A High Current Injector for the Heidelberg Test Storage Ring TSR

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Abstract

Many experiments at the Heidelberg Test Storage Ring TSR - especially laser cooling - are limited by the low currents delivered by the MP-tandem. An injector for singly charged ions consisting of a high current source , two RFQs and eight 7-gap resonators will provide up to three orders of magnitude increase in intensity. In the second phase, an ECR source for highly charged ions will be added and the high current injector will be used in combination with the Heidelberg heavy ion postaccelerator. This new system will deliver beams up to Uranium with energies above the Coulomb barrier of the heaviest elements. In this paper the design and status of the project is presented.

1 INTRODUCTION

The existing accelerator facility at the Max-Planck-Institute in Heidelberg consists of a 12 MV tandem Van-de-Graaff accelerator, a post-accelerator and the heavy ion Test Storage Ring TSR [1]. Positive ions injected into the TSR are obtained from a pulsed negative ion sputter source followed by a stripping process in the terminal of the tandem accelerator and possibly second and third stripping processes before and after the post accelerator. With different stacking techniques - multiturn injection, rf-stacking and electron cooling stacking [2]- high currents of long lived ion beams can be accumulated in the TSR in spite of weak currents delivered by the tandem.

As shown in table 1,only low currents of singly charged Li^+, Be^+ can be stored at present. Accumulation of Li^+ and Be^+ is done by multiturn injection alone, due to the modest output of the negative ion source as well as short beam lifetimes in the storage ring. These weak beam currents strongly hamper laser cooling experiments done with these ion species. A new injector will increase the beam currents for these two ion species. The proposed high current injector will consist in its first phase of a commercial "CHORDIS" ion source [3] for the production of high current beams of Li^+ (20mA) and Be^+ (4mA), followed by two RFQ accelerators and eight 7-gap resonators.

Also, for highly charged ions present TSR experiments are frequently limited by low beam currents due to losses from multiple stripping. In the second phase, an ECR source for highly charged heavy ions will be added to the injector. The final energy of $E \geq 1.7$ MeV/u after the injector is optimized for the existing post accelerator. The layout of the new injector in the first phase is shown in figure 1. The transfer line from the ion source to the RFQs contains quadrupoles as focusing elements, bending magnets to analyze the charge and mass spectrum and beam diagnostic elements. Two 30° bending magnets transfer the beam to the existing beamline.

Table 1: *Energies, currents and lifetimes of some ion beams stored in the TSR (injector=tandem post accelerator combination)*

Ion	Energy [MeV]	Intensity (injector) [μA]	Intensity (ring) [μA]	lifetime (e-cooled) [sec]
p	21	54.0	3300	220000
$^6Li^+$	12	0.1	2	10
$^7Li^+$	13	0.9	12	48
$^9Be^+$	7	0.7	2	16
$^{12}C^{6+}$	73	60.0	18000	7500
$^{32}S^{16+}$	195	0.4	1500	450
$^{63}Cu^{26+}$	510	0.1	110	240
$^{80}Se^{25+}$	480	1.8	110	204

2 THE ION SOURCE

For the production of high currents of Li^+ and Be^+ with low duty factor (5Hz, 500μs) the commercial ion source CHORDIS [3] will be used. In the sputter version to be used to produce Be^+ beams, a negatively biased sputter target is located at the extraction electrode. Scaling results obtained for a Cr^+ beam, a current of 4 mA Be^+ is expected [4]. For the production of Li^+, sputtering of Li-alloys is forseen. It has also been considered to produce Li^+ in a separate oven. Extracted ion currents of 20 mA should be possible.

