PROPOSAL OF A 325 MHz LADDER-RFQ FOR THE FAIR PROTON-LINAC *

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Abstract

Within the scope of the research programm with cooled antiprotons at FAIR a new proton Linac is proposed and beeing designed. The currently operating injectors HLI and HSI are especially designed for high mass to charge ratios but do not deliver enough beam current for the operation with protons, which necessitates a new beam injector optimized for protons. In the low energy section a new RFQ has to be designed working at a frequency of 325 MHz and at an rf duty factor up to $2 \cdot 10^{-3}$. It will accelerate protons from 95 keV to 3 MeV. Basically there are three design options for the RFQ. A 4-Rod, a 4-Vane and a Ladder-type RFQ, which is discussed in this paper. First of all it has neglectable dipole components. The ratio between the electic dipole and quatrupole field is lower than one percent [1]. Furthermore the manufacturing at reasonable costs and production time looks promising. In the following the new layout both from a mechanical and manufacturing point of view as well as a RF tuning concept are shown.

INTRODUCTION

The idea of the Ladder-RFQ firstly came up in the late eighties [2, 3] and was realized successfully for the CERN Linac3 operating at 101 MHz [4] and for the CERN antiproton decelerator ASACUSA at 202 MHz [5]. Within the 4-ROD design the challange is to minimize dipole components and to have geometrical dimensions which are suitable for a mechanical manufacturing and assembling. At frequencies above 250 MHz the 4-Vane-type RFQ is used so far. Many versions for low and high duty factors have been realized successfully until now. Draw backs are the high costs per meter, the compplexity oas well as the challenging RF tuning procedure of that structure: The dipole modes tend to overlap with the quadrupole mode. Safe beam operation conditions are resulting in ambitions mechanical vane tolerances. In the proposed ladder-RFQ version, the stems show an extended height which increases the resonance frequency and which results in an homogeneous current flow towards the mini-vanes. The mini-vanes are embedded via precisely machined carrier rings into the copper shells (see fig.2). To proof the mentioned advantages and realizability of the Ladder RFQ a prototype was designed and beeing built. The result are shown in this paper.

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