The RFQ-Accelerator for the High Current Injector of the TSR

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Abstract

As a part of the new High Current Injector of the Heidelberg Test Storage Ring TSR a four-rod RFQ-accelerator is under construction. The RFQ is designed for acceleration of intense singly charged ion beams like $^6Li^+$, $^7Li^+$ and $^9Be^+$ needed for laser cooling experiments at the TSR. The RFQ is also capable of accelerating highly charged heavy ions with a specific charge of $q/A \geq 1/9$. For the design output energy of 0.5 MeV/u an accelerator structure length of 6 m is needed, which will be realized by combining two individual resonator tanks. In order to reduce beam losses at the entrance of the second resonator the drift length between the resonators had to be minimized. The operation frequency of 108.48 MHz is equal to the frequency of the 7-gap resonators and the existing post accelerator. For a maximum interrod voltage of 71 kV a rf power of 80 kW per resonator (duty cycle 25%) is needed. The general features and the present status are described in this paper.

1 INTRODUCTION

The accelerator facilities at the Max-Planck-Institut für Kernphysik in Heidelberg will be upgraded by a new high current injector [1][2], which is under development. It consists of a CHORDIS ion source [3] for the production of intense ion beams with low charge states, a RFQ-accelerator, which works as a pre-accelerator for the low velocity ions and a short linac with eight 7-gap resonators [4]. Later an ECR source can be added for the production of heavy ion beams.

Radio Frequency Quadrupole (RFQ)-accelerators [5] are the favoured structures to accelerate intense ion beams at low energies. The rf quadrupole field generates a transverse focusing force, so that space-charge dominated beams can be handled with a large transverse acceptance. Adiabatic bunching of the injected dc-beam and efficient acceleration is achieved by suitable modulation of the electrodes.

A four-rod structure [6] has been chosen for the RFQ-accelerator of the new injector. As shown in fig. 1 it consists of an arrangement of stems and circular electrodes. Thus the resonance structure is a chain of capacity loaded $\lambda/2$ oscillators. The eigenfrequency of the resonator and the flatness of the electrode voltage along the rods can be adjusted by choosing the proper thickness of copper plates located between the stems.

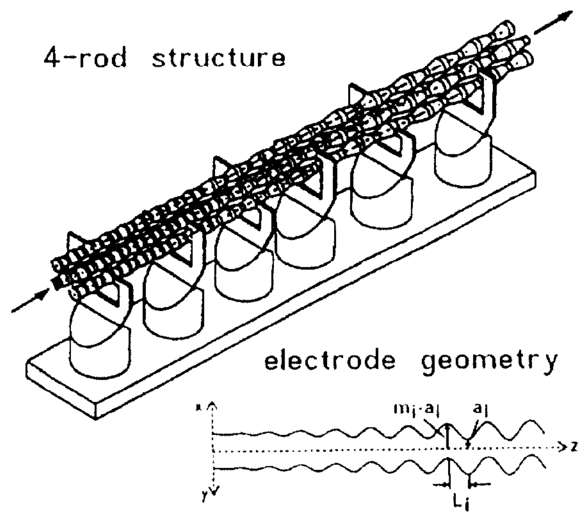

Figure 1: *Schematic view of a four-rod RFQ-accelerator and the electrode modulation parameters* [7], *a: aperture, m: modulation factor, l: length of cell.*

2 RFQ DESIGN

The RFQ is designed to accept ions with an energy of 4 keV/u and a specific charge of $q/A \geq 1/9$. The output energy of 0.5 MeV/u matches the beam to the following 7-gap resonator [4]. The operating frequency of 108.48 MHz is equal to the frequency of the other accelerating components of the injector.

The desired properties are obtained with a 6 m long accelerator structure for a maximum interrod voltage of 71 kV (1.4× Kilpatrick limit). The RFQ is divided into two independent resonator tanks to simplify the manufacturing of the vacuum chambers. The geometrical as well as the rf properties of each tank are similar to the GSI HLI-RFQ [8], so no model studies are required. A rf power of 80 kW is necessary, if a quality factor comparable to the GSI HLI-RFQ can be assumed. With the existing rf generators a rf power of 80 kW at a duty cycle of 25% or up to 20 kW in cw-mode can be supported. The design parameters of the RFQ-accelerator are listed in table 1.

