THE 7-GAP RESONATORS OF REX-ISOLDE

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Abstract

The REX-ISOLDE LINAC delivered a first successfully accelerated radioactive beam with 2 MeV/u in November 2001 with only two out of three 7-gap resonators to the experiment, a MINIBALL triple cluster detector. In March 2002 the design energy of 2.2 MeV/u was exceeded by 0.1 MeV/u. REX-ISOLDE (Radioactive Beam Experiment at ISOLDE)- a European project supported by 22 institutions- aims to study the structure of exotic nuclei using radioactive beams. Radioactive nuclei delivered by the mass separator ISOLDE at CERN are accelerated using a novel concept. First singly charged ions from ISOLDE are accumulated in a Penning trap (REX-TRAP), then they are converted to highly charged ions in an Electron Beam Ion Source (REX-EBIS), cleaned by a high resolution mass spectrometer and finally accelerated by a LINAC up to 2.2 MeV/u. We will present first results obtained in those 2 beam times and give an outlook about the expected beam parameters for future experiments.

1 INTRODUCTION

REX-ISOLDE is a first generation Radioactive Ion Beam (RIB) project [1] to explore the structure of very neutron rich Na, K, Ca and Mg and demonstrates a new and efficient possibility of the acceleration of exotic ions. Singly charged ions from the ISOLDE online separator are accumulated and bunched in a Penning trap [2], with their phase space being reduced by buffer gas cooling. The ions are then injected into an Electron Beam Ion Source (EBIS) [3], where their charge state is increased by bombarding them with an electron beam of typical 0.5 A. Behind a mass separator [4] the ions are injected into a short Linac.

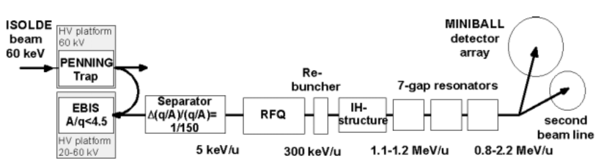

Figure 1: Schematic layout of REX-ISOLDE

The Linac consists of a 3 m long RFQ to bunch, focus and to accelerate the beam to 0.3 MeV/u. The RFQ is followed by an IH-structure and three 7-gap resonators. The accumulation and breeding time neede by REX-TRAP and EBIS of 15 to 20 ms and the extracted pulse length of 100 μs define the time structure of the Linac. The typical operation parameters of the Linac (101.28 MHz) in pulsed mode are a repetition rate of 50 Hz and a pulse length of 600 μs. After a momentum analysis in a dipole magnet the beam can be switched to presently two target stations. An overview of the REX-ISOLDE experiment is shown in Fig. 1.

2 THE 7-GAP LINAC

The high energy section of the REX-Linac consists of three 7-gap resonators similar to those developed for the High Current Injector in Heidelberg [5]. Operating at 101.28 MHz those resonators are optimised for synchronous particles of β_s=5.4%, 6.0% und 6.6%. The number of gaps per resonator is a compromise between high accelerating voltage and flexibility of the transit time factor. A view into an open 7-gap resonator is given in Fig. 2. 6 drift tubes are connected to spirals, ending in a half shell. The total resonator voltage is about 1.7 to 1.8 MV at a typical power of 90 kW. Beam dynamic calculations showed normalized acceptances of 1.2 mm mrad for the x-plane and 3 mm mrad for the y-plane. The output of the IH-structure is matched with a triplet to the acceptance of the 7-gap Linac, a doublet behind the first 7-gap resonator is necessary for transverse focussing.

Figure 2: View into a 7-gap resonator.

2.1 Parameters of the 7-gap resonators

The resonators were tested up to an input power of 105 kW in pulsed mode. No problems occurred due to mechanical resonances (at 50 Hz repetition rate) or multipactoring effects. With a beam test the following parameters of Table 1 of the resonators were determined. The deviation between the voltages (at 90 kW), reached in the low level tests and in the beam tests are due to heating effects in the surface resulting in a lower conductivity.

Table 1: Parameters of the 7-gap resonators

Reso-nator	parameter	Low level test	Beam test
5.4%	Voltage [MV] Z [MΩ/m]	1.88 ±0.08 71±6	1.77 ±0.05 62.5 ±4.0
6.0%	Voltage [MV] Z [MΩ/m]	1.94 ±0.04 68.5 ±2.7	1.81±0.05 59.7 ±3.6
6.6%	Voltage [MV] Z [MΩ/m]	2.00 ±0.04 66.9 ±2.7	1.88 ±0.05 59.5 ±3.5

Nevertheless for all 3 resonators the voltages reached exceed the design value of 1.74 MV.

