COMMISSIONING-RESULTS OF THE REX-ISOLDE LINAC*

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Abstract

At REX-ISOLDE at ISOLDE/CERN radioactive ions are post accelerated with a 10 meters linac for experiments in nuclear-, astro- and solid state physics. For the efficient acceleration to energies between 0.8 and 2.3 MeV/u the principles of charge breeding of radioactive ions by an electron beam source was introduced at REX. The linac in its current stage consists of a 4-rod RFQ, a 20-gap IH drift tube cavity and three seven-gap splitring resonators. It is able to accelerate up to a mass to charge ratio of 4.5. 2002 has been the first year of nuclear physics experiments with REX-ISOLDE. The experiments done so far using Coulomb excitation and particle transfer reactions require good beam quality at the two target stations. Therefore commissioning measurements of the linac were made and are still being done. The results of those measurements will be presented showing the current energy spreads and radial emittances of the different cavities.

INTRODUCTION

2002 was a successful year for REX-ISOLDE as several experiments took place with different accelerated Mg-, Na- and Sm- and Li-isotopes. The beam energy range of those beam times was starting from 300 keV/u for implantation using just the RFQ up to 2.3 MeV/u using the RFQ, buncher, IH-cavity and all three 7-gap resonators. As an experience of the different beam times it had also been discovered how sensitive the system is on small changes of amplitude and phases of the different cavities. The requirements at the target are to deliver the full beam through a 3 to 5 mm aperture on the target. Losses had to be minimized and the beam size reduced. Therefore one had to focus mainly on a smaller energy distribution of the beam in front of the bender. The energy dispersion could otherwise lead to a broad beam in the dispersive plane which can result in an activation of the target edges. This paper focuses on the recent measurements on the first part of the linac namely the RFQ, the buncher and the IH-cavity.

MEASUREMENTS OF THE SEPARATOR'S EMITTANCE

In order to examine the beam quality in front of the linac emittance measurements in front of the RFQ were done. Two EBIS operation modes have been tested, one with highly charged ions from residual gas and one using He-ions to reach higher beam currents needed for emittance measurements of the linac at higher energies. The emittances with ions from residual gas fulfil very well the expected values with a transverse phase space of 10 π mm mrad in x-direction and 15 π mm mrad in y-direction. The emittances measured with higher currents have grown due to the fact that one had to saturate the EBIS electron beam with helium to get enough current for the high energy emittance measurements. Therefore the transverse phase space increased to 35 π mm mrad in x-direction and 90 π mm mrad in y-direction.

MEASUREMENTS ON THE MATCHING SECTION

A very sensitive region regarding the beam quality is the matching section between the REXRFQ and the IH-cavity. After being accelerated from 5 keV/u to 300keV/u by the RFQ a re-buncher is needed to match the phase-space to the phase acceptance of the IH-cavity of $\pm 8°$.

Beam energy spreads

The RFQ itself is rather uncritical as the amplitude is well known and its phase is the reference for the other cavities. The energy spread was measured to ±1.5% in agreement to PARMTEQ calculations and recent measurements [1,2]. A more detailed analysis had to be done regarding the buncher's properties. As the rf-low level-system was modified several times the buncher had to be re-calibrated in phase and amplitude. By using the 0° accelerating phase and acceleration at different power levels we could gain an effective shunt impedance of $19.9\ \mathrm{M\Omega/m}$, which is in good agreement with the results from low level measurements [3]. Measuring the energy-spread of the buncher at different power levels which correspond to certain effective voltages one received a curve shown in figure 1. Just in the range from about 10 to 40 kV effective resonator voltage there is a discrepancy due to the energy resolution of the bending magnet, which is about 0.4-0.6% for a 1mm slit in front of the magnet. The shape of the energy-curves for different buncher power-levels is shown in figure 2. The typical three peak shape of the RFQ energy distribution is preserved. The ideal injection condition for the following IH structure is the curve with a tank loop level (A_{tank}) of 1.42V which corresponds to an effective buncher voltage of 70kV for a mass to charge ratio of four. One can see that the buncher broadens the RFQ energy distribution and shifts the maxima slightly. In order to get a more realistic simulation, the RFQ beam energy distribution has to be taken into account regarding simulations of the longitudinal emittance for the other cavities behind the buncher.

*This work has been supported by the BMBF

Emittance measurements of the matching section

Emittance measurements of the linac took place at the 20°-beam line of the REX-ISOLDE linac. As the energy spread is increasing the x-emittance values due to the bending magnet's dispersion, one should concentrate on the values in the non dispersive plane (y). The normalized y-emittance of the RFQ was measured to 0.16 π mm mrad and of the buncher to 0.17 π mm mrad. So there is no significant emittance growth in the re-buncher.

