PROPERTIES OF THE FRONT PART OF THE REX-ISOLDE LINAC*

S. Emhofer, O. Kester, T. Sieber, D. Habs, K. Rudolph, H. Bongers, LMU München, 85748
Garching, Germany
A. Schempp, U. Ratzinger, IAP, 60325 Frankfurt/Main, Germany

Abstract

The structures of the linear accelerator of the Radioactive beam Experiment (REX-ISOLDE) [1] at ISOLDE/CERN are completely assembled, and test measurements with stable beams at Munich and Heidelberg have been carried out. The front part of the accelerator [2], which has been developed at Munich, consists of a mass separator, a 4-rod RFQ, a rebuncher section and an IH-drifttube-structure. This front part will deliver mass separated highly charged ions with an energy between 1.1 and 1.2 MeV/u to the seven-gap resonators developed at the MPI-K Heidelberg [3], which will finally deliver beams with an energy between 0.8 and 2.2 MeV/u to the target stations. Emittance measurements at the REX-ISOLDE test beam line at Munich, including the injection beam line, the RFQ and the rebuncher section, will be presented as well as measurements of the energy distribution from the RFQ and measurements of the transmission efficiency.

1 THE REX-ISOLDE TEST BEAM LINE

1.1 Experimental Setup

The test beam line at the accelerator laboratory at Garching has been built up to perform He^{1+} beam experiments with the RFQ and the following matching section between RFQ and IH structure. Its injection system consisted of a duoplasmatron ion source, a prototype of the REX-ISOLDE diagnostic box and an electrostatic quadrupole quadruplet from the REX-ISOLDE mass separator. In a first stage, the emittance was measured behind the injection system, to check the quality of the beam and to compare the measured beam parameters to the COSY calculations for beam injection. In the following step, the test beam line was built up completely like shown in Fig. 1. For the beam analysis behind the RFQ and the matching section, a second diagnostic box was used to measure the beam current (transmission) and to change the beam diameter for injection into the buncher. The bunch structure of the RFQ-beam was detected with a fast 50Ω Faraday cup. The energy spectra of the RFQ and the buncher were measured with a 90° bending magnet, which was later replaced by the emittance scanner for final emittance measurements. For all experiments, the particle dynamics of the beam line have been simulated with the codes COSY, PARMTEQ and TRANSPORT for comparison with experimental data.

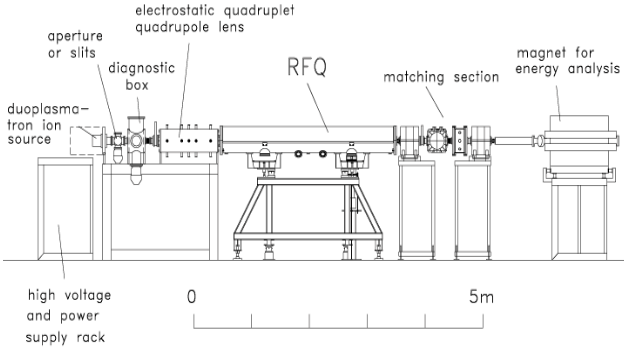

Figure 1: Drawing of the REX-ISOLDE test beam line.

1.2 Beam Tests with the RFQ

The tests with the REX-RFQ [4] were done to verify the design calculations concerning transmission, energy spread, bunch structure and output emittances of the accelerator. Further, the dependence of these parameters on the rf-power, beam current and input emittance has been measured.

The transmission through the RFQ at different electrode voltages is plotted in Fig.2. The injected beam was (like calculated before and measured at the injection system) in both directions convergent, fitting quite accurately into the acceptance of the RFQ (200 π mm mrad). The injected emittances were about 30 π mm mrad at an energy of 5 keV/u. The beam current was 1 μA (2ms/50Hz macro pulse). The beam current was measured with the two identical Faraday cups of the REX-diagnostic boxes before and behind the RFQ. The error - due to source instabilities and secondary electron effects - is estimated to 5%. Nonetheless, the transmission is >95% starting at an electrode voltage of 33 kV. At lower voltage levels, the beam is partially only transported, respectively accelerated to lower energies than the desired 1.2 MeV. The design voltage of the RFQ for ions with A/q=4 is 37.3 kV (see Fig. 2).

To investigate the behaviour of the RFQ output energy at different electrode voltages, energy measurements were done with the same injection parameters, varying only the rf-power in the RFQ. The result is shown in Fig. 3.

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* work supported by the BMBF under contracts 06 LM 868 I/TP:4, 06 HD 802 I and 06 LM 974

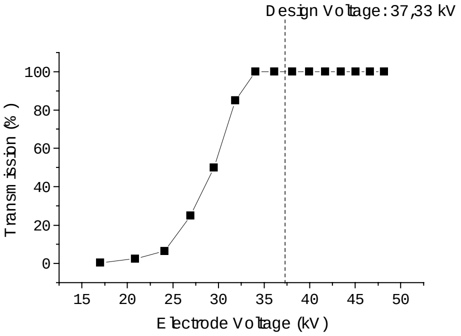

Figure 2: Transmission through the REX-RFQ at different electrode voltages.