Table 1: *Characteristic parameters of the RFQ*

RFQ tank no.	1	2
input energy E_i/A	4 keV/u	250 keV/u
output energy E_a/A	250 keV/u	500 keV/u
specific charge q/A	$\geq 1/9$	
length of tank L	300 cm	
inner diameter D	32 cm	
modulation period $\beta\lambda$	8...64 mm	64...96 mm
aperture a	5...3.1 mm	3.1...2.8 mm
frequency f	108.48 MHz	
power consumption P	80 kW	
electrode voltage U_0	71 kV	
duty cycle	25%, 50 Hz	
acceptance (norm.) ϵ_N	0.5 π mm mrad	
energy spread $\Delta T/T$	$\pm$ 0.5%	
pulse length $\Delta\phi$	$\pm$ 20°	

The mechanical design of the vacuum chambers was done inhouse. As shown in fig. 2 there is a large top lid, which allows an easy installation of the resonance structure. The vacuum tanks were machined from two stainless steel tubes of 32 cm diameter, 3 m length and 27.5 mm wall thickness specially manufactured for our purposes. The copper plating will be done soon at the GSI Darmstadt.

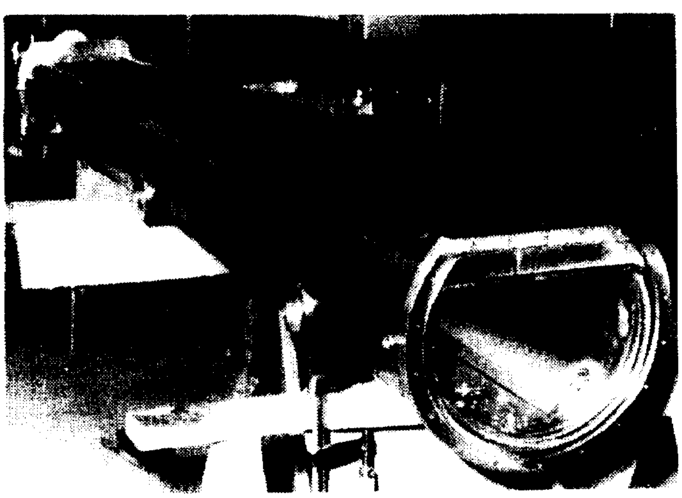

Figure 2: *View of a RFQ vacuum chamber*

Fig. 3 shows parts of the vacuum chambers and the resonance structure at the connection of the two RFQ-resonators. The ion beam is directly injected from the first into the second resonator. Because of the divergence of the beam at the exit of the first resonator the drift length between the electrodes must be as short as possible. The vacuum chambers are directly bolted, therefore the drift length could be limited to 8 cm. Beam diagnostic elements like scrapers can be mounted inside the shieldings, which seperates the resonators electrically.

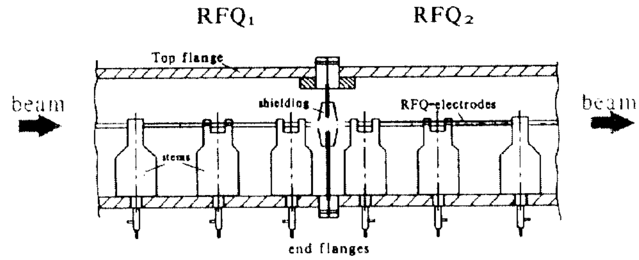

Figure 3: *Connection of the two RFQs*

The interrod voltage U_0 as well as the aperture a and the modulation parameter m determines the focusing strength, whereas the cell length is dominated by the synchronous phase φ_s and the ion velocity β. Generally a RFQ contains 4 sections, i.e. radial matcher, shaper, gentle buncher and the acceleration section. A special design method [9] already used for several RFQ-linacs – for example the GSI HLI-RFQ [8] – allows a reduction of the total length. The method is characterized by a fast increase of the modulation m and the synchronous phase ϕ in the buncher section without use of a shaper. The design parameters of the GSI HLI-RFQ has been adapted to the properties of the first resonator tank of the RFQ. The second tank is mainly used for acceleration. Adjustments were done in the entry section of the second tank to compensate the time spread increase of the beam after the drift. Also a radial matcher section is used for transversal matching of the beam into the second resonator. The voltage between the rods was assumed to be 71 kV. In fig. 4 the design parameters along the axis of the RFQ structure are shown.

