TEST AND FIRST EXPERIMENTS WITH THE NEW REX-ISOLDE 200 MHZ IH STRUCTURE*

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Abstract

For the REX-ISOLDE accelerator, a new accelerating structure is at the moment installed and tested. It will raise the final energy from the present 2.3 MeV/u to 3 MeV/u. The aim is to increase the mass range of the nuclei available for nuclear spectroscopy from mass 40 to mass 80. The new accelerator component is a 0.5 m IH-structure, working at the double REX frequency of 202.56 MHz. It was originally developed as a 7-Gap resonator for the MAFF [1] project and later adapted to the requirements at REX by changing from a 7-Gap to a 9-Gap resonator to match the lower injection energy. We present the design of the resonator and the results of the rf-tests, commissioning and first operation during the 2004 running period.

INTRODUCTION

In order to make a wider range of isotopes from ISOLDE/CERN available for nuclear physics experiments at REX-ISOLDE [2], an energy upgrade of the REX accelerator has been proposed. It was decided to do the upgrade in two separate steps (see fig. 1). The first step – increasing the energy from the previous 2.3 MeV/u to 3 MeV/u – was recently achieved by installing an additional IH 9-gap cavity in the REX beam line. The second step includes major changes in the setup of the machine By replacing two of the existing 7-gap resonators with a 1.5 m IH structure, the energy will be raised from 3 MeV/u to ~4.2 MeV/u. Since this energy is beyond the limits of several currently installed beam optics elements, a redesign of the high energy beam transport is required at the same time.

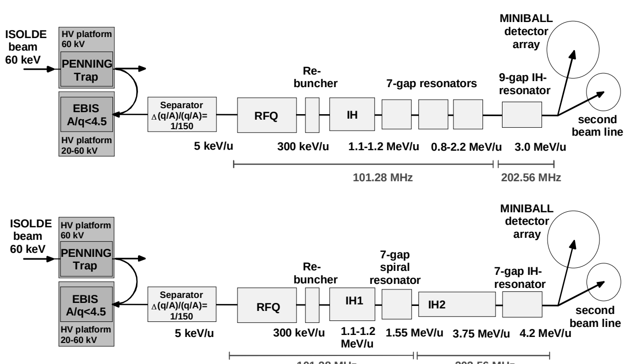

Figure1: Upgrade of the REX-ISOLDE Linac.

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For the MAFF project a design has been worked out for two identical short 7-gap IH structures, providing the desired energy variation for the MAFF-Linac. The main advantage of this accelerator type compared to the split-ring resonators of REX-ISOLDE lies in the higher shunt impedance, allowing a variation of the final energy over a comparatively wide range (3.7 – 5.9 MeV/u) with only two short cavities. Since acceleration and deceleration must be possible to cover this energy range, the particle dynamics design at MAFF was very similar to the 7-gap resonators of REX-ISOLDE, which means constant gap lengths and a synchronous phase defined by the phase the particles experience in the middle gap.

In the first design for the REX 3MeV/u upgrade, it was foreseen to change the MAFF resonator from a 7-gap to a 9-gap resonator – keeping a constant cell length, corresponding to 2.5 MeV/u synchronous particle energy. Nine gaps were necessary to match the lower injection energy of 2.2 MeV/u instead of 3.7 MeV/u. However, measurements at the Tandem accelerator of the Maier-Leibnitz Laboratory in Garching showed that this gap geometry leads to a rather low transit time factor [3]. Thus the drift tube geometry was changed to a $\beta\lambda/2$ profile for fixed input and output energies. Table 1 shows the geometry and rf-parameters of the resonator.

Table 1: Resonator parameters of the 9-gap IH-cavity

	IH 9gap
Frequency [MHz]	202.56
outer tank length [mm]	676
inner tank length [mm]	520
half shell radius [mm]	145
cell length [mm]	38.5 – 58.5
gap length [mm]	19 - 27
drift tube length [mm]	32
drift tube diameter in./out. [mm]	16 / 22
maximum rf-power [kW]	100
duty cycle [%]	10
Kilpatrick	1.5
shunt impedance (pert.) [MΩ/m]	218
Q_0	10100

The above 9-gap design includes a smaller diameter of the drift tubes compared to the original 7-gap structure to keep the resonant frequency at 202.56 MHz. The gap voltage distribution used for the LORASR simulations

was calculated with MAFIA and verified first on a 1:1 copper model and later on the power resonator.
Figure 2 shows the resonator after installation in the REX beam line, before the lead shielding was installed.

