BEAM TESTS OF THE VE-RFQ CYCLOTRON INJECTOR*

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Abstract

The new VE-RFQ-injector for the cyclotron at HMI in Berlin is now being comissioned, The ECR-source together with the RFQs [1, 2] supply heavy ion beams with 90 - 360 keV/u for q/A $>$ 0.15 matched to the isochronous cyclotron. Properties of the new injector and results of first beam tests will be presented.

1 INTRODUCTION

The Ionen-Strahl-Labor (ISL) [3], the former VICKSI-facility, at the Hahn-Meitner-Institut in Berlin has replaced the former Tandem-injector with a combination of an ECR-ion source together with a two stage 4-Rod-Variable Energy-RFQ. Next to the 6 MV Van de Graaff injector, which provides ions at lower intensities but higher final energies out of the cyclotron (32 MeV/n for q/A = 1/2), the ECR-RFQ combination provides beams of higher intensity and final energies between 1.5 and 6 MeV/n. This energy meets the demands of solid state physics. To our knowledge this is the first cyclotron which uses an RFQ as a direct injector. Figure 1 shows an overview of the beamline.

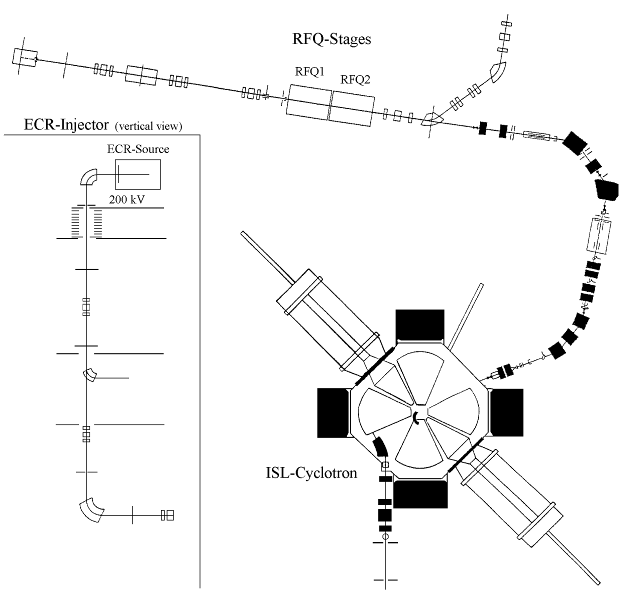

Figure 1: Scheme of the beamline

This VE-RFQ [4, 5] has three special features: First of all it is frequency variable through a moveable tuningplate, which shortens the effective length of the stems. Opposite to single frequency RFQ, where the output energy is fixed by frequency and electrode-shape, the frequency variation leads to a variable output energy proportional to $\sqrt{f}$. The RFQ at ISL covers a frequency-range from 85 to 120 MHz and works on the eighth harmonic of the cyclotron frequency.

Secondly the RFQ is splitted into two stages with the second stage designed to work either in accelerating- or transport-mode. This expands the energy variation of the RFQ from 90 keV/n to 360 keV/n. The concept of an RFQ working as a radial focusing transport channel has not been tested before with a bunched beam [6, 7, 8].

The third point is that this RFQ operates in cw-mode with a maximum power consumption of 20 kW per stage. Therefor the design has been optimized to provide proper cooling of the electrodes, stems and the tuningplate.

Table 1 gives a summary of the ISL-RFQ properties and Figure 2 shows the open RFQ.

Table 1: ISL-VE-RFQ parameters

Length (split into two stages)	3 m
diameter	0.5 m
number of stems per stage	10
minimum aperture	2 mm
min/max E_{in}	$15.16/29.72$ keV/n
min/max E_{out}	$90.98/355.09$ keV/n
charge-to-mass-ratio	1/8 - 1/2
frequency-range	85 - 120 MHz
duty factor	100% (cw)
max power consumption p. stage	20 kW

2 CONTROL SYSTEM

2.1 Frequency-tuner

Already the first simulations of the frequency-tuner revealed that its design would be difficult, as the simulations showed an eigenmode of tuner near 120 MHz, the highest

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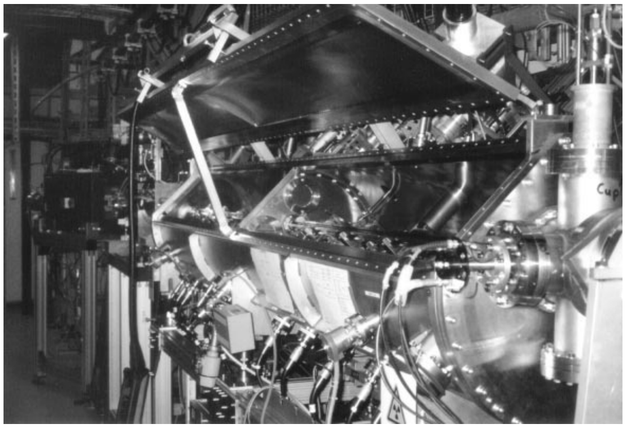

Figure 2: Picture of the open RFQ at HMI

operation frequency of the RFQ. First tests with our standard tuner (a rod with a cup) confirmed the simulations. To raise the eigenmode of the tuner its front part was changed to a small cylinder instead of the cup to decrease the capacitance against the electrodes. The rear part was changed into a large cylinder to decrease the inductivity. This design had the lowest eigenmode at about 135 MHz [9]. Figure 3 shows a picture of this design.

