*A VE-RFQ-INJECTOR FOR A CYCLOTRON**

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Abstract

Based on the development of the variable energy 4-rod-RFQ a new injector for the ISL heavy ion cyclotron at the HMI Berlin (the former VICKSI machine) is under construction. The ECR source together with two VE-RFQs will replace the 8UD-Tandem injector to meet the demands of solid state physics users. The design of the new RFQ injector and the status of the project will be discussed.

I. INTRODUCTION

The ISL [1] is an isochronous cyclotron with four separated sectors. It has an external injection of beams with variable energy from either a CN-Van-de-Graaff or an 8UD-Tandem. Figure 1 shows the layout of the accelerator complex.

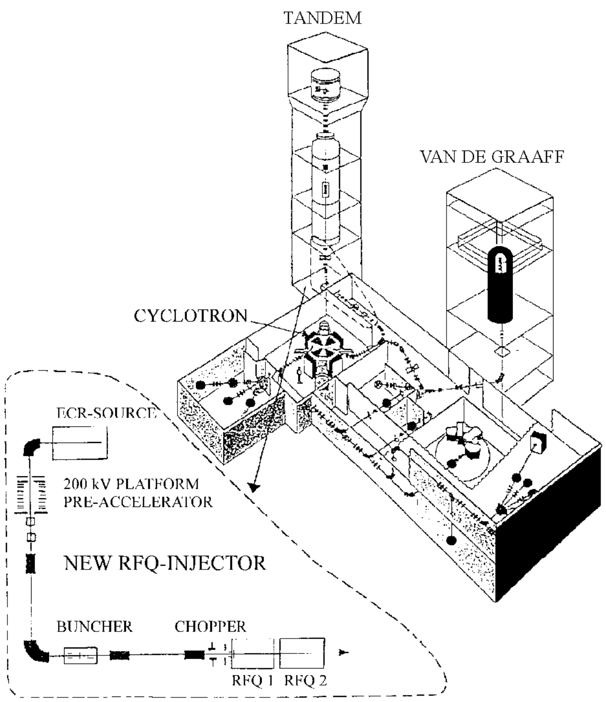

Fig. 1 Scheme of the heavy ion accelerator complex with the planned changes in the encircled area

The scientific program at the ISL has been changed from nuclear physics to solid state physics [2]. To get higher intensities in the energy range between 2 to 6 MeV/u, the tandem injector will be replaced by a combination of an ECR ion source on a 200 kV platform and a VE-RFQ, to meet demands from solid state physics users. The combination will accelerate the ions to energies between 0.09 and 0.36 MeV/u to cover the range of final energies out of the cyclotron between 1.5 and 6 MeV/u.

II. THE VE-RFQ-STRUCTURE

In a Radio Frequency Quadrupole (RFQ) structure [3,4] acceleration is achieved by a geometrical modulation of quadrupole electrodes leading to axial components of the field.

The fixed velocity profile is typical for RFQs. It can only be changed by varying the cell length L or the frequency f. The second possibility of changing the Wideröe [5] resonance condition: $L = ß_p\lambda_0/2 = v_p/2f$, is the way which has been used for RFQs with variable energy (VE-RFQ) [6]. For this reason it's possible to change the output energy using the same electrode system by varying the resonance frequency of the cavity: $v_p \sim f$, $T \sim v_p^2$.

To change the frequency of the 4-Rod-RFQ, a type of RFQ resonator developed in Frankfurt [7], the resonator can be tuned capacitively or inductively. Figure 2 shows the latter way of tuning by a movable tuningplate, which varies the effective length of the stems.

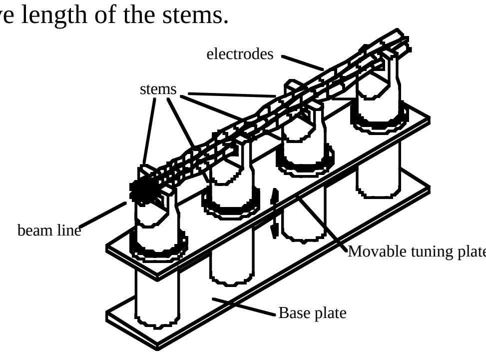

Fig. 2 Scheme of the VE-RFQ

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 in Lyon (France) [8,9]. It is designed for E_{in}=10 keV/u and an output energy between E_{out}=50 keV/u and E_{out}=100 keV/u for m=50u.

