RF-PROPERTIES OF THE VE-RFQ-INJECTOR FOR THE ISL-CYCLOTRON*

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Abstract

The separated sector cyclotron at the ISL (Ionen-Strahl-Labor, Berlin) will get a new injector. The RFQ-part of the injector consists of two closely coupled VE- (Variable Energy) RFQs with an input energy range of 15 to 30 keV/n and an output energy range of 90 to 360 keV/n. For direct injection into the cyclotron a small energy spread and a duty factor of 100 % are needed, which is difficult for RFQs. Calculated and measured rf-properties of the RFQs will be discussed.

Introduction

The scientific program at the ISL, the former VICKSI-(Van de Graff Isochron Cyclotron Kombination für Schwere Ionen) facility has changed from nuclear physics to solid state physics [2]. The VICKSI-facility consists of two external injection beamlines, a Van-de-Graff and a Tandem injector with a separated sector cyclotron as postaccelerator. To meet the demands of the solid state physics users the Tandem injector will be replaced by a combination of an ECR source mounted on a 200 kV platform and a two stage VE-RFQ. The ECR-RFQ-combination will accelerate the ions to energies between 0.09 and 0.36 MeV/n to cover the range of final energies out of the cyclotron between 1.5 and 6 MeV/n.

The VE-RFQ-Structure

In an RFQ structure [3] the accelerating longitudinal fields are achieved by a geometrical modulation of the quadrupole electrodes, as shown in figure 1. The shape of the electrodes is characterized by the parameters aperture radius a, modulation m and the cell length L.

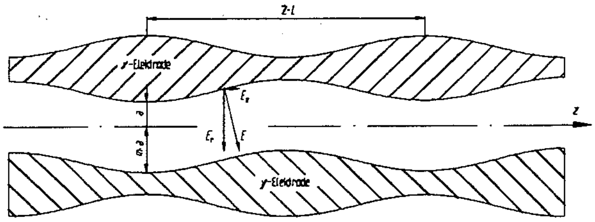

Fig. 1: The shape of the modulated electrodes.

Due to the Wideroe resonance condition [4], where β_p is the normalized particle velocity, v_p the particle velocity and f the frequency:

$$L = \frac{\beta_p \lambda}{2} = \frac{v_p}{2f}, \qquad (1)$$

the fixed particle velocity profile can only be varied by either changing the cell length or the frequency. The second possibility is the way which has been used for RFQs with variable energy [5]. For this reason it is possible to change the output energy E_{out} using the same electrode system: $v_p \propto f$, $E_{out} \propto v_p^2$.

To change the frequency of the 4-Rod RFQ, a type of resonator developed in Frankfurt [6], the resonator can be tuned capacitively or inductively. Figure 2 shows the inductive tuning by a movable tuning plate, which varies the effective length of the stems.

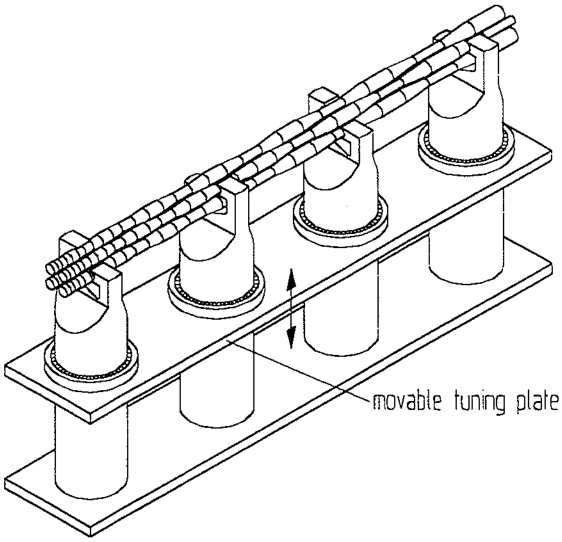

Fig. 2: Scheme of the VE-RFQ.

In Frankfurt the VE-RFQ was developed at first for the application as a cluster postaccelerator at the 0.5 MV Cockroft-Walton facility at the IPNL (Institut Physique Nucleaire Lyon, France) [7, 8]. This accelerator is designed for an input energy between E_{in}=5 keV/n and 10 keV/n and an output energy between E_{out}=50 keV/n and 100 keV/n.

Based on the positive experiences of this project, a first combination of an ECR source with a VE-RFQ has been built for the IKF (Institut für Kernphysik, Frankfurt). The RFQ is designed for a minimum charge-to-mass-ratio of 0.15, an output energy of E_{out}=100-200 keV/n, a maximum electrode voltage of 70 kV and has a structure length of 1.5 m.