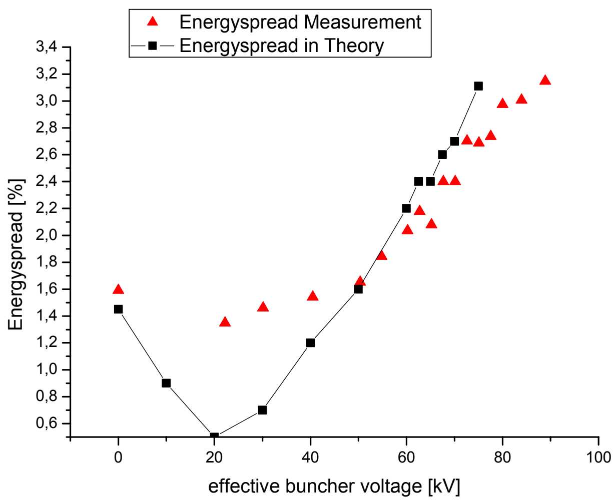

Figure 1: The measured energy spread of the buncher in dependence of effective voltage levels compared to simulation results.

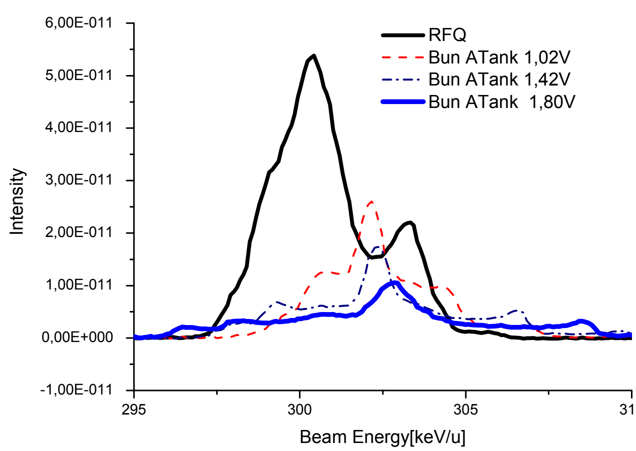

Figure 2: The energy-distribution of the RFQ beam compared to the one of the beam with different power levels of the buncher.

MEASUREMENTS ON THE IH-DRIFT TUBE CAVITY

The IH-cavity is the booster accelerator of REX-ISOLDE accelerating the bunched beam from the RFQ-energy of 300keV/u to an energy of max. 1.2MeV/u. There are 20 gaps which produce an effective acceleration voltage of 4.05MV meaning an effective voltage in the gaps of 4.16MV for the maximum A/q-value of 4.5. The difference of those two values is used for re-bunching using the KONUS-beam dynamics [4].

Tuning of the proper amplitude and phase

The main goal for the IH-drift-tube-cavity was to set the proper phase and amplitude. Therefore simulation calculations with different phases and amplitude levels for the IH were done using the LoraSR computer code [4]. The bunch of results has been compared to measurements of energy spectra from the IH-cavity. The proper IH amplitude was mainly set by reducing the amplitude of the IH until the energy spread of the beam was reduced to the expected value. Figure 3 shows the simulation for 95% of the IH-voltage amplitude and the suiting measurement-curve. The upper edge of this curve is in well agreement with the LORASR calculations.

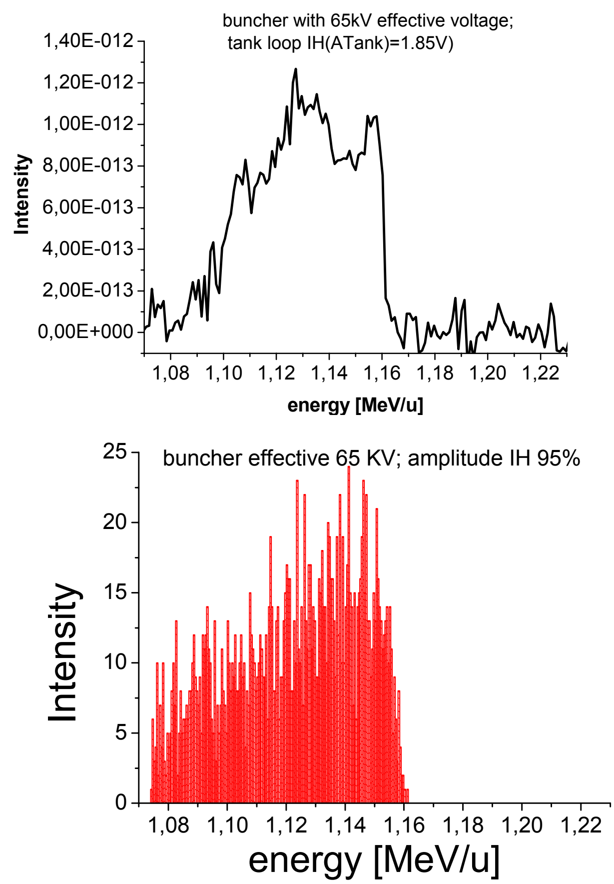

Figure 3: The measured energy-spread of the IH at a tank loop voltage of 1.85V compared to theory for 95% of amplitude.

