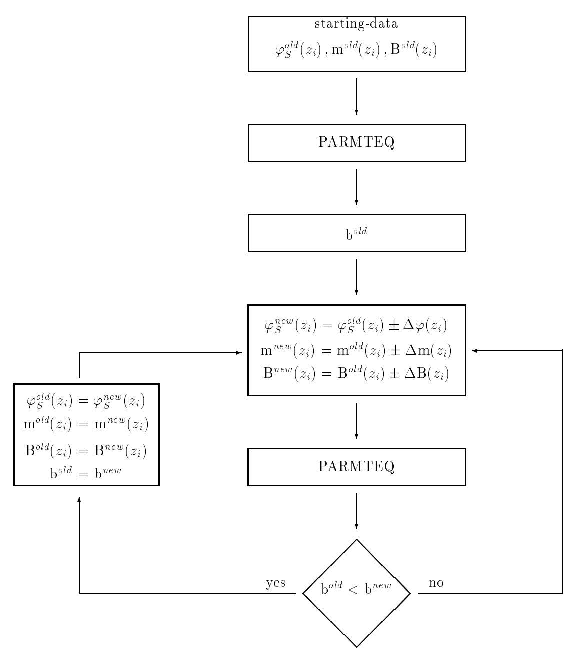

Figure 4: *Diagram of the optimizing algorithm.*

rithm. This new method is based on random variations of the design parameters synchronous phase φ_s, modulation m and focussing parameter B and governed by the value of a scalar function $b(T, L)$ which takes only two criteria into account: the length L of the resonator for a fixed final energy and the calculated particle transmission T [see Fig. 4]. Fig. 5 shows the parameter behavior of the old 71 kV–design and the re–designed 60 kV electrodes. By reducing

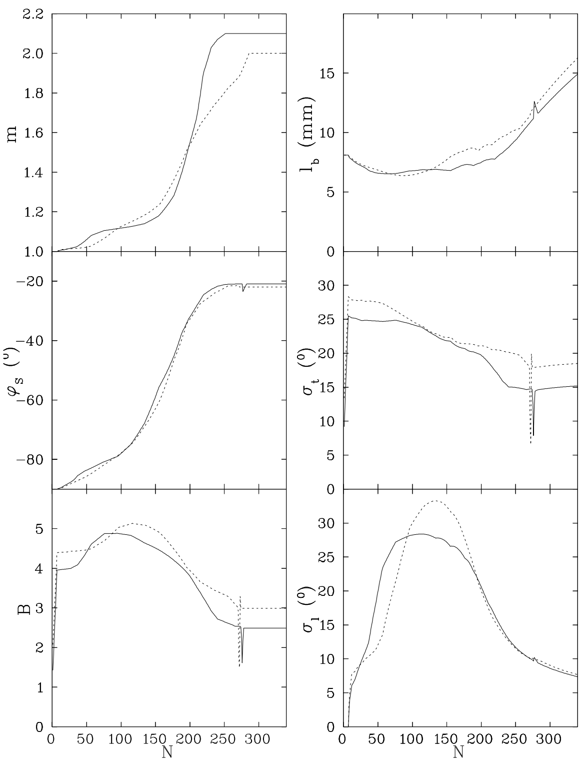

Figure 5: *Comparison between old (dashed line) and re–designed (solid line) electrodes: m = modulation, φ_s = synchronous phase, B = focusing parameter, l_b = bunch length, σ_l = long. and σ_t = trans. phase advance.*

the electrode voltage the aperture is also reduced when the focusing parameter B along the acceleration structure is maintained. This leads to higher capacities between the rods which in turn results in a lower shunt impedance. Therefore it was tried to find an electrode design with a reduced focusing parameter along the new electrodes maintaining at least the old particle transmission. Moreover the rod tip of the new electrodes is going to be milled with a 20–25% smaller radius reducing the electrode capacity by 10% as calculated with MAFIA–simulations. However the smaller radius increases multipole components but the effect on the quadrupole field has the same order of magnitude as the effect caused by $\pm$0.2mm misalignment of the rods and is therefore tolerable.

The 7–gap resonators

With increasing ion velocity, RFQ acceleration becomes less efficient and other accelerating structures such as seven–gap resonators are more economical. Therefore the third part of the high current injector consists of 8 seven–gap resonators with an eigenfrequency of 108.48 MHz operating at 80 kW rf power with 25% duty cycle. To simplify the construction, the resonators are designed as four pairs of identical resonators for synchronous velocities of β_s=3.7, 4.5, 5.1 and 5.7% [5]. All 7–gap resonators have been calibrated with a particle beam with synchronous velocity. From the energy distribution of the beam behind

β_s [%]	U_0 [MV] (N=80kW)	β_s [%]	U_0 [MV] (N=80kW)
3.7 **I**	1.73	5.1 **I**	1.69
3.7 **II**	1.67	5.1 **II**	1.74
4.5 **I**	1.79	5.7 **I**	1.70
4.5 **II**	1.73	5.7 **II**	1.71

Table 2: *Measured resonator voltages with beam tests.*

the resonator, the accelerating voltages could be derived, table 2, and were found in agreement with the bead perturbation measurements. The resonators are finished and have successfully undergone high power–rf tests up to 100 kW at a duty cycle of 25%. Neither mechanical vibrations due to ponderomotive forces nor multipactoring problems have been observed.

Acknowledgement

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