# Progress of the Heidelberg High Current Injector

C.-M. Kleffner, S. Auch, M. Grieser, D. Habs, V. Kößler,
M. Madert, R. Repnow, D. Schwalm
Max-Planck-Institut für Kernphysik, Heidelberg, Germany
H. Deitinghoff, A. Schempp
University of Frankfurt, Frankfurt, Germany
E. Jaeschke, R. von Hahn
BESSY, Berlin, Germany
and S. Papureanu
KFA Jülich, Germany

## *Abstract*

The accelerator facilities at the Max-Planck-Institut für Kernphysik in Heidelberg will be upgraded by a new high current injector which is under development. The first phase will consist of a high current ion source (CHORDIS) for singly charged ions, two 4-ROD-RFQ-resonators and eight 7-gap-resonators. The ion source has already delivered the design current of several mA $Li^+$. New 'vane-like' electrodes with good cooling properties and good mechanical stability allow the operation of the RFQ-resonators at high power level and duty cycle. The eight 7-gap-resonators were constructed and tested. The final energy of the injector (E = 1.8 MeV/u) is matched to the existing post-accelerator. By adding an ECR- or an EBIS- source, the new injector-post accelerator system will be able to deliver beams up to uranium with energies above the Coulomb barrier. The progress of the project will be described.

## I. Introduction

Laser cooling experiments at the Heidelberg heavy ion storage ring TSR with ultra cold beams [1] 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 three orders of magnitude. The high current injector will consist in its first phase of a commercial CHORDIS ion source[2], two RFQs [3] and eight 7-gap resonators [4].

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 $^7Li^+$- or $^9Be^+$-beams will be injected directly into the postaccelerator acting as a transfer line. For 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°-magnets. The new injector also operates at 108.48 MHz like the existing post accelerator. The ion velocity of $\beta = v/c = 6\%$ 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 of operation with up to 25% duty cycle.

## II. The Ion Source

For the production of high currents of $Li^+$ and $Be^+$ with low duty factor (5 Hz, 500 µs) the commercial ion source CHORDIS [2] 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. Table I shows a list of all ion species produced so far and the intensities of the analyzed currents in CW mode. Also the extraction voltage $U_{ex}$ is given. For $Be^+$ and $Li^+$ the ion source is used in the sputter version.

Table I
List of ion species and current intensities produced so far with the CHORDIS-source in CW mode

| ion type | regime | $U_{ex}$[kV] | I [mA] |
|---|---|---|---|
| $^4He$ | gas | 17.5 | 2.5 |
| $^7Li$ | sputter | 17.5 | 2.0 |
| $^9Be$ | sputter | 30.0 | 0.21 |
| $^{40}Ar$ | gas | 17.5<br>30.0 | 2.5<br>9.0 |
| $^{48}Ti$ | sputter | 30.0 | 0.37 |
| $^{53}Cr$ | sputter | 30.0 | 0.17 |
| $^{56}Fe$ | sputter | 30.0 | 0.46 |

As far as $Li^+$ is concerned, the design value of 2 mA was achieved with 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. The intensity of 0.2 mA is 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.

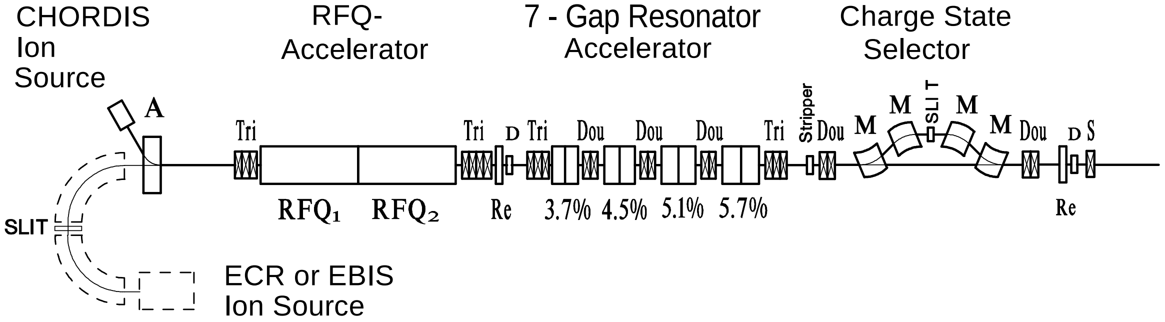

Figure. 1. Schematic layout of the new high current injector. A, M, S, Dou, Tri: magn. dipoles and lenses, Re: rebuncher, D: beam diagnostic. The ion source for highly charged ions (ECR or EBIS) and the charge state selector are planned for the second construction phase. The ion source will then be located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

## III. The RFQ-Resonators

The second section of the high current injector consists of two 4-rod-RFQ resonators [3] 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.