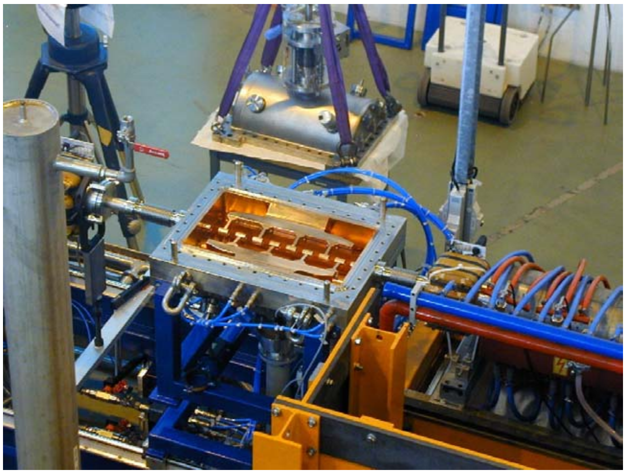

Figure 2: Open tank of the IH 9-gap accelerator, installed in the REX beam line.

BEAM DYNAMICS CALCULATIONS

The input for the LORASR simulations is delivered by the original LINAC design calculations for the 7-gap resonators, which were verified in detail during the commissioning phase of REX-ISOLDE [4]. The main goal of the calculations (after having once fixed the drift tube geometry) was to find out to what extend the structure is still energy variable, even if it has a design for a fixed input and output energy. Due to the short length and the small number of gaps as well as the relatively high injection energy, one can expect that the beam quality and transmission after the 9-gap resonator are much less sensitive to changes in the accelerating voltage than it is found in long IH structures at lower energies.

The design injection energy produced by the 7-gap resonators is 2.25 MeV/u at a phase spread of ± 15° (after 1.3m drift) and at an energy spread of ± 0.45 %. Transversely, the beam is injected with an emittance of $\varepsilon_{n,x,y}$ = 1.4 π mm mrad in both planes convergent, whereby only slightly converging beams led to the best transmission.

To test the energy variation, the resonator voltage was changed in steps according to the measurements at different rf-power levels. This downscaling of the gap voltages was done – starting from the design voltage at 3 MeV/u - using the pickup values measured at the power levels shown in the diagrams. The spectra in figure 3 show that the transmission as well as the energy spread stay in a reasonable range down to an output energy of 2.55 MeV/u. With this result (which could be verified during the measurements shown below) the REX accelerator becomes continuously energy variable over a range from 0.8 MeV/u to 3 MeV/u.

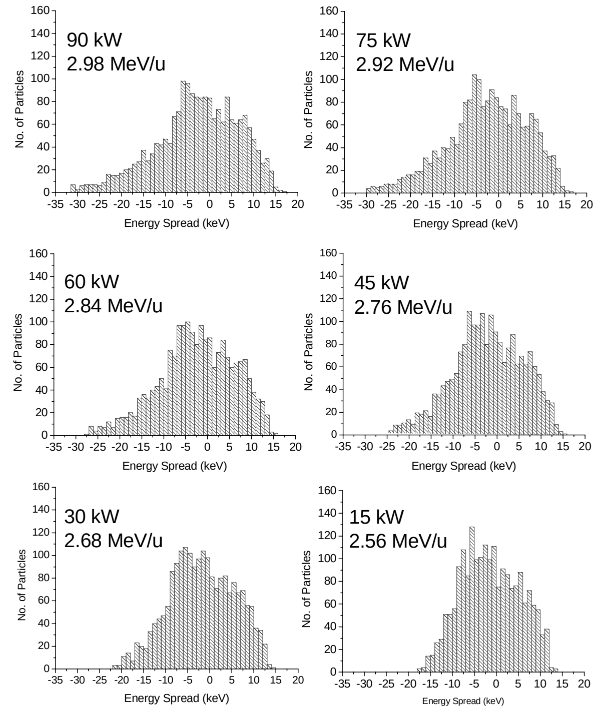

Figure 3: Energy spectra at different acceleration voltages.