During the energy measurements, the beam current behind the magnet was - due to slits at the entrance and the exit of the bending magnet - in the range of several nA. Fig. 3 shows, in which way the energy of the particles increases with increasing electrode voltage. PARMTEQ calculations have shown comparable spectra as the measurements in Fig. 3. At too low voltages, the particles are dropped out of the $\beta\lambda/2$ velocity profile, producing separate peaks. The distances in energy between these peaks correspond to a resonant acceleration of the ions in following buckets, which is supported by the increasing synchronous phase (see Fig. 3, spectrum at 34.9 kV). This behaviour will be further investigated in [5]. At too high voltages, the intensity of the 1.2 MeV peak decreases, which is an effect of the deteriorated transverse output emittance (beam losses in the matching section).

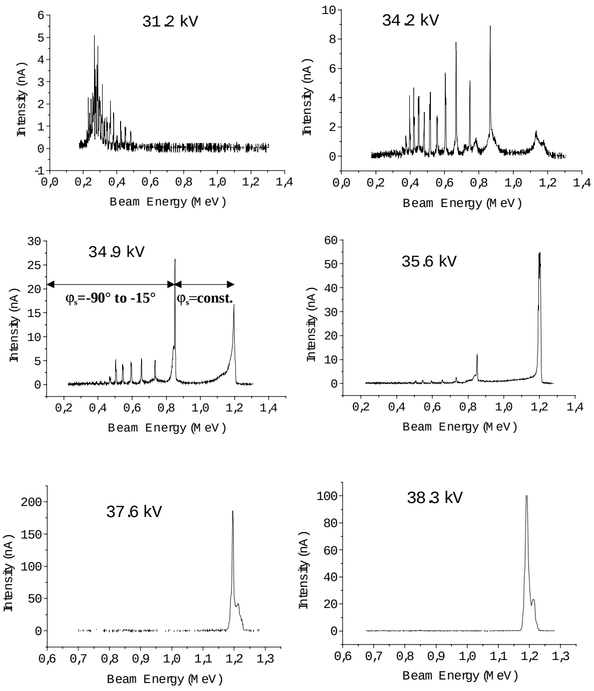

Figure 3: Evolution of the RFQ energy spectra with increasing electrode voltage.

From low-level measurements and spectroscopy of bremsstrahlung, the Rp value of the RFQ had been determined to 145 kΩm. In order to verify the rf-measurements, we varied the rf-power, until the energy peak was symmetric and in best agreement with the PARMTEQ design calculations. Fig. 4 shows the spectrum measured at 28.35 kW compared to the PARMTEQ calculation for an electrode voltage of 37.3 kV. The Rp-value derived from this measurement is (with $Rp=U^2/N$) 146.5 kΩm. The energy spread ($\Delta E/E_{Design}=\pm1.5\%$) is with ±1.3% very small. The small discrepancy of the absolute energy is caused by problems with the calibration of the magnet.

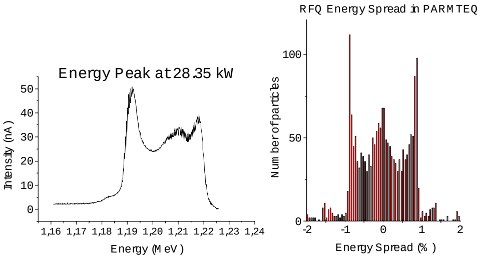

Figure 4: Energy peak of the REX-RFQ at 28.35 kW compared to PARMTEQ data.

The measurement of the time structure of the RFQ-bunches was achieved with a fast 50Ω Faraday cup. From PARMTEQ and TRANSPORT calculations we expected a phase spread of the bunches of ±15° at the RFQ-exit and a phase spread of ±35° behind the drift to the place of measurement. The measured peak bunch current was 100 μA, which is (with a pulse current of 20 μA at this measurement) in excellent agreement with the designed bunching factor of 12 and the calculated bunch-broadening during the 1.75 m drift. The length of the bunches in time was (FWHM) ~2 ns, a value which fits (with the given accuracy) also very well to the theoretical data (1.7 ns).

In Fig.5 emittance measurements of the RFQ are shown for different injection emittances. In a,b) the injection emittance was about 100 π mm mrad in c,d) about 10 π mm mrad for a 5 keV/u He^+ beam. The emittances have been measured behind the matching section (see Fig.1). Fig.5 shows in addition the calculated envelope behind the RFQ assuming a normalized emittance of 0.6 π mm mrad. The measurements have proven that a small injected emittance will be preserved. The emittance of the EBIS beam will be below 10 π mm mrad at 5 keV/u. Thus the measurements have proven, that this rather small emittance can be injected in the IH-structure as well. In fig.5a and b it is shown that the RFQ emittances are smaller than the emittances calculated with PARMTEQ by filling 90% of the acceptance.