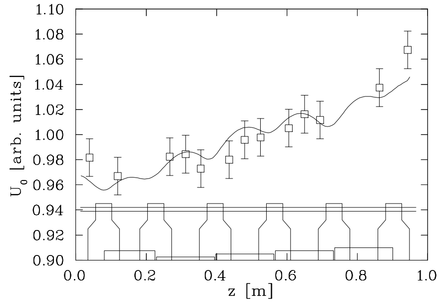

Figure. 2. Inter-electrode voltage distribution.
line: MAFIA-calculation

3-D calculations with MAFIA [6] and measurements have been made for the newly designed electrodes with a shortened prototype resonator of 1 m length. Figure 2 shows the measurements and the calculations of the flatness of the voltage between the electrodes.

Power tests were done with the RFQ-prototype at a power level of 15 kW in CW mode. This is more than a factor of 2 higher than the design value for the 3 m long RFQ-resonators. The resonator was operated several weeks without any problems with respect to mechanical stability or sparking between the electrodes. Moreover, by injecting a light ion beam of suitable velocity, bunching and accelerating tests were performed with the prototype resonator, detecting the accelerated hunches with a fast Faraday-cup behind the resonator. Figure 3 shows the measured time structure at a rf-power level of 10 kW.

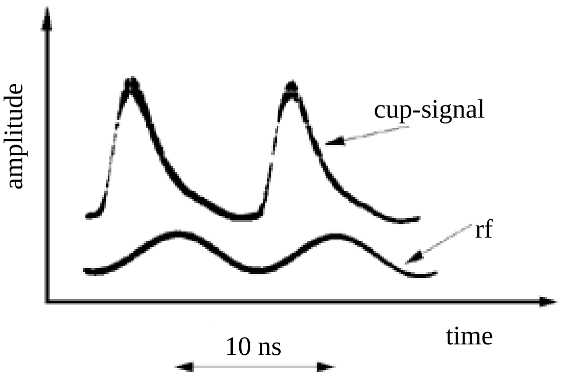

Figure. 3. Cup signal of $H_2^+$- bunches, accelerated in the RFQ-prototype

The measured peak amplitudes of the hunches at different electrode voltages of the RFQ-prototype were compared with calculations with the program PARMTEQ [7] (Figure 4) to estimate the shunt impedance of the structure. The shunt impedance of $R_s = 115$ kΩm was found in good agreement with the low-level measurements.

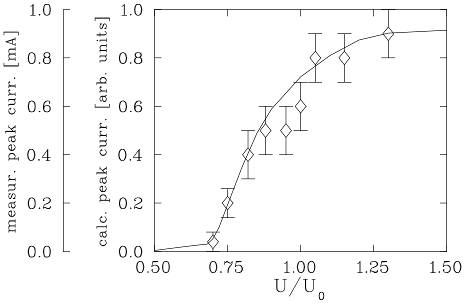

Figure. 4. Measured and calculated (line) peak currents of the accelerated $H_2^+$- beam in the RFQ-prototype. $U_0$: design electrode voltage

After the successful tests with the prototype resonator, the 3 m long electrodes for the first RFQ-resonators were installed in the vacuum tank and aligned (Figure 5). Low level measurements and power tests are in preparation.

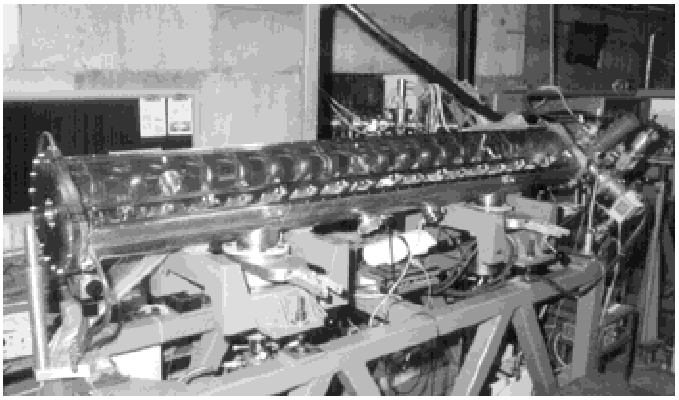

Figure. 5. View into the vacuum chamber of the first RFQ-resonator

## IV. The Seven-Gap Resonators

With increasing ion velocity, RFQ acceleration becomes less efficient and other accelerating structures such as the seven-gap resonator, developed at the MPI für Kernphysik [4] are more economical. To simplify the construction, the resonators are designed as four pairs of identical resonators for synchronous velocities of $\beta_s$ =3.7, 4.5, 5.1 and 5.7%. Based on measurements for the high velocity prototype of a seven-gap resonator [4], an effective accelerating voltage of 1.4 MV is expected for a low β-resonator, which operate at 80 kW rf power with 25% duty cycle. Scaled down models for the four different resonators have been used to optimize field distributions and shunt impedances. Based on these measurements, all eight seven-gap resonators have been fabricated so far [5]. In figure 6, a seven-gap resonator with a flange removed is shown. Segments on both sides of the inner resonance structure allow to adjust the required eigenfrequency to 108.48 MHz. The tuning plate, below the resonance structure, is clearly visible. The rf power is coupled into the resonator near one of the three legs which connect the resonance structure to the tank.

Table II
Measured resonator voltages with the beam test

| $\beta_s$ [%] | $U_0$ [MV] (N=80kW) | $\beta_s$ [%] | $U_0$ [MV] (N=80kW) |
|---|---|---|---|
| 3.7 **I** | 1.73 | 5.1 **I** | 1.69 |
| 3.7 **II** | 1.67 | 5.1 **II** | 1.62 |
| 4.5 **I** | 1.79 | 5.7 **I** | 1.61 |
| 4.5 **II** | 1.73 | 5.7 **II** | 1.66 |

All 7-gap resonators have been calibrated with a particle beam with synchronous velocity. From the energy distributions of the beam behind the resonator, the accelerating voltages could be derived (Table II) and were found in agreement with the bead perturbation measurements.

All 7-gap 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.

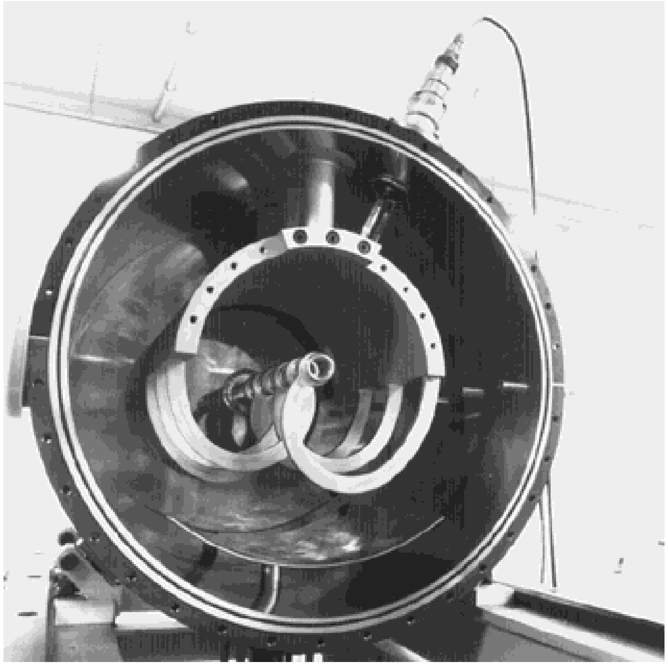

Figure. 6. The 7-gap power resonator (β=3.7%)

## V. Outlook

The shielding vault of the MP-Tandem-Accelerator was constructed from concrete blocks and was completely rebuilt yielding nearly 2 meters of additional space aside the MP for the new injector, thus allow us to assemble the new rf-resonators in their final location on the optical axis of the present postaccelerator. The first beams from the high current injector in its first phase are expected to be available in early 1996.

## VI. Acknowledgement

We would like to thank the MPI technicians for their valuable work which made the development of the high current injector possible.

## References

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

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

[3] C.-M. Kleffner, PhD thesis, Heidelberg, 1994

[4] M. Grieser, PhD thesis, Heidelberg, 1986

[5] 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), pp. 270-274

[6] T. Weiland, On the numerical solution of Maxwell's Equations and Applications in the field of accelerator physics, IEEE PAC 1984, vol. 15, pp. 245-292,1984

[7] K.R. Crandall, R.S. Mills, and T.P. Wangler, BNL 51143, p. 20,1980