COMMISSIONING OF THE REX-ISOLDE LINAC*

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Abstract

The radioactive beam experiment (REX-ISOLDE) is now in the commissioning phase. REX-ISOLDE is a pilot experiment for testing a new concept of post acceleration at ISOLDE/CERN. The concept of REX-ISOLDE using a Penning trap-EBIS combination as a charge breeder and a compact LINAC for post acceleration requires detailed tests of all components in order to get a high efficiency. First measurements with REXTRAP, the transfer beam line and the REXEBIS have been done as well as first acceleration of stable beams from the EBIS with use of REXRFQ.

1 INTRODUCTION

REX-ISOLDE employs a Penning trap to continuously accumulate the radioactive ions delivered by the ISOLDE mass separator [1]. The task of the trap is twofold, namely the bunching of the beam for fast injection into the Electron Beam Ion Source (EBIS) and the improvement of the transverse beam emittances by buffer gas cooling [2]. The breeding device is the EBIS, which allows the charge multiplication of light radioactive isotopes to an $A/q < 4.5$ within 20 ms for nuclei with $A < 50$. The injection energy of the RFQ of 5 keV/u is matched by pulsing the EBIS high voltage platform from 60 kV retardation potential down to the appropriate extraction voltage 5*(A/q) kV. The charge breeding system includes a charge state selector after the EBIS, permitting to resolve the few radioactive ions from the residual gas ions that are equally well ionised inside the EBIS. An achromatic device was chosen in order to avoid the deterioration of the resolution of a pure magnetic system by the energy spread of the ions extracted from the EBIS [3]. The ions are expelled from the EBIS within 50 µs and then bunched and accelerated in the RFQ to 300 keV/u. Then the beam is matched to the longitudinal and transverse acceptance of the IH-structure and accelerated further by the IH-structure and three 7-gap split ring resonators. After a momentum analysis in a dipole magnet, which can switch the beam to different ports, the ions reach the experimental set-up. This can either be the γ-ray spectrometer MINIBALL or a small set-up for scattering or implantation experiments.

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2 BEAM PREPARATION

Bunching of the radioactive beam is required in the proposed acceleration scheme because charge-state breeding in the EBIS requires about 20 ms and the LINAC operates with a duty factor of 10% and a maximum RF-pulse length of 2 ms. The repetition rate will be 50 Hz. For the low-intensity radioactive beams it is advantageous to compress the ions in short pulses in order to increase the signal to background ratio in the measurements.

2.1 REXTRAP

A complete operation cycle of REXTRAP comprises the retardation of the 60 keV radioactive ion beam from ISOLDE, the injection over the entrance barrier into the buffer gas region (10^{-3} mbar), the transverse cooling by RF-sideband technique and the extraction of the cooled ions [4]. Each step requires careful tuning in order to reach high overall efficiency in the ion throughput. Overall efficiencies between 10 and 30% for ISOLDE beams and up to 45% with beams from a test ions source have been reached so far. A strong dependence of the efficiency on the ion number above 10^5 ions per cycle has been found. TOF spectra reveal additional hints of space-charge effects in the trap for the above mentioned intensity range.

Due to the Coulomb repulsion the phase space of the ions increases in the longitudinal as well as in transverse direction [5], so the acceptance of the EBIS is exceeded. For most of the radioactive ion beams from ISOLDE this is not a limiting factor since the beam intensity is lower. In some cases the isobaric contamination can be higher, then further purification together with more efficient cooling method in the trap have to be applied.

2.2 REXEBIS

In the REXEBIS mono-energetic electrons from an electron gun are used to further ionise the injected radioactive ions. The electron beam is compressed by the magnetic field of 2 T to a current density larger than 200 A/cm^2 over a distance of 0.8 m. The electron beam has an energy of 5 keV. To assure a high efficiency, each step of a breeding cycle, the injection, breeding and extraction need carefully tuning of the source and optimisation of the optical system.

For a sufficient injection the beam phase space of the ion beam must fit into the electron beam acceptance. An

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estimation of the upper limit of the acceptance, which includes the electron beam space charge and the magnetic field gradient, yields to 11 π mm mrad at 60 keV injection energy. Furthermore the trapping capacity of the electron charges must exceed the number of charges which are produced in the breeding cycle. The maximum number of charges that can be confined at a neutralisation level of 10% equals $6*10^9$. Thus the EBIS can easily trap the ion intensities provided by the trap. A low compensation level and thereby a large radial confinement potential is necessary to keep the acceptance sufficiently large and to avoid ion escape from the trapping region. On the other hand a higher degree of compensation using gas from a feed has an ion-cooling effect [6].