The RFQ-concept for the ISL-cyclotron

To inject into a cyclotron, the RFQ has to provide a bunched beam at a well defined injection energy determined by the inner radius of the cyclotron. The energy variability of the separated sector cyclotron will be kept by using an injector which has a variable energy and a variable frequency like the

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VE-RFQ. The operating frequency of the RFQs must be synchronized with the cyclotron frequency. RFQs have a fixed ratio of input to output energy given by the cell length of the first and last acceleration cell. This is similar to the energy gain factor of a cyclotron. For these reasons a VE-RFQ is well suited as an injector for a cyclotron [9].

The new injector consisting of an ECR source and a VE-RFQ has to fit into the existing Tandem beamline. To stretch the energy range of the injector the RFQ will be split into two RFQ stages, mounted in one vacuum-chamber. Each stage with a length of 1.5 m consists of a ten stem 4-Rod RFQ-structure. With a power consumption of 20 kW per stage an electrode voltage of 45 kV will be possible.

The RFQs will be driven in two different modes of operation. In the high energy mode both RFQs accelerate, the output energy of the cyclotron is between E_{out}=3 MeV/n and E_{out}=6 MeV/n with a harmonic number of 5 for the cyclotron. In the low energy mode the second RFQ has a detuned phase and works as a quadrupole transport channel. The energy range of the cyclotron in this mode is between E_{out}=1.5 MeV/n and E_{out}=3 MeV/n. The cyclotron works on the harmonic number 7. In both modes the frequency of the RFQ is tuned to the eighth harmonic of the cyclotron frequency. Parameters are given in table 1.

Table 1
Main accelerator parameters.

RFQ:

min. / max. E_{in}	15 / 30 [keV/n]
min./max. E_{out} RFQ$_1$	90 / 180 [keV/n]
min./max. E_{out} RFQ$_2$	180 / 360 [keV/n]
energy gain factor RFQ$_1$	6
energy gain factor RFQ$_2$	2
charge to mass-ratio	1/5 - 1/8
frequency	85 - 120 [MHz]
max. electrode voltage	45 [kV]
length / diameter	3 / 0.5 [m]

Cyclotron:

injection radius	0.43 [m]
extraction radius	1.8 [m]
frequency	10 - 20 [MHz]
max. dee-voltage	140 [kV] (peak)
energy gain factor	16.8 - 18.6

The RFQ output emittance depends largely on the input conditions. For matched input beams with an energy spread $\Delta E/E < 1.5$ %, a normalized emittance $\varepsilon_n < 0.5\,\pi$ mm mrad and a bunch length $\Delta t < 1$ ns a transmission of 100 % is expected. To reach this beam quality it is necessary to have a buncher-chopper system between the ECR and the RFQs [10].

The ECR source is mounted on the 200 kV platform formerly used for the Tandem(see figure 3).

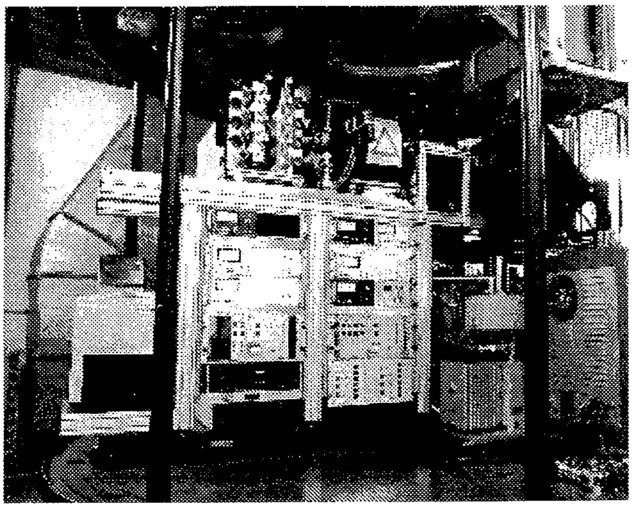
Fig. 3: ECR source mounted on the platform.

The vertical beam is bent by 90°, passes through the buncher-chopper system and will be injected into the RFQs. The final matching into RFQ$_1$ will be done by a triplet lens. The beam from RFQ$_2$ is transported into the injection beamline of the cyclotron, to which a rebuncher has been added to make a proper time focus for the cyclotron.

Rf-Properties

The rf-properties were calculated with the code MAFIA Ver. 3.2 [11], to check several structural details. The main point of interest is the relation between the tuning plate position and the frequency as well as the dependance of the shuntimpedance and the Q-value on the frequency, as shown in figure 4.