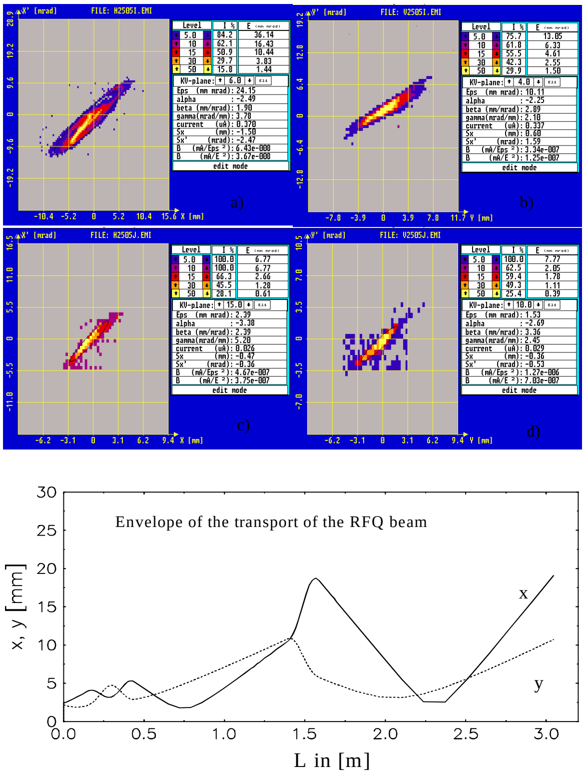

Fig. 5: Emittance measurements at the RFQ.

1.3 *Measurements at the Rebuncher Section*

A main goal of the measurements at the test beam line was to prove the ability of the matching section to match the beam from the RFQ with the required parameters to the acceptance of the IH-structure.

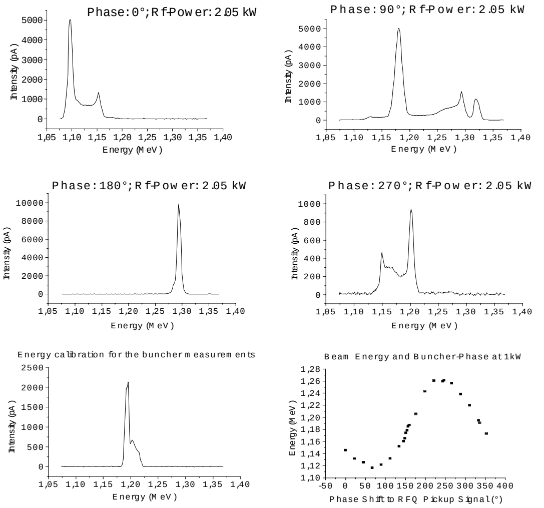

Figure 6: Energy spectra of the rebuncher at different phases together with the RFQ-peak as a reference and the beam-energy in dependence of the buncher phase.

The measurement of the longitudinal beam parameters was done by analysis of the energy distribution of the beam. TRANSPORT calculations showed a required buncher voltage of 72 kV (integrated voltage), to reduce the phase spread from ±35° to the required ±10° at the IH entrance. With a shunt impedance of 11.92 MΩ/m, this corresponds to an rf-power in the buncher of 2.05 kW. From the calculations, the energy spread (resulting from the time focusing of the buncher) is given to ±2.8%. Fig. 6 shows the energy spectra behind the buncher at the 4 relevant buncher phases. The measured energy spread at the bunching phase (270°) is with ±3.2% slightly larger than the calculated value and indicates, that an rf-power of ~1.8 kW will be sufficient for the IH-injection. The final optimisation of the buncher voltage will be done with beam at ISOLDE, regarding the transmission through the IH-structure.

2 RF-TESTS WITH THE REX-ISOLDE IH-STRUCTURE

2.1 *Optimisation of the gap voltage distribution.*

The IH structure is currently completely assembled. Only parts of the cooling system and the lead-x-ray-shielding are not yet installed. Problems occur because of a too thick copper layer (500 µm instead of 50 µm) on the drift tubes, which causes a too low resonance frequency. By low level measurements of the gap-voltage distribution a proper reduction of the undercut length was estimated to fix this problem, while the new drift tube structure is in production [6]. With the new undercut length the proper gap-voltage-distribution for 1.2 MeV/u can be reached. The gap voltage distribution for 1.1 MeV/u will be fulfilled after new, proper sized drift tubes are mounted during next shut-down-period in winter 2000.

2.2 *The RF-parameters*

The measured quality factor is 16500, the shunt-impedance 330 MΩ/m. These values are comparable to GSI-HLI IH-structure (Q=20000; Z=370 MΩ/m) and tank 1 of CERN-LINAC3 (Q=12550; Z=340 MΩ//m). From the measured values it is expected that about 60 kW rf-power will be sufficient to reach the gap-voltages for A/q=4.5.

REFERENCES

[1] Proposal to the ISOLDE Comittee, CERN ISC94-25
[2] O. Kester et al., The REX-ISOLDE Linac, EPAC '98, Stockholm, Sweden, 1998, p. 728
[3] H. Podlech et al., Nucl. Instr. and Meth. B139 (1998) 447
[4] T. Sieber et al., Design and status of the REX-ISOLDE RFQ, LINAC'98, Chicago, 1998, p. 777
[5] T. Sieber, PhD thesis, LMU München, in preparation
[6] S. Emhofer, diploma thesis, Ludwig-Maximilians-Universität München, December 1999