Based on the positive experiences of this project, a first combination of an ECR ion source with an VE-RFQ has been built for the IKF Frankfurt. The VE-RFQ structure is designed for a minimum specific charge of q/A=0.15, an output ion energy of E_{out}=100-200 keV/u, a maximum electrode voltage of 70 kV and has a structure length of 1.5 m.

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III. RFQ AS CYCLOTRON-INJECTOR

A first proposal to use an RFQ to improve the axial injection system of a compact cyclotron was made by Hamm [10]. To inject in a Separated Sector Cyclotron, the RFQ has to provide a bunched beam at a well defined injection energy given by the inner radius of the SSC. The operating frequency of the RFQ must be synchronised with the cyclotron frequency, which for RFQs normally means a fixed output energy per nucleon, which would match to fixed energy cyclotrons. To keep the energy variability of the cyclotron it's necessary to have an injector which has also a variable energy and frequency. VE-RFQs have a fixed ratio of output to input energy given by the length of the first and last modulation cell. This is similar to the energy gain factor of a SS-Cyclotron which makes them well suited as injectors [11]. To cover the energy range of 1.5-6 MeV/u the injection energy E_{in} of the ISL must be between E_{in}=90 keV/u and E_{in}=360 keV/u, at cyclotron frequencies of 10 to 20 MHz.

The new injector consisting of an ECR-source and a VE-RFQ has to fit into the existing tandem beam line. To stretch the energy range the RFQ will be split into two RFQ stages. Each stage with a length of 1.5 m consists of a ten stem 4-Rod-RFQ-structure. With a rf-power of 20 kW per stage an electrode voltage of 50 kV is possible. In the first mode of operation both RFQs accelerate, the output energy of the cyclotron is between E_{out}=3 MeV/u and E_{out}=6 MeV/u with a harmonic number of 5 for the cyclotron. There are two possibilities for the low energy beam mode, where the RFQ_2 works as a transport channel. RFQ_1 accelerates while the frequency of RFQ_2 is detuned. The second possibility is that RFQ_2 has the same frequency as RFQ_1, but is detuned in phase. In this mode the energy range of the cyclotron is between E_{out}=1.5 MeV/u and E_{out}=3 MeV/u. The cyclotron works on the harmonic number 7. In both modes the RFQs are tuned to the eighth harmonic of the cyclotron frequency. A overallview of the ECR-RFQ-Cyclotron complex is shown in figure 3, characteristic data are given in table 1.

