ACCELERATION OF RADIOACTIVE ION BEAMS AT REX-ISOLDE*

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Abstract

In 2001 the linear accelerator of the Radioactive beam Experiment (REX-ISOLDE) delivered for the first time accelerated radioactive ion beams with a beam energy of 2 MeV/u. REX-ISOLDE uses the method of charge state breeding, in order to enhance the charge state of the ions before injection into the LINAC [1]. Radioactive singly charged ions delivered by the on-line mass separator ISOLDE are first accumulated in a Penning trap, then charge bred to an A/q < 4.5 in an electron beam ion source (EBIS) and finally accelerated in a LINAC from 5 keV/u to the final energy between 0.8 and 2.2 MeV/u [2]. Measurements of the interplay between the REXTRAP, the transfer line and the EBIS have been done as well as the first commissioning of the whole accelerator. The properties of the different elements could be determined and a first optimisation of the system could be carried out. In two test beam times in 2001 stable and radioactive Na isotopes (^{23}Na-^{26}Na) have been accelerated and transmitted to a preliminary target station. There ^{58}Ni and ^{9}Be targets have been used to populate exited states via Coulomb excitation and nuclear transfer reactions. First results of the commissioning and of the beam times will be presented.

1 INTRODUCTION

The radioactive beam experiment REX-ISOLDE at ISOLDE/CERN was designed to deliver post accelerated radioactive ion beams with a variable energy between 0.8 and 2.2 MeV/u. In order to address many nuclear physics aspects, the full variety of beams available at ISOLDE should become accessible as accelerated beams for experiments. Thus, a new technology of charge multiplication and post acceleration was introduced for the first time. The charge-state breeder defines the time structure of the beam delivered to the LINAC and it adjusts the A/q of the ions below 4.5. Despite the moderate size of the accelerator the charge multiplication of the radioactive ions allows to access the heavier mass region of the nuclear chart, which is not possible in case of acceleration of monocharged ions. The charge state breeder allows the acceleration of ions with A < 40 to energies at the Coulomb barrier with a LINAC of only 9 m length. Future upgrade plans foresee a two step plan to raise the beam energy to about 4.2 MeV/u. Thus, heavier isotopes up to A = 150 can be investigated in the near future.

The systematic study of nuclear structure will be divided in three blocks comprising Coulomb excitation reactions, transfer reactions and fusion-evaporation reactions. Due to the charge-state breeder a significant fraction of isotopes of the nuclear chart are available for experiments. Thus, REX-ISOLDE can investigate bound and unbound nuclei in the dripline region for light nuclei, and will be able to investigate heavy fission fragments and nuclei close to the N=Z line in the near future.

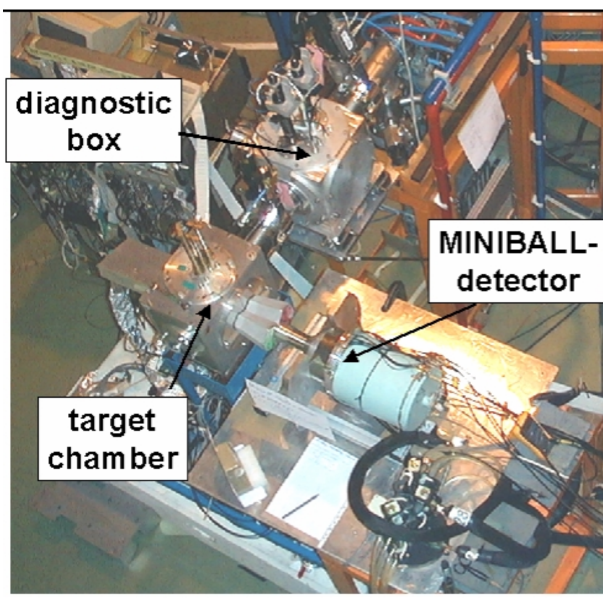

Figure 1: Picture of the target set-up of the test beam time

In the commissioning beam time radioactive sodium beams have been transmitted on a ^{58}Ni target for Coulomb excitation experiments and on a ^{9}Be-target to study neutron pickup reactions. For that purpose a temporary

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target set-up including a Si-strip-detector and one MINIBALL triple cluster detector has been installed (fig.1).

In the beam time the γ- and particle detection and the data acquisition system could be tested. γ-spectra have taken from the n-transfer reaction between ^{24}Na and ^{9}Be in coincidence with the two particle detection in the Si-detector. The ^{8}Be->2α decay allows a clear signature for the n-transfer. The high resolution spectra allow identification of the populated levels. The spectra reveal that very little is known about nuclei only one or two neutrons away from stability. The γ-background in the target area, competitive reaction channels and different target materials have been studied as well. Gating of the detector with the short EBIS extraction pulse allows a good underground reduction.