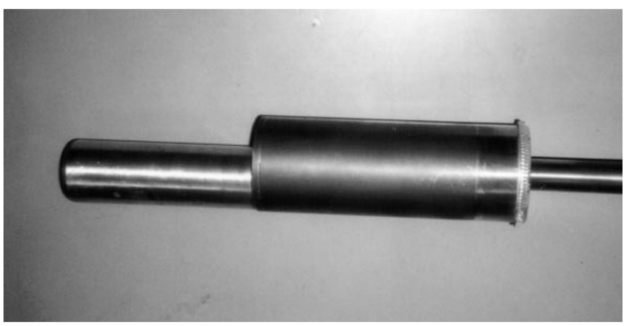

Figure 3: First tuner-redesign

High power tests at NTG in Gelnhausen and after the reinstalation of the RFQ at HMI showed that the frequency-variation of the tuner was not sufficent. Due to thermal expansion of the contacts between stems and tuning-plate during operation the resonance-frequency of the RFQ is shifted to higher frequencies. The range of the tuner was too small to compensate this effect and the normal detuning during operation, so the big tunig-plate had to be moved too to restart the RFQ.

The final shape of the tuner increased the frequency-variation by a factor 2.5 and has no eigenmodes lower than 125 MHz. Figure 4 shows a picture of the final tuner.

2.2 Automatic Tuning

To simplify the operation with the RFQs, a computer routine has been developed to perform a self tuning and adjusting sequence by the preset input-parameters rf-frequency and RFQ-electrode-voltage.

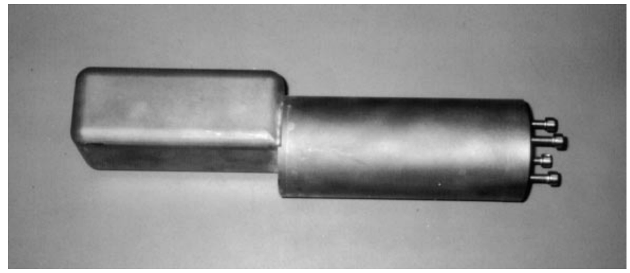

Figure 4: Final tuner-design

In a first step all moveable parts of the RFQ and the rf-power-amplifiers are set to frequency dependent values taken from data-tables. Then the computer performs an optimaziation of the amplifiers to ensure an output of at least 20 kW cw. After this the RFQ is set to the proper resonance-frequency, mainly by moving the tuner. After minimizing the reflected power the correct phase-relation for the resonance-control is set. In contrast to fixed frequency resonators this relation varies because of the changing wavelength and has to be precisely tuned for each frequency.

The second part of the program sets the RFQ to a given electrode voltage. Results from gamma-spectroscopy at a fixed power consumption and various frequencies together with a measured signal from an RFQ-probe provide the necessary information. By an assumed optimal quadratic relationship between power consumption and electrode-voltage resp. probe-signal all parameters are calculated from these measured values. If the calculated value for the probe-signal is reached, the control is given back to the ISL-operators who then can optimize the injector system settings.

3 BEAM MEASUREMENTS

During the last six months a set of beam measurements has been made. It showed that the RFQ successfully reached the design goals and provides the necessary output-energies. The beam has also been injected successfully into the cyclotron.

E.g. a $^{86}Kr^{14+}$ with 300 MeV has been succesfully extracted out of the cyclotron with 2.5 μA before the RFQ and 500 nA after the cyclotron [10].

Even more important is that the transport-mode of the second stage has also been tested succesfully with an $^{129}Xe^{14+}$ beam with 196 MeV and 1.35 μA before the RFQ and 100 nA after the cyclotron. The experiments showed also that a calculated transmission of 2/3 (without a chopper in front of the RFQ) can be reached. Figure 5 shows a result from beam measurments.

4 CONCLUSIONS

The RFQ succesfully reached its design-goals and the new injector for the ISL-cyclotron is now ready for operation.

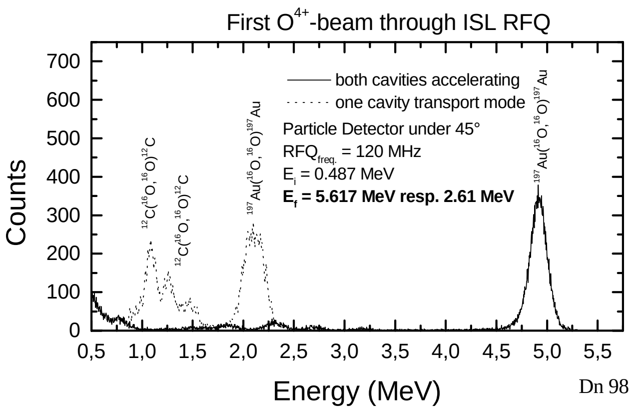

Figure 5: O^{4+}-beam spectroscopy

Training for the operators is scheduled for April. Further work has to be done to improve the contact-rings which connect the moveable tunigplate to the stems. It turned out that after some time of tuning and operation some contact-fingers were broken. This does not affect the operation of the RFQ but a more reliable design has to be found.

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