The calcuated transit time factors in the fifth gap – which is taken here as a reference - always stay between 0.855 and 0.865. The good flexibility in output energy of the accelerator allows a wider range of mass to charge ratios to be available at energies around 3.0 MeV/u, than limited by the currently maximum available rf-power. With an rf-power level limited to 90 kW, the maximum A/q at 3.0 MeV/u is at the moment A/q = 3.5. Thus, during the first runs with radioactive ions, compromises could be found, like e.g. accelerating $^{76}Zn^{20+}$ ions (A/q = 3.8) at 90kW to ~2.9 MeV/u. Table 2 shows the calculated parameters of the 9-gap resonator for regular operation at 3 MeV/u and for the variable energy.

Table 2: Design parameters of the 9-gap IH-cavity

	IH 9gap
input energy [MeV/u]	2.2
output energy [MeV/u]	2.55 - 3.0
energy spread [%]	1.0 – 1.6
phase spread [°]	25
transmission [%]	100
TTF on axis in gap No. 5 (2.55 – 3.0 MeV/u)	0.855 – 0.866
maximum A/q (90kW)	3.5
radial acceptance $\alpha_{x,y,norm}$ [π mm mrad]	1.4

BEAM TESTS

From the low level measurements and LORASR calculations we expected for the IH structure an effective shunt impedance of 163 MΩ/m. An energy gain of 0.75 MeV/u requires for ions with A/q = 3.5 an effective acceleration voltage of 2.63 MV, which corresponds at the given shunt impedance and structure length to an rf-power of 85 kW. We therefore performed the tests with a N^{4+} residual gas beam from the REXEBIS. The injected current was in the range of 50 pA in the beginning and went down to ~10 pA because of the slits in front of the energy spectrometer, which were used to reduce the emittance influence on the energy spectra. Figure 4 shows the measured spectra.

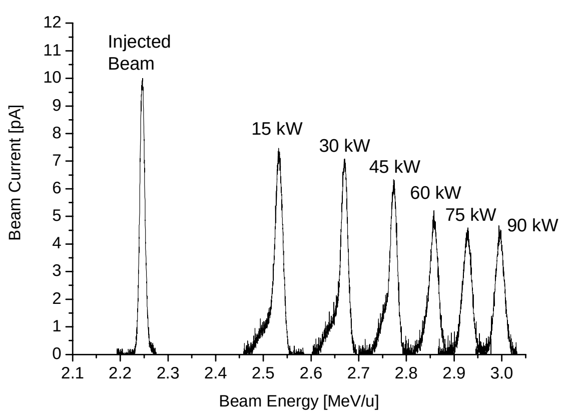

Figure 4: Energy spectra measured with a A/q = 3.5 beam.

The measured final energies are in good agreement with the calculations. The decrease of the beam current at higher energies occurs because the beam transport was optimized for a parallel 2.25 MeV/u beam through the spectrometer instead of a convergent injection into the 9-gap. With an optimized injection and a beam transport scaled to the different energies, the transmission was close to 100 %.

The energy peaks at lower power levels show a tail towards the low energy side, which might be the result of a slightly wrong injection phase. However, the FWHM of the peaks correspond remarkably well to the design calculations.

Calculating the effective shunt impedance for an effective acceleration voltage of 2.63 MV at 90kW gives a value of η_{eff} = 154 MΩ/m. With an average transit time factor of 0.865 we derive a shunt impedance of η = 205 MΩ/m. If the decrease of the shunt impedance at higher power levels due to the heating of the resonator is taken into account, this value fits nicely to the η = 218 MΩ/m from perturbation measurements.

CONCLUSION

With the successful test and first operation during nuclear physics experiments, the first stage of the REX-ISOLDE energy upgrade has become reality. At the same time it could be shown that the REX-LINAC is still fully energy variable from 0.8 MeV/u up to the final energy of now 3.0 MeV/u. To increase the maximum A/q of the ions at 3 MeV/u, work is under progress to reach the nominal rf-power of 100 kW. In parallel we will investigate the possibility of increasing the injection energy.

REFERENCES

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