2 THE CHARGE-STATE BREEDER

The charge state breeder of REX-ISOLDE comprises a large Penning trap and an Electron Beam Ion Source (EBIS). The device successfully bred ions from a test ion source as well as radioactive ions from the ISOLDE mass separators. This is the first charge state booster that breeds weak intensities of some pA of radioactive ions for injection into a LINAC. Tests have been done with Na-, K- and Al-isotopes. The REXEBIS has produced the first charge bred ions in August 2001 and has been running non-stop through the commissioning runs. It has delivered stable $^{39}K^{10+}$ and $^{23}Na^{6+}$ beams from the REXTRAP test ion source. Stable beams from ISOLDE have been used to breed $^{27}Al^{7+}$- and $^{23}Na^{6+}$-ions and to accelerate them for detectors tests. With radioactive $^{26}Na^{7+}$ and $^{24}Na^{7+}$ beams (about $5*10^{5}$ p/s) γ-spectra have been taken.

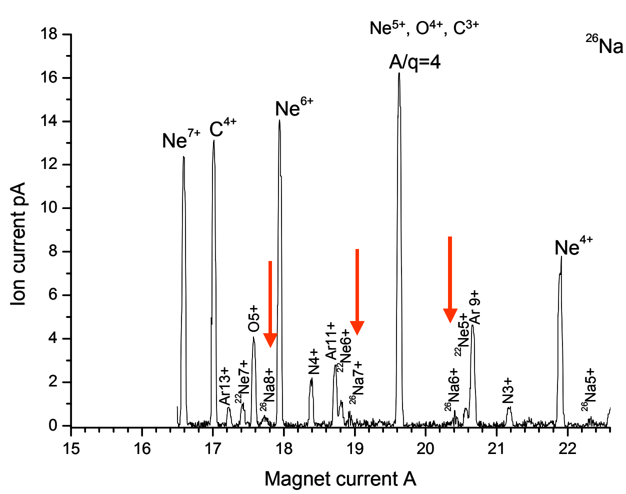

Figure 2: Charge state spectra of ^{26}Na

A breeding efficiency with the EBIS of about 16% in one charge state could be reached for Na and K. Including the trap efficiency of about 50% the breeder efficiency in one charge state is about 8%. In fig.2 the first charge state spectrum of a radioactive species (^{26}Na) is shown. Fig.2 shows the very small background contamination from residual gas ions produced in the EBIS. This low background allows the identification of very low intensities (down to 100 fA) of charge bred radioactive ions. The S-shaped beam line between the EBIS and the LINAC is a mass separator which separates the few highly-charged radioactive ions out of the ions from the residual gas. Isotopes from the EBIS could be separated by the REX mass separator with a resolution of (A/q)/Δ(A/q)=100. A third order beam optics calculation of the separator revealed a resolution of 110 for an injected beam with ε =10 π mm mrad at 5 keV/u. The total transmission of the mass separator is about 75-90%.

3 THE REX-ISOLDE LINAC

The linear accelerator of REX-ISOLDE consists of different types of resonant structures to meet the requirements of the experiments [2]. The RFQ and IH-structure take the ions to an intermediate energy of 1.2 MeV/u where they are post accelerated or decelerated by the 7-gap resonators. All structures operate at 101.28 MHz, half of the CERN proton LINAC frequency and with maximum 10% duty cycle. The transverse design acceptance of 0.6 π mm mrad (normalized) of the REX-ISOLDE LINAC is large in comparison to the EBIS emittance of about 0.06 π mm mrad. This conservative design of the acceptance is based on typical extraction emittances from an ECR sources. The macrostructure of the accelerated ions have a typical bunch width of 10-50 µs and a pulse distance of 20 ms. The calculated micro structure (bunch length) will have a pulse width depending on the final energy between 1.3 ns at 2.2 MeV/u and 13 ns at 0.8 MeV/u at the target. The time between the bunches will be 10 ns. Thus at 0.8 MeV/u the beam will be continuous over the length of the macro pulse. The expected energy spread of the beam at the target will be 1.5% at 2.2 MeV/u and 5% at 0.8 MeV/u [3].

All resonators are located in the experimental area of the ISOLDE hall. Due to space restrictions, no additional concrete shielding could be installed in the hall. Therefore the structures with the highest gap voltages (380 kV) must be shielded with lead. From safety restrictions we have to stay below 10 µS/h at the lead shield surface for the highest power level and for the 10% duty cycle. Especially the pumping ports of the 7-gap cavities had to be shielded, because X-rays escaping through those ports can disturb the measurements at the MINIBALL position. Thus a lead wall has been installed beside the 7-gap resonators which sufficiently shields the target region.