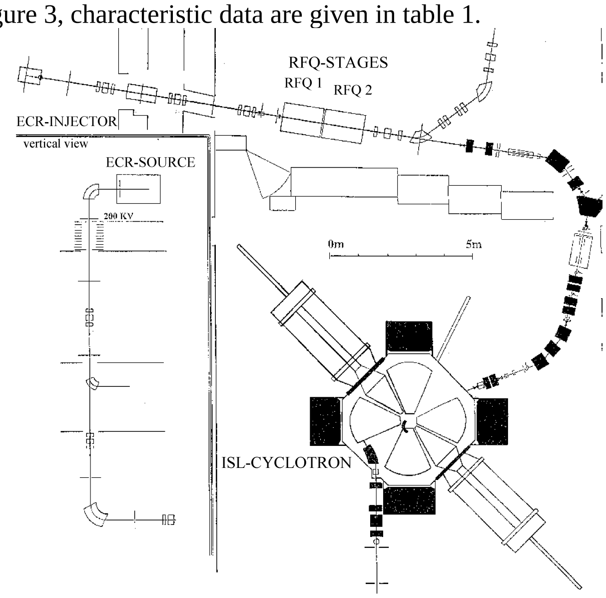

Fig. 3 Overallview of the cyclotron with the new injector

RFQ:	
min./max. E_{in}	15.16/29.72 [keV/u]
min./max. E_{out} RFQ 1	90.98/178.35 [keV/u]
min./max. E_{out} RFQ 2	178.35/355.09 [keV/u]
Energy gain factor RFQ 1	6
Energy gain factor RFQ 2	1.96
charge-to-mass-ratio	1/8-1/4
Frequency	85-120 [MHz]
Electrode voltage (max.)	50 [kV]
Length/diameter	3/0.5 [m]
Cyclotron:	
K-factor	134 [MeV]
Injection radius	0.43 [m]
Extraction radius	1.8 [m]
Rf-frequency	10 to 20 [MHz]
max. dee-voltage	140 [kV] (peak)
energy gain factor	16.8-18.6
Harmonic number H	2 to 7

Table 1: Main accelerator parameters

The RFQ-output emittance depends largely on the input conditions. For matched input beams with $\Delta E/E$ < 1,5 %, normalised emittance $\varepsilon_n < 0.5\ \pi$ mm mrad and a bunch length Δt < 1 ns a transmission of 100 % is expected. To reach this beam quality it's necessary to have a buncher-chopper system between the ECR and the RFQs [12].

The ECR-source is mounted on the 200 kV platform, formerly used for the tandem. The vertical beam is bent 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.

IV. BEAM DYNAMICS

The beam dynamic calculations were made with the code PARMTEQ. Figure 4 shows results for the first mode of operation, both RFQs accelerate, at a frequency of 120 MHz, with rms-emittances.

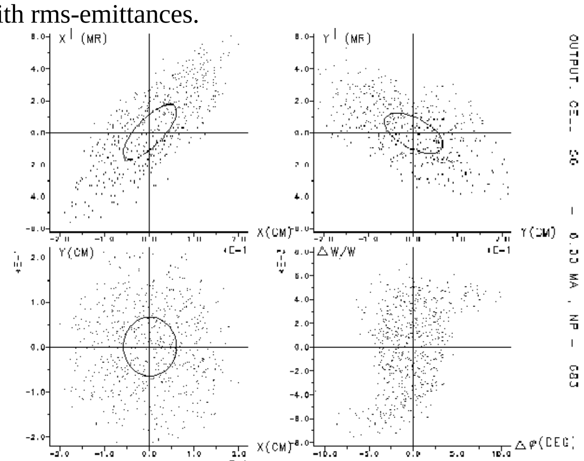

Fig. 4 Output beam, both RFQs accelerate

In the low energy beam mode the two possibilities of transportation through RFQ_2 were investigated. With RFQ_2 detuned in frequency, there is no stable phase relation between RFQ_1 and RFQ_2. Therefore all the minimum and maximum energies shown in figure 5a are possible. Figure 5b shows the region (arrow) with a proper phase for the possibility with RFQ_2 detuned in phase. The figures show E_{out} as a function of the input phase of RFQ_2. The output beam with $\Delta\varphi$=65° is shown in figure 6.

V. STATUS AND SCHEDULE

At present the RFQ-design is being optimised, especially the low energy beam mode. The mechanical design of the RFQ-tank is done, the details of structure support stems and electrode cooling are fixed (see figure 7).

The RFQ-system is being manufactured by NTG [13]. First tests are scheduled for December 1995.

VI. REFERENCES

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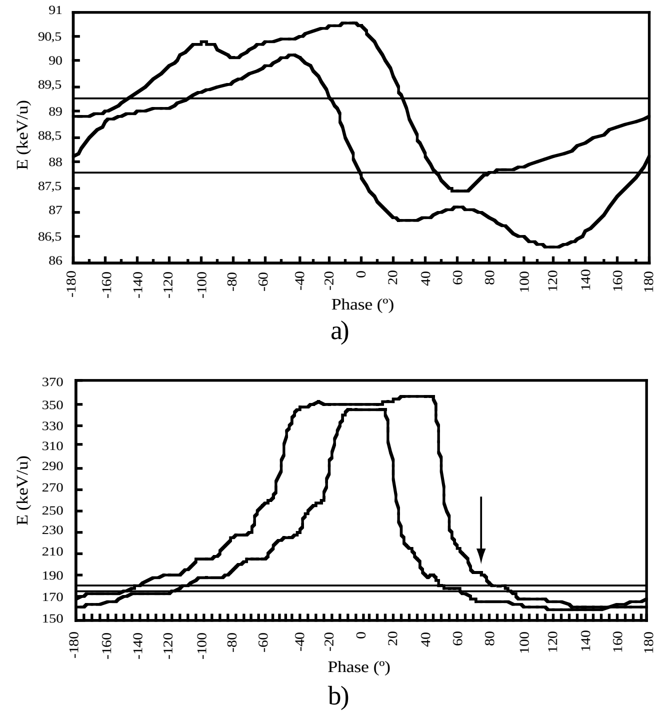