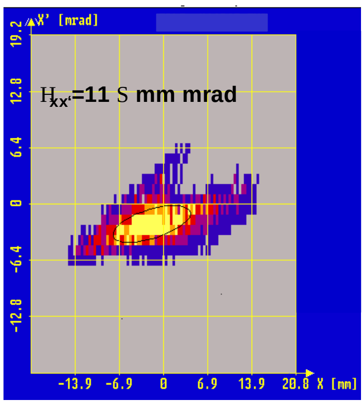

Figure 2: EBIS emittances measured for 22 ms confinement time, I_e = 300 mA, U_{trap} = 5000 V, U_{ext} = 20 kV. The beam emittance is about 15 π mm mrad.

The overall emittance of the EBIS, which includes all ion species has been measured to 15 π mm mrad (fig.2). Highly charged ions have the tendency to accumulate along the beam axis. This occurs due to cooling collisions with low-charged ions that are evaporated away [6], and because of the increased potential depth for the highly charged ions experience [2]. As a consequenc the highly ionised ions should be located within the centre of the measured phase space in figure 2.

Evidence of varying emittance with the extracted charge state is presented in the residual gas spectrum shown in figure 3. The mass separator after the EBIS is an achromatic system using a Nier spectrometer set-up. In this set-up the energy dispersion of the magnet for mass selection is compensated by an electrostatic cylinder deflector. The peak width in the mass spectrum, i.e. the resolution of the separator, does only depend on the emittance of the beam [3]. Thus the acceptance of the mass separator is restricted to 10 π mm mrad, if the mass resolution shall exceed 150. In figure 3 one can see that the peak width of the highly charged La ions (La^{17+}) is much smaller compared to the peak of the low charged O ions (O^{2+}). The resolution of the mass separator for the O^{2+}-peak is only 50. Hence the emittance of the O^{2+}-beam from the EBIS must be above 10 π mm mrad.

3 THE REX-ISOLDE LINAC

The REX-ISOLDE LINAC operates at a resonance frequency of 101.28 MHz. The duty cycle is 10% assuming 2 ms RF-pulses at 50 Hz repetition rate. All structures are driven with 100 kW power amplifiers which allow a maximum reflected power of 6 kW. The designed overall transmission is 95% for a typical EBIS emittance of 15 π mm mrad. Therefore the emittance, transmission and the energy spread of the LINAC structures is being investigated.

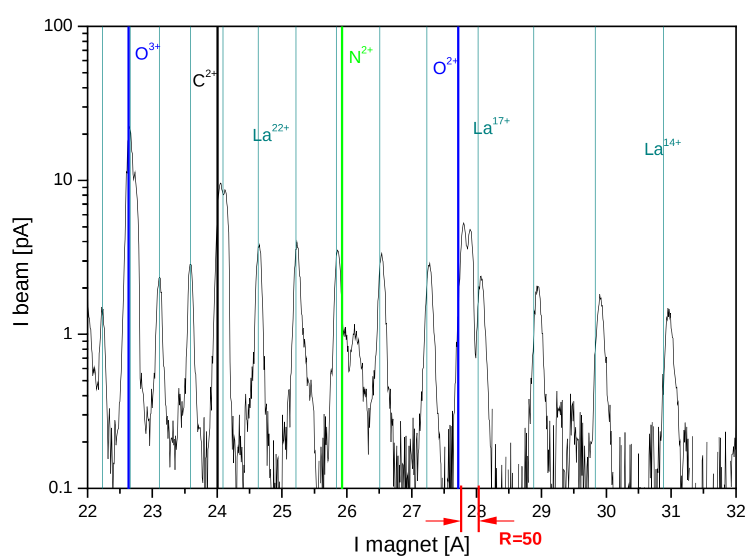

Figure 3: Rest gas spectrum of the REXEBIS for 20 ms confinement time Peaks from residual gas elements like O, C and N can be determined. A fence of La peaks due to overheating of the cathode can be recognised.