The power supplies for the ion source are installed on a 40 kV platform. A 60° double focusing dipole, switchable between two ion sources, is used to analyse the ion species

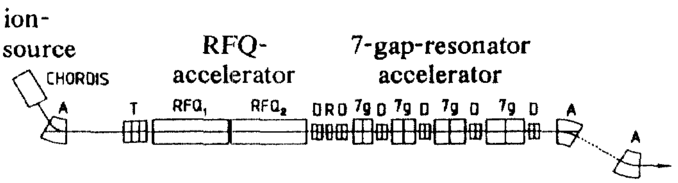

Figure 1: *Layout of the new high current injector. (D = quadrupole doublet, 7g = 7-gap resonators , A = dipole magnet, T = triplet).*

and charge state. A quadrupole triplet lens is provided to match the extracted beam with the acceptance of the RFQ accelerator.
As the laser cooling experiments of Li^+ require ions in their metastable $^3S_1$ state, a gas cell either before or after the 7-gap resonators will be installed.

3 THE RFQ ACCELERATOR

The second section of the high current injector consists of two 4-rod RFQ resonators [5] [6] operating at a charge to mass ratio $Q/A \geq 1/9$ as required for $^9Be^+$. A rf power of 80 kW per resonator is necessary to produce a voltage of 70 kV between the electrodes. The rf-supplies required are identical to those already used in the existing post accelerator. The RFQs operate at a frequency of 108.48 MHz. The energy at the output of the first RFQ resonator will be 250 keV/u, the second increases this energy to 500 keV/u. Beam dynamics calculations with the PARMTEQ code [8] are in progress to fine tune the 4-rod structure and to investigate the matching of the two RFQs. The overall mechanical design of the tanks and stems is fixed. Both tanks have an inner diameter of 32 cm and a length of 300 cm. The tanks were designed inhouse and fabricated by industry.

4 THE 7-GAP RESONATORS

With increasing ion velocity, RFQ acceleration becomes less efficient and other acceleration principles are superior. The 7-gap resonators [9] [10] developed at MPI für Kernphysik are more efficient in converting the supplied power to acceleration voltage. An intermediate IH-structure was also considered as in the new GSI injector [11], but it was decided to go directly from the RFQ structure to individual resonators as this technique is well established in Heidelberg. By combining the two RFQs with eight 7-gap resonators a flexible design can be obtained.

Low power models of 7-gap resonators, for ion velocities of 3.7%, 4.5%, 5.1% and 5.7%, have been built at a scale of 1:2.5 in order to study the characteristics of these resonators. Each resonator has a single resonance structure which is shown in figure 2. It consists of a copper half shell to which three copper arms are attached on each side. Drift tubes are added to the ends of the arms which are rotatable in the half shell to set up the eigenfrequency and voltage distribution. One full scale resonator has already been built. Power tests have been carried out with a pulse power of 80 kW (duty factor 1:4). For a power consumption of 80 kW the sum of the amplitudes of the gap voltages U_0 is 1.8 MV.

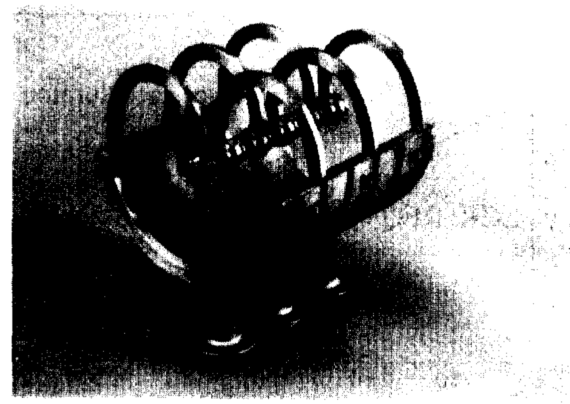

Figure 2: *Resonance structure of the 7-gap resonator*

Variation of the output energy of the new injector can be accomplished by tuning the phase and/or amplitude of the last active resonator. With four 7-gap resonators an energy of 7.3 MeV for $^9Be^+$ and with all eight 7-gap resonators an energy of 13.3 MeV for $^7Li^+$ can be obtained. The new injector is thus able to supply the required beams for laser cooling experiments at TSR in a stand alone operation.