At an rf power of 90 kW and a pulse length of 1 ms the radiation level is about 1 mrem/h. Therefore, the resonators were shielded with lead which suppressed the radiation to a level of about 10 µS/h . To reduce the background radiation at the target area even more a second movable lead shielding was installed. The 7-gap Linac part together with the lead shielding is shown in Fig.3.

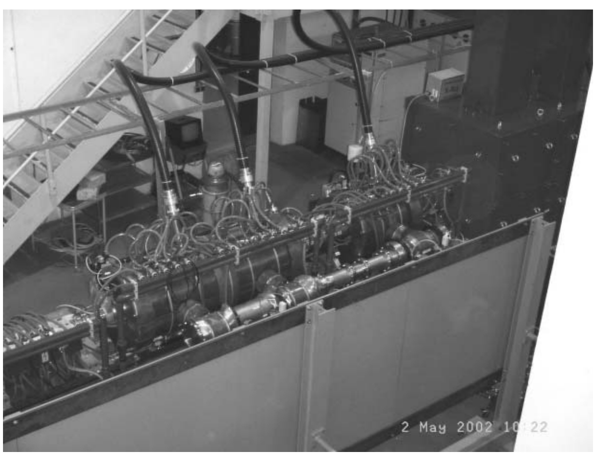

Figure 3: View on the three 7-gaps

2.2 Commissioning and first beam time

After a commissioning period in which all resonators were operated beyond their design value in a very stable mode, amplitudes and phases of all resonators were set with a stable Na- beam from the rest gas of the EBIS. As the high resolution phase shifters were not yet available we had to set the phases with standard delay units borrowed from the PS group, which have worse specifications than the high resolution phase shifters, in particular they do not allow a fine tuning of the phases. Nevertheless, we were able to accelerate charge bred ions of ^{23}Na, ^{24}Na, ^{25}Na, ^{26}Na and ^{39}K up to 2 MeV/u with a transmission of about 70 to 80% through the whole Linac. Due to a broken preamplifier the 3rd resonator of the 7-gap section could not be used. Nevertheless, 2.0 MeV/u could be achieved by increasing the input power of the remaining two and by setting the synchronous phase to 0 degree.

When switching between the different isotopes the scaling of the whole Linac with A/Q turned out to be very efficient: By maintaining the settings of the phases and by scaling of the amplitudes and settings of the lenses the same transmission for the new A/Q was reached. Due to not yet fully understood problems to reproduce the calibration of the amplitudes of the three 7-gap resonators the amplitudes were adjusted with the input power. To set the required synchronous phase we determined by the maximum acceleration at a given amplitude the 0 degree phase. From the 0 degree the required phase could be set.

2.3 Second beam time

Although the commissioning of REX-ISOLDE is not yet finished, the second beam time in March 2002 was already performed on a user request. From the accelerator point of view this beam time was very successful. All resonators were running stable. The rf preamplifier was repaired and also a new high voltage transformator was included. The accelerated ion species were Na with A=23, 24, 25, 26, 27 and 28. The charge state was in all cases 7+. Due to the required energy of 2.3 MeV/u all synchronous phases of the 7-gap resonators had to be set to 0 degree. Due to this settings the beam envelope is worse than for the design case of 2.2 MeV/u. The emittance grows by a factor of 4 in x-direction in comparison with the emittance of the designed synchronous phase of –20 degree. Moreover, the longitudinal beam shape changes to a much longer bunch length. In Fig. 4 the output parameters

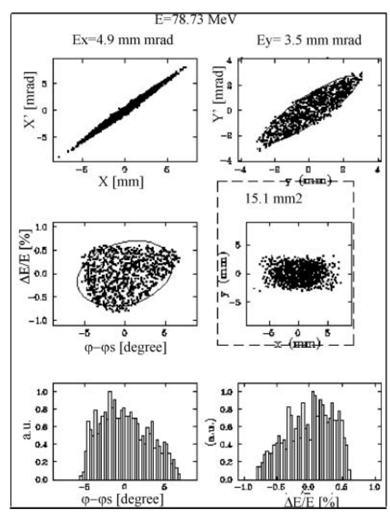

Figure 4: Phase space diagrams for an rf phase setting of ϕ_s = -20 degree.