3.1 REXRFQ

The REXRFQ and the matching section have been tested in Munich and in a first test beam time at ISOLDE. The emittance growth has been determined for a He^{+}-beam with ε_{norm} = 0.1 π mm mrad injected into the RFQ. Figure 4 shows the measurements in comparison with the PARMTEQ calculations. From the measurements one can conclude that there is no emittance growth for emittances which are slightly larger than the EBIS emittance. A comparison with PARMTEQ shows very good agreement with zero current simulations of the REXRFQ.

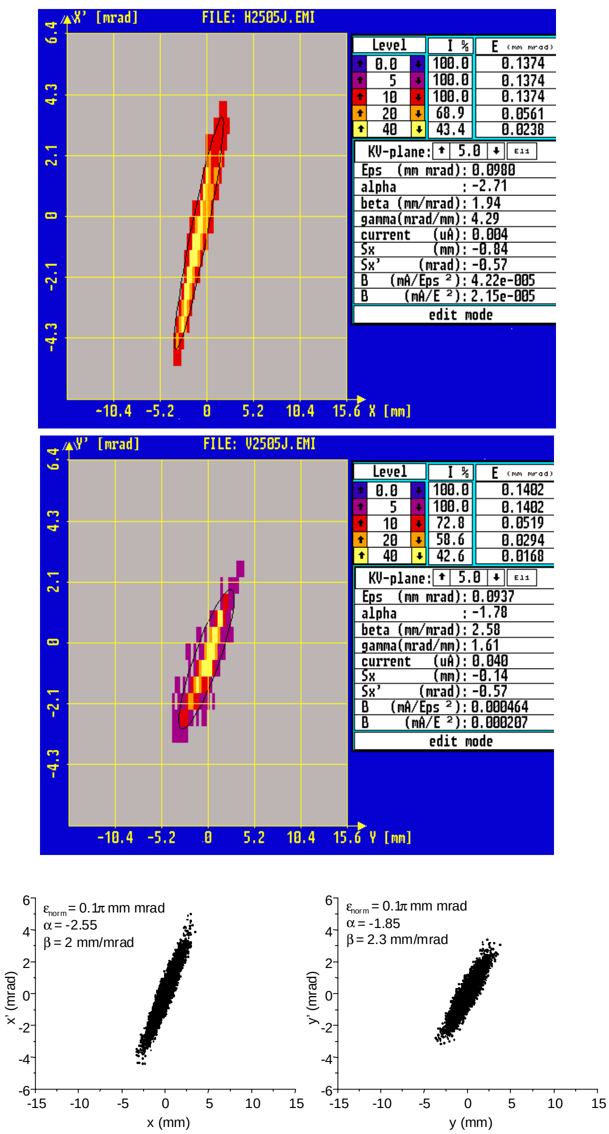

Figure 4: Measured and calculated emittances of the REXRFQ for a He^{+} beam. The injected emittance corresponds to 0.1 π mm mrad (normalized).

In Munich full transmission could be observed with injected beams of 0.1 π mm mrad (normalized). In beam tests at ISOLDE a maximum transmission of about 90% could be reached with O^{4+} and C^{3+} ions, for similar emittances. Also for smaller beam phase spaces the transmission could not be increased. Due to the poor vacuum in the mass separator and injection line (10^{-6} mbar) 10% of the highly charged ions became lost due to charge exchange with rest gas atoms. Thus an improvement of the vacuum conditions is mandatory.

4 INFRASTRUCTURE

For the following commissioning experiments with the IH-structure and the 7-gap resonators a variety of infrastructure installations had to be completed. First of all the installation of the 100 kW RF-power amplifiers was done including tests with a dummy load. In addition the power lines toward the cavities were installed and cut to the right length that the cavity resonance is located in the middle between two line resonances. The vacuum system is divided into five sections each controlled by an SPS. All vacuum elements are installed and operational. The cooling circuits of all cavities have been completed and connected to the ISOLDE cooling system. The cooling system of the IH-structure is the most complicated one due to the required heat exchange unit. The IH-structure consists of normal steel, which can not be cooled with demineralized water. The REX-ISOLDE LINAC is not located in a separate, shielded building, but in the ISOLDE hall among other experiments. In order to reduce the X-ray dose from the drift tube cavities with high gap voltages, lead shields have been installed. The dose rate level must stay below 5 µSv/h in 0.5 m distance from the lead shield, which could be proved in test measurements in Munich and Heidelberg.

When the cabling of the low level rf-control system has been completed the beam tests with IH-structure and the 7-gap resonators will follow. Energy and emittance measurements will be completed until the first beam time with radioactive ions in October.

5 REFERENCES

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