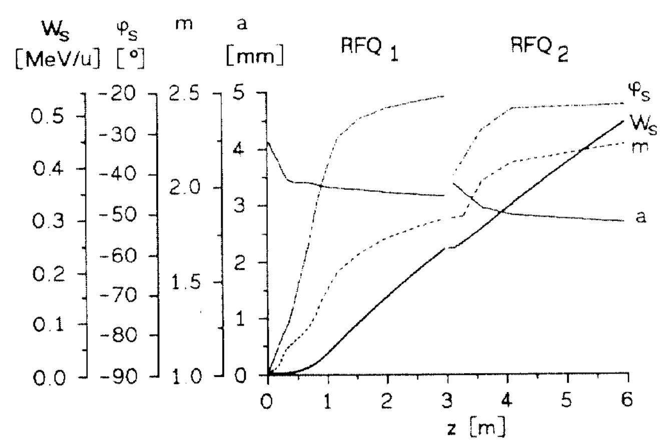

Figure 4: *Electrode parameters along the RFQ*

3 BEAM DYNAMIC CALCULATIONS

Fig. 5 shows the results of the calculations with the PARMTEQ code [10]. For a matched beam and the design emittance of 100 π mm mrad at 4 keV/u (norm. emittance ϵ_N = 0.3 π mm mrad) the transmission is 80% at an increase of the normalized emittance ϵ_N of 1.4 for the full beam.

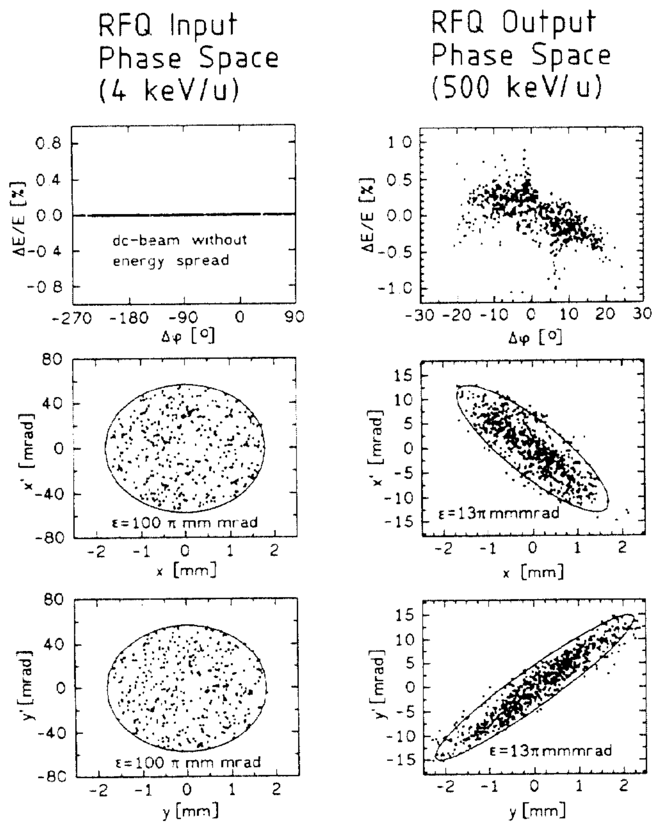

Figure 5: *Input and output emittances*

To minimize the beam divergence at the exit of the first tank and to optimize the beam matching between the two resonators, two cells at the end of the first tank and two cells at the entrance of the second tank has been modified. Fig. 6 shows the influence of this matching section on the transversal beam trajectories. Additional calculations with the 3-D code MAFIA are planned to investigate the influence of fringe field at the ends of the electrodes.

4 OUTLOCK

The design of the RFQ is nearly finished. Assembly and tuning of the rf structures are scheduled for the end of August this year.

5 ACKNOWLEDGEMENT

The ingenious design work of the technicians of the MPI Heidelberg is gratefully acknowledged.

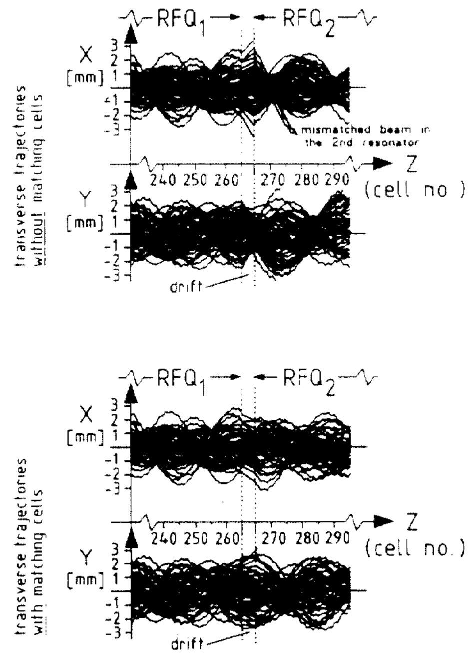

Figure 6: *Transversal beam trajectories with and without matching cells between the RFQ-tanks*

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