Fig. 5 E_{out}-Phase, a) F_{RFQ1} =85 MHz, F_{RFQ2}=120 MHz, b) F_{RFQ1} = F_{RFQ2}= 120 MHz

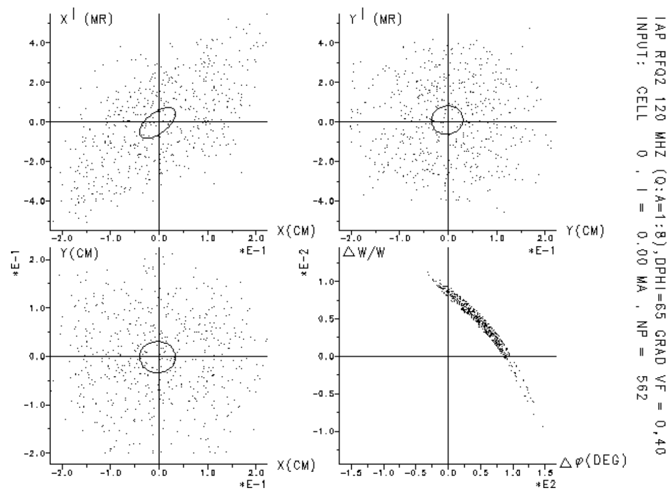

Fig. 6 Output beam, second RFQ detuned in phase

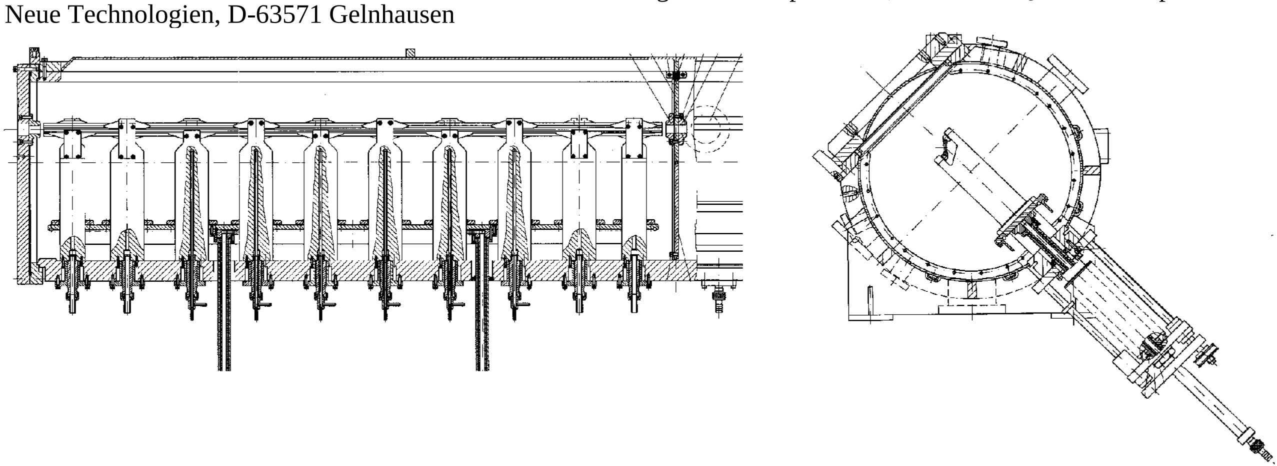

Fig.7 View of the first RFQ stage