The different LINAC structures shown in figure 3 have been successively tested with beams from the rest gas of the EBIS in order to determine the right amplitude and phase settings. Due to the lack of the high resolution phase shifter modules so far, the commissioning is not yet completed. For injection of beam into the IH-structure the re-buncher of the matching section had to be tuned to the right phase and amplitude. Therefore measurements of the beam energy and the energy spread in dependence on the re-buncher acceleration phase have been carried out. The measurements have been done with a rest gas beam from the EBIS with A/q = 4. Figure 4 shows the 0° and 180° acceleration phase. The maximum energy shift is 20 keV/u, which correspond to 80 kV effective acceleration voltage. With the right phase setting full transmission through the IH-structure could be reached. For the preliminary calibration of the bending magnet in front of the target station we used beam from the RFQ.

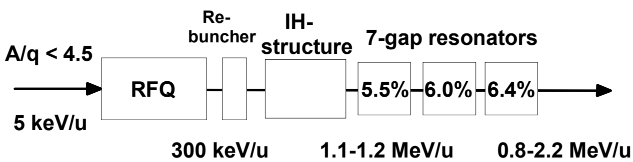

Figure 3: Schematic drawing of the REX-ISOLDE LINAC.

Beam energy spread of beams from the different cavities and transverse beam emittances have not been measured yet. In addition, the adjustment of different energies in the range of 0.8-2.2 MeV/u has not been done either. However in two beam times, the REX-ISOLDE LINAC could accelerate charge bred ions of ^{23}Na - ^{26}Na and ^{39}K to 2 MeV/u with only two of the three 7-gap resonators running at 0°-phase. Due to a broken pre-amplifier, the power amplifier of the last 7-gap resonator could not run in that beam time.

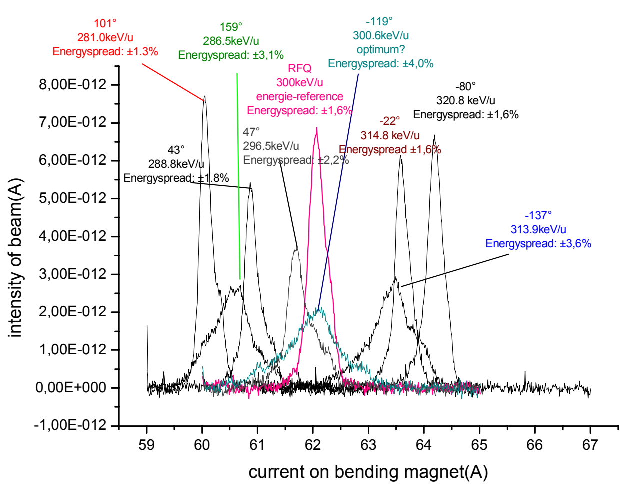

Figure 4: Measurement of the energy spread of the RFQ and of the re-buncher in the matching section at different acceleration phases.

With the different isotopes the scaling of the beam line settings and of the resonator power levels could be tested. At REX-ISOLDE there is no possibility to use a pilot beam in order to adjust the LINAC, because the stable beams for adjustment have to be delivered by the EBIS as well. In order to get no stable contamination, we have to choose an A/q of the radioactive ions away from any rest gas contaminants. Thus, we use a “buddy beam” with an A/q close to the radioactive beam we want to accelerate. The whole LINAC follows very accurately a linear scaling of all elements with the A/q of the ions. It could be proved that the LINAC beam line is able to transport beams with A/q<4.5 to the target region at 0.3 MeV/u (RFQ-energy) and at 1.2 MeV/u without losses. The transmission of the LINAC has been 70-80% at 2 MeV/u without steering and with no fine adjustment of the phases. The beams could be focused through a 3 mm aperture in front of the target. In the test beam time in November an overall transmission of Na-isotopes of about 2% through the whole REX-ISOLDE system starting from the ISOLDE monocharged ion source to the REX-ISOLDE target station could be reached.

CONCLUSIONS

In 2001 the REX-ISOLDE LINAC delivered first radioactive Na-beams with 2 MeV/u to the target station. The concept of charge state breeding has been proved successfully and first setting of the whole LINAC could be determined. In addition the test of a MINIBALL cluster detector together with a silicon strip detector was successful and delivered a first γ-spectrum of ^{25}Na and information about the γ-background in the ISOLDE hall. In 2002 beam times dedicated to n-rich Na-isotopes, Mg-isotopes, for ^{9}Li and to a first test with heavier nuclei will be done. In addition the LINAC commissioning will be completed using a He off-line ion source, which is in preparation now. This offline source can deliver up to 1 μA He^{+}-beams, which allow measurements of the transverse emittance. The higher beam intensity of the offline sources in comparison to the EBIS allows more accurate measurements of the energy spread of the beam from the different structure.

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