5 THE NEW INJECTOR - POST ACCELERATOR COMBINATION

Ions from the CHORDIS or the ECR source compatible with a charge to mass ratio of $Q/A \geq 1/9$ are accelerated in the RFQs to an energy of 0.5 MeV/u. In the eight 7-gap resonators an additional energy of 11 MeV can be provided per charge state resulting in a final energy of at least 1.7 MeV/u corresponding to a velocity of $\beta \geq 6\%$. Stripping and bunching is performed between the new injector and the post-accelerator. The new injector does not interfere with the operation of the tandem and the tandem together with the postaccelerator will be further available for all beam lines.

In figure 3 and 4 a comparison is shown between the final energies and intensities for ion beams as a function of mass number for the present and future configurations. At present, negative ions from the source are stripped once in the terminal of the tandem and again before injection into the post accelerator. While the maximum energies are comparable for both configurations, the advantage of the

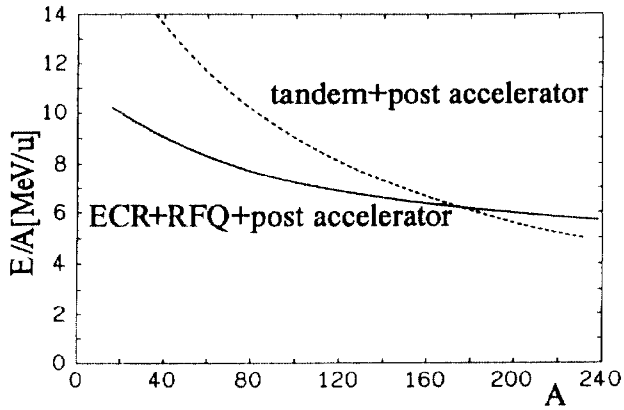

Figure 3: *Ion energy per nucleon as a function of mass number for the new configuration (ECR+RFQ+post acclerator) and the present configuration(Tandem+post accelerator).*

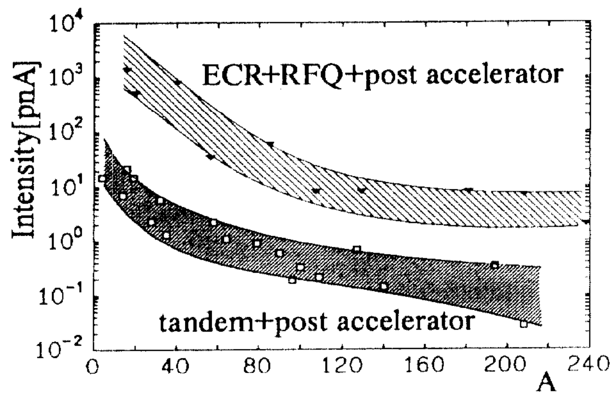

Figure 4: *Ion currents as a function of mass number for the new configuration (ECR+RFQ+post accelerator) and the present configuration (Tandem+post accelerator). The shadowed area denotes the expected range of intensities.*

new injector is the increase in beam current by a factor of 100. The small currents for A$\geq$100 of the present facility have limited their use in nuclear physics experiments. For the values displayed in figure 3 and 4, a duty factor of 25% was assumed. This new system will deliver beams up to Uranium with energies above the coulomb barrier of the heaviest elements. For A$\leq$80 a CW operation of the high current injector is possible, for A$\leq$40 the particle energies are above Coulomb barrier of Uranium.
The energy spread of the ions after the RFQs is estimated to be $\pm$1% which transforms into $\pm$0.5% at the end of the new injector, about a factor 5 to 10 larger than typical energy spreads obtained with the tandem after the second stripper. These large energy spreads are tolerable for almost all conceivable single pass experiments because the energy losses of ions in typical targets are comparable. The worse beam quality from the new injector is improved by electron cooling. For the TSR, multiturn injection becomes somewhat less efficient, but this is certainly outweighed by the higher intensities of the primary beam.

6 ACKNOWLEDGEMENT

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