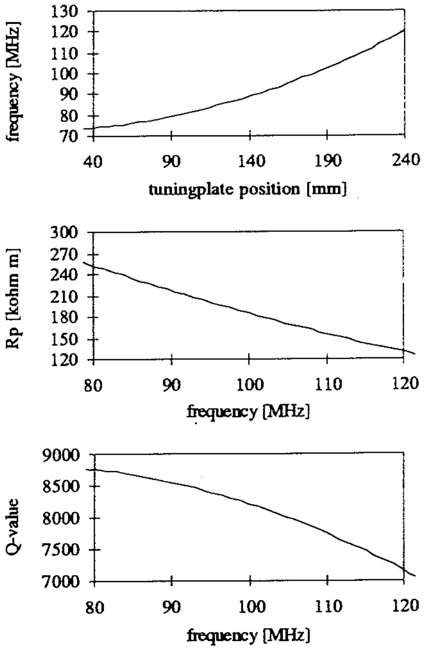

Fig. 4: Relation between the position of the tuning plate and the rf parameters.

Another point of interest is the electrode voltage along the RFQ (flatness), which should be constant. Calculations have shown that the flatness is a function of the frequency. The value of 3 % at the highest frequency is noncritical, at lower frequencies it decreases, as shown in figure 5.

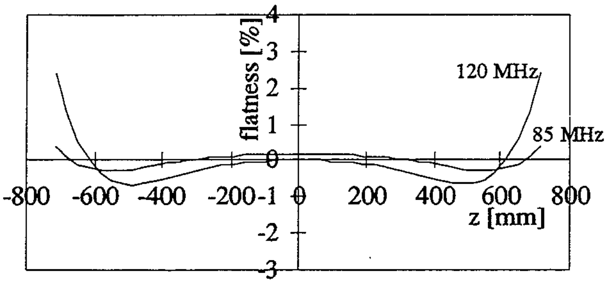

Fig. 5: Flatness.

With MAFIA the loss distribution at the different RFQ-components has been calculated. Results show that 64 % of the power will be lost at the stems (at 85 MHz). At 120 MHz the losses are: electrodes 31 %, tuning plate 19 % and electrode supports 12 %.

The duty factor of 100 % and the maximum power consumption of 20 kW together with the calculated losses at the different components were the arguments for a modified electrode material with an integrated cooling channel.

To compensate the frequency shift caused by thermal effects at high power level an additional tuning element is required. The effect of the slow tuner to the frequency varies with the resonance frequency as shown in figure 6.

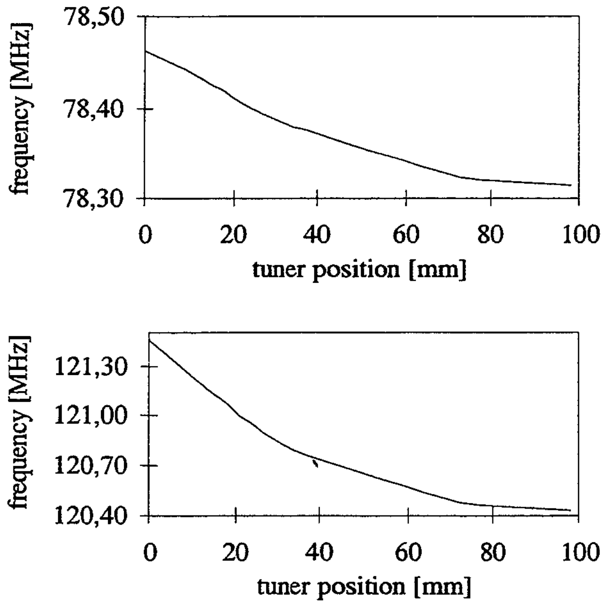

Fig. 6: Frequency to tuner position.

Status and schedule

The vacuum chamber is copper plated and leak tested, the stems are aligned and mounted in the cavity. The components (tuning plate, vacuum pumps, etc.) are installed (figure 7).

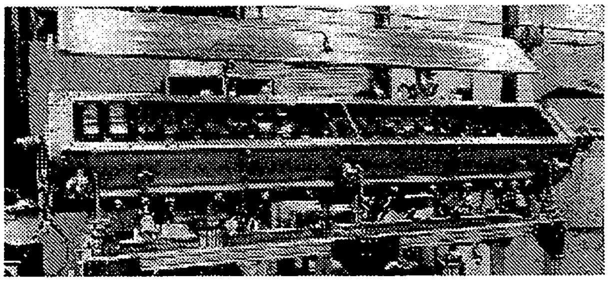

Fig. 7: View of the resonator.

The electrodes and their supports are manufactured and will be brazed together with the water cooling. First low level measurements are scheduled for September 1996, the high power tests at NTG[x] will start in Oktober 1996.

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