With those measurement it could be proved that 1.95V of tank loop amplitude is the proper operation mode for the IH at a mass to charge ratio of 4. This level is reached with 43kW rf-power. The resulting absolute shunt impedance was calculated to 330 MΩ/m and is in exact agreement with results from X-Ray measurements of the gap-voltages and low level measurements. There one obtained 300 to 330 MΩ/m [5]. With this amplitude energy-distributions at different phase settings where measured and compared to theoretical ones. The proper phase was identified. The energy-spectra and the calculated spectra at the optimal phase are shown in figure 4. They agree very well in width and in the overall shape. At the proper phase (0°) the measured energy spread is ±0.8% while from calculations it was expected to be ±1%. The energy spreads at different phases agree well over the full measurable range. Figure 5 shows the energy spread over a phase range of more than 40°. First analysis of this discrepancy led to the following explanation: The simulations were done using waterbag distribution of particles in all three phase spaces (6-d). In reality the longitudinal emittance is injected into the IH-structure does not coincide with a waterbag distribution, it is filled less at the edges. This can be concluded from the shape of the energy distribution in figure 2. Calculations using the simulation results of the longitudinal emittance from the RFQ and the matching section will be carried out in the next step to proof the agreement with the measurements.

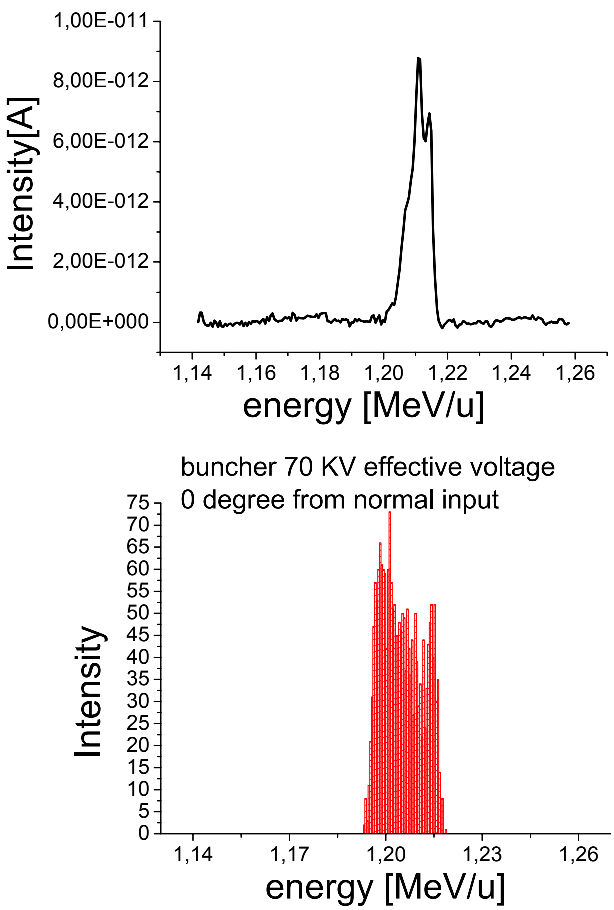

Figure 4: In the upper part of the figure the measured energy-spectra of the IH-cavity is shown, in the lower part the simulated one.

Emittance measurements

Beam emittances from the IH-structure were already taken last year, but at that time the amplitude was not tuned properly which was resulting in a large emittance growth. At that time the normalised emittance was measured to 0.27 π mm mrad which would mean an emittance growth factor of 1.6 within the IH-cavity. The following measurements carried out at known phase and amplitude will be done together with the measurement of the other cavities in the following beam period in 2003.

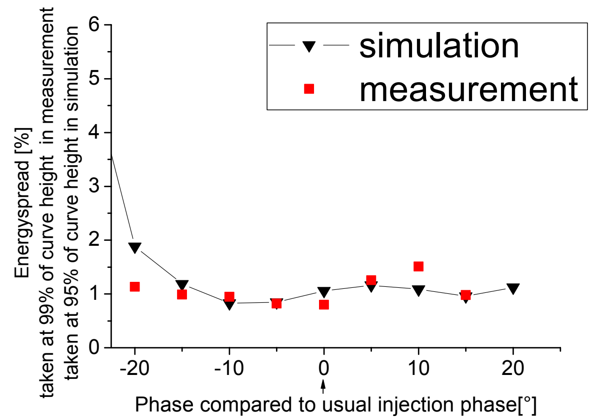

Figure 5: The measured energy-spread of the IH compared to theory in dependence on the phase. The proper phase is marked at 0°.

The emittance measurement device will be placed at the zero degree beam line to be able to measure the x- and y-emittances without the dispersion problem of energy spread being transformed into radial emittance. One expects an emittance growth factor less than 30% comparing with the exit emittances from the buncher. In the following run the commissioning of the RFQ, buncher, IH-cavity and 7-gap resonators will be finished. This year experiments are scheduled in July and September/October accelerating different Na- and Mg-isotopes with the new improved beam quality. In between the radioactive beam experiments a new 202.56 MHz 9-gap cavity will be installed to energy upgrade the REX-ISOLDE linac. With it one will be able to reach a beam energy of approximately 3.0 MeV/u.

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