behind the 3rd 7-gap resonator for an rf phase setting of ϕ_s = –20 degree are presented, while in Fig. 5 the corresponding parameters for ϕ_s= 0 are shown. The emittance growth for ϕ_s= 0 results, of course, in a larger

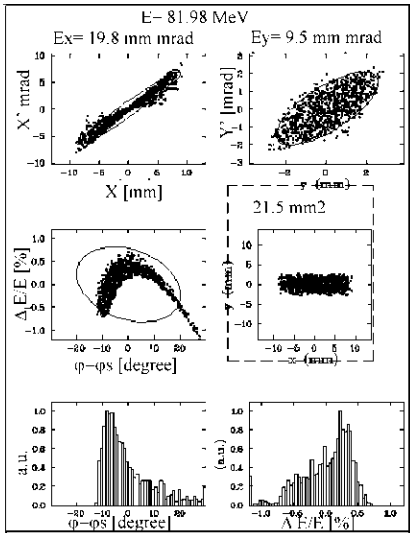

Figure 5: Phase space diagrams for an rf phase setting of ϕ_s = 0 degree.

beam spot, which is shown in Fig. 6 and Fig. 7. Nevertheless, with the aid of an optimised optic calculation we found a setting for a

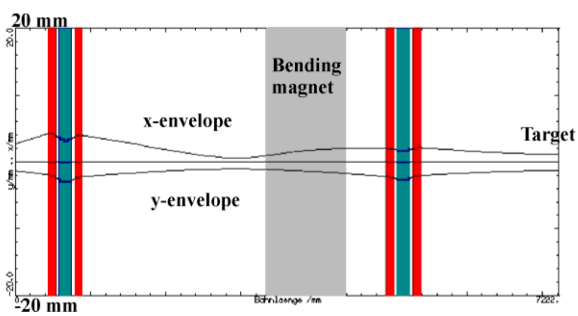

Figure 6: Beam envelope between the end of the last 7-gap resonators and the target in the ϕ_s = –20 degree case

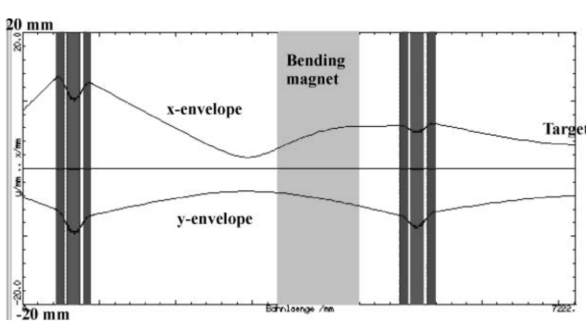

Figure 7: Beam envelope between the end of the last 7-gap resonator and the target in the ϕ_s= 0 degree case

sufficient small beam spot of less than 10 mm diameter on the target. In Fig. 8 the beam spot in the diagnostic box 1m in front of the target is shown. The intensity was about 10 pA, the spot diameter is smaller than 3 mm.

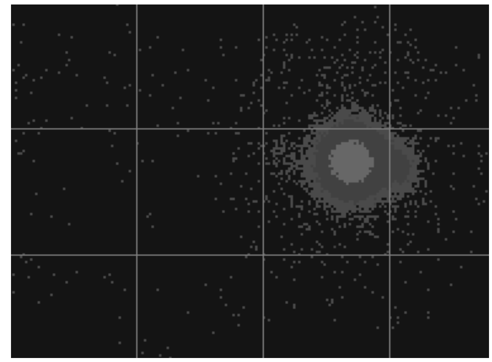

Figure 8: beam spot of a stable beam close to the target

2.4 Outlook

A first energy upgrade to 3.1 MeV/u is planned by inserting an additional 9-gap IH-cavity in the drift space behind the last 7-gap resonator and the bending magnet. The new resonator will have an eigenfrequency of 202.56 MHz and is a rebuild of a prototyp of a 7-gap IH-structure planned for MAFF [6]. It is foreseen to operate the 7-gap resonators such as to reach the 2.25 MeV/u which is required as input velocity for the new 9-gap. Beam dynamics calculations suggest to operate 7-gap 1 and 7-gap 2 at design amplitudes and phases, while 7-gap 3 is operated at 1.9 MV (possibly with about 95 kW) at a synchronous phase of 3 degree. In that case the output parameters of the three 7-gap resonators are very close to the design values even for an energy of 2.25 MeV/u.

3 REFERENCES

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