LOW-FREQUENCY HIGH-CURRENT SPIRAL-RFQ INJECTORS*

A. Schempp, H. Deitinghoff, U. Bessler, A. Kipper, T. Sieber
Institut für Angewandte Physik der J. W. Goethe-Universität, D-60054 Frankfurt am Main, Germany
J. Klabunde, P. Spädtke
GSI, Gesellschaft für Schwerionenforschung mbH, D-64220 Darmstadt, Germany

Abstract

A new high current injector (HSI) for all ions up to Uranium is planned at GSI to increase the number of particles in the SIS up to the space-charge limit [1]. An RFQ prototype for the acceleration of U^{2+} has been built and tested. It operates at 27 MHz and covers the crucial first part where the beam is matched and bunched. Results of rf- and beam-tests will be presented. In addition a particle dynamics layout for the new charge state U^{4+} will be introduced.

Introduction

The GSI accelerator system consists of the new 18 Tm heavy ion synchrotron SIS and the experimental storage ring ESR, both fed by the old UNILAC. With these new rings and the UNILAC injector it is possible to accelerate all elements up to Uranium to energies above 1 GeV/u. The SIS and the ESR are now working for more than 3 years.

Two new injectors HSI (**Hochstrominjektor**) and HLI (**Hochladungsinjektor**) have been planned to fill the SIS ring with short bursts of high-current heavy-ion beams and to continue providing low current, high duty-factor beams for the nuclear physics research program at the UNILAC.

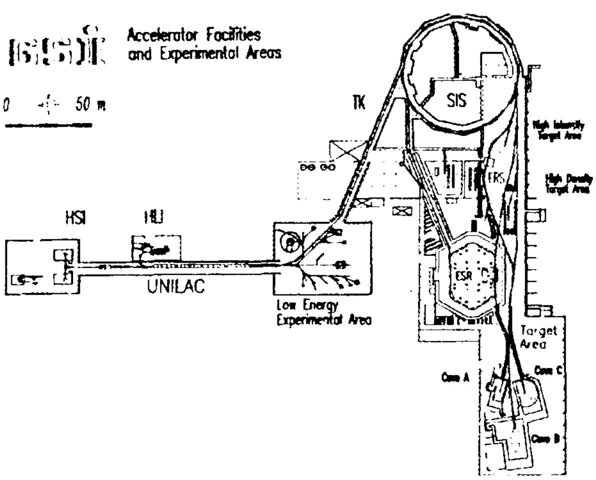

Fig. 1: View of the GSI accelerator system

The high current injector HSI is designed to fill the SIS up to its space charge limit and will accept e.g. U^{2+} or Xe^{+} beams with currents as high as 25 mA at low initial particle energies of 2.2 keV/u. The Spiral-RFQ-accelerator is working at the (UNILAC)-Wideröe frequency of 27 MHz, which allows a beam transfer without frequency jump. A gas stripper at 216 keV/u will produce a reasonable fraction of the necessary charge-state of U^{10+} for acceleration in the second Wideröe part of the UNILAC. The second gas stripper at 1.4 MeV/u provides the U^{28+} beam for postacceleration in the Alvarez-part of the UNILAC and injection into the SIS. Fig. 1 shows a layout of the GSI accelerator system.

The Spiral-RFQ-Prototype

For this high-current injector scheme a prototype of the Spiral-RFQ [2,3,4,5] has been built for both, rf- and beam-test purposes. The structure length is 4 meters but nevertheless the electrodes consist of the first 231 RFQ-cells, one third of the HSI's total cell number. These 231 cells cover the crucial low energy part of the HSI-RFQ, where the dc beam is converted into a bunched beam. Therefore the prototype can give relevant information on beam properties e.g. emittance growth. A survey over the main parameters of the RFQ-Prototype is given in table 1.

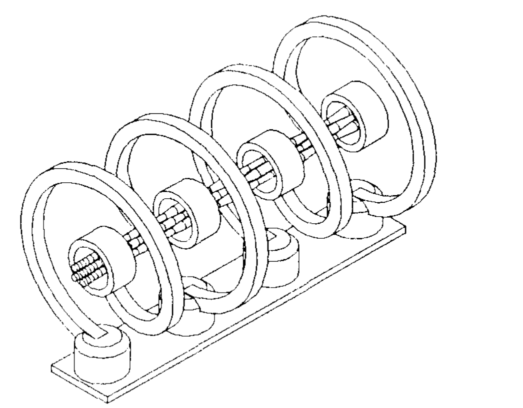

Fig. 2: Scheme of the Spiral-RFQ resonator

TABLE 1
Main Parameters of the RFQ

f	27.1 [MHz]	length	3.95 [m]
cells	231	Rp	520 [kΩm]
T_{in}	2.2 [keV/u]	T_{out}	17.6 [keV/u]
$\varphi_{s,final}$	39 [°]	a	6.0 [mm]
m_{max}	1.458	α_N	0.9 [π·mm·mrad]
U_{el}	1.51 A/ξ [kV]	I	0.23 A/ξ [mA]

A rectangular vacuum chamber made of Aluminium has been chosen for the Spiral RFQ. Eight large lids give easy access and simplify the mounting and adjustment of the

* Supported by the BMFT under contract 060F351I

RFQ electrodes. The structure has been aligned with an opto-mechanical system. The rod-electrodes are fixed on electrode carriers, each about 100 mm long and with precisely milled washers to the spiral supports which allow an alignment with a precision of approx. ± 0.1 mm, less than 3 % of the aperture radius. Fig. 2 shows a scheme of a spiral-RFQ resonator cell.

Experimental Results

The first beam experiments have been done at the Institut für Angewandte Physik (IAP) [4,6,7]. Due to the limited rf power and extraction voltage light ions (He^+) have been used for the experiments. The corresponding electrode voltage and beam current are 6 kV and 0.8 mA, respectively.

The field distribution along the beam axis has a maximum deviation of less than 2 %. An Rp value of 520 kΩm could be determined, which has been checked with X-ray spectroscopy at higher field levels. In cw-operation an input power of 7.2 kW was achieved. No mechanical and cooling problems could be observed.

For beam tests the He^+-beam from a duoplasmatron source was matched into the RFQ by two electrostatic einzellenses. For beam analysis an emittance measurement device, a fast Faraday cup and an analyzing magnet had been installed. The maximum transmitted beam current was 980 μA, but due to the input emittance with the typical aberrations of einzellenses the transmission at design voltage has been only about 40 %. PARMTEQ calculations with this input emittance delivered transmission curves which are in good agreement with the measurements.

For further experiments with singly charged heavier ions the RFQ has been installed at the GSI's test-injector stand. The electrodes were then readjusted to yield the same alignment quality as the at the first beam experiments. Fig. 3 shows the experimental set-up at GSI.

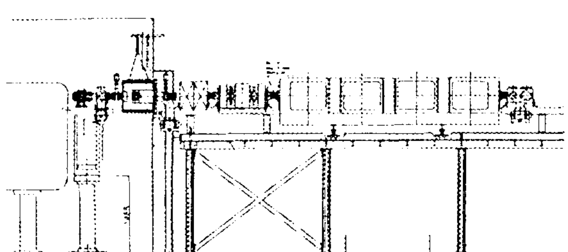

Fig. 3: Set-up of the RFQ-prototype.

The ion beam is extracted from a CHORDIS ion-source and transported and matched into the RFQ with the beam-line originally used for the MAXILAC accelerator. It consists of a magnetic quadrupole doublet lens followed by a triplet lens. Behind the RFQ a fast Faraday cup is installed for beam current and bunch measurements. The ion energy can be determined by an analyzing magnet which can be replaced by an emittance measurement device.

The beam experiments were done with He^+, Ne^+ and Ar^+. Bunch forming began at electrode voltages of 4 kV (He^+), 18 kV (Ne^+) and 33 kV (Ar^+). These values can be used to calculate the rf power needed for U^{2+} which is 260 kW (Rp = 520 kΩm). The beam line was optimized for maximum beam current behind the RFQ by the quadrupole setting. The maximum achieved beam current was 0.55 mA for He^+, 0.4 mA for Ne^+ and 1 mA for Ar^+. These rather low values could not be improved by increasing the electrode voltage, unlike the results achieved at IAP. Fig. 4 shows the peak beam current for a Ne^+-beam as a function of the rf power.

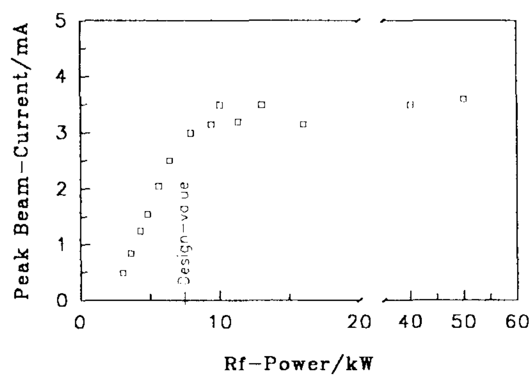

Fig. 4: Peak beam current for Ne^+ vs. rf level.

To measure the input emittance the RFQ has been replaced by an emittance scanner. These experiments revealed an asymmetrically mismatched ion beam for the quadrupole settings used for the beam experiments, which may explain the low transmission.

First high-power rf experiments showed a decreasing Q value for higher rf levels. So the "cold" Q value ($Q_0 = 4406$) dropped to a Q value of $Q_0 = 2828$ at an rf level of 67 kW. Up to an rf level of 75 kW no sparking occurred, with higher rf levels heavy sparking appeared. Slow conditioning with gradually increased rf levels could improve the Q value and the sparking limit. At the moment the Q value for rf levels up to 180 kW input power is similar to the low-level Q values and no sparking appears. Due to radiation-protection restrictions higher rf levels could not be applied to date.

To prepare future beam experiments the beam extraction of the ion source, the dc preinjector gap and the beam transport will be optimized. After improving the X-ray shielding further conditioning can be done to apply the maximum rf level of 260 kW for U^{2+}.

RFQ-Design for U^{4+}

Alternatively to the upgrading of the UNILAC by a huge RFQ and a stripper a different layout of the GSI high current injector is now discussed, based on further development of the Penning-source and the IH-accelerator structure. So a high beam intensity can be reached with higher charged heavy ions like 10 mA of U^{4+}, directly from the ion source without an intermediate stripper. The total UNILAC Wideröe-section would then be replaced by a short RFQ together with 4 IH-cavities.

To obtain good beam quality for the injection into the IH-structure the design parameters should include short bunch width and little energy spread as well as minimum emittance growth. Strong transverse focusing can be achieved by e.g. a low frequency like 27 MHz. Tab. 2 gives a survey over the main RFQ parameters.

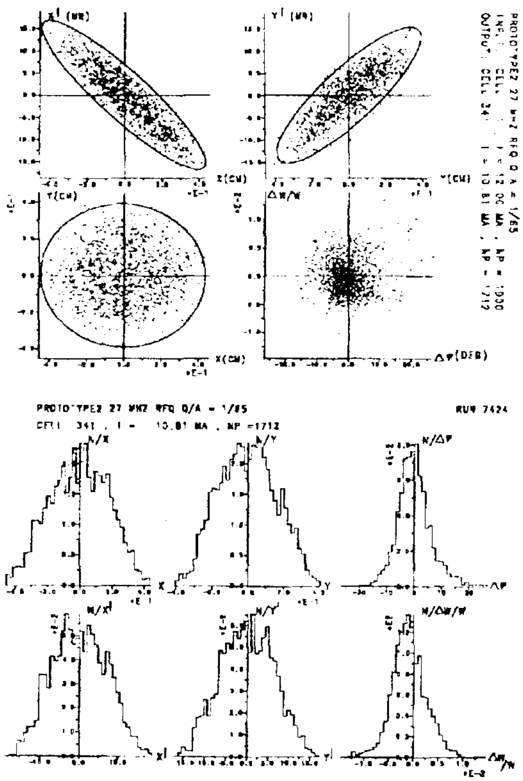

Fig. 5: Output emittance for 12 mA beam current.

TABLE 2
Main Parameters of the U^{4+}-RFQ Layout

f	27.0 [MHz]	m	1 ... 2.05
length	11.08 [m]	a	0.725 ... 0.5 [cm]
T_{in}	2.2 [keV/u]	T_{out}	100 [keV/u]
U_{el}	125 [kV]	φ_{syn}	90 ... 30 [°]
σ_r	30 ... 24 [°]	α_{syn}	0.8 [π mm mrad]

Beam calculations have been done with the program PARMTEQ. For the input beam standard parameters were chosen: transverse waterbag, longitudinal d.c., no initial energy spread. Fig. 5 shows the output emittances for 12 mA beam current. Here the transmission is 90 %, radial and longitudinal emittance growth is < 2.5 %. (100 %-beam). The histograms for phase width and energy spread in fig. 5 demonstrate the good beam quality achieved with this design [8].

A change of the frequency to 36 MHz, which is also considered, does not affect these results significantly.

Conclusion

The Spiral-RFQ is a well suited accelerator for high current heavy-ion beams. The Spiral-RFQ prototype and the experience with layout and tests are the basis for other designs e.g. for "lighter ions" like U^{4+} and U^{6+} (at 27 and 36 MHz). It could be applied for the proposed injectors for singly charged radioactive beams at LBL, INS and TRIUMPF.

References

[1] N. Angert, L. Dahl, J. Glatz, J.Klabunde, M. Müller, B. Wolf, "The UNILAC Modifications for an Improved Synchrotron Injector Performance", EPAC 90, Ed. Frontieres (1990) 503

[2] A. Schempp, H. Deitinghoff, A. Kipper, "Development of a 27 MHz Heavy-Ion Spiral-RFQ", NIM A278 (1989) 169

[3] H. Deitinghoff, A. Schempp, A. Kipper, H. Klein, "Particle Dynamics in a Low Frequency High Current RFQ Prototype", Part. Acc. 37/38 (1992) 47

[4] A. Schempp, A. Kipper, H. Deitinghoff, J. Madlung, "The GSI High Current RFQ Prototype", NIM B79 (1993) 714

[5] H. Deitinghoff, A. Kipper, A. Schempp, "Beam Dynamics Calculations for a Prototype of a High-Current Heavy-Ion RFQ", Il Nuovo Cimento Vol. 106 A, N. 11 (1993) 1503

[6] A. Kipper, A. Schempp, H. Deitinghoff, U. Bessler, T. Sieber, C. Staschok, J. Klabunde, P. Spädtke, "Status of the Beam Experiments with the 27 MHz Spiral-RFQ Prototype", GSI-Report 94-10 (1994) 29

[7] A. Kipper, A. Schempp, H. Deitinghoff, J. Madlung, T. Ludwig, K. Volk, O. Engels, A. Firjahn-Andersch, "Experiments with the High.Current RFQ Prototype", Il Nuovo Cimento Vol. 106 A, N. 11, (1993) 1525

[8] H. Deitinghoff, A. Schempp, U. Bessler, A. Kipper, "First Design of a 27 MHz High Current RFQ for U^{4+}", GSI-Report 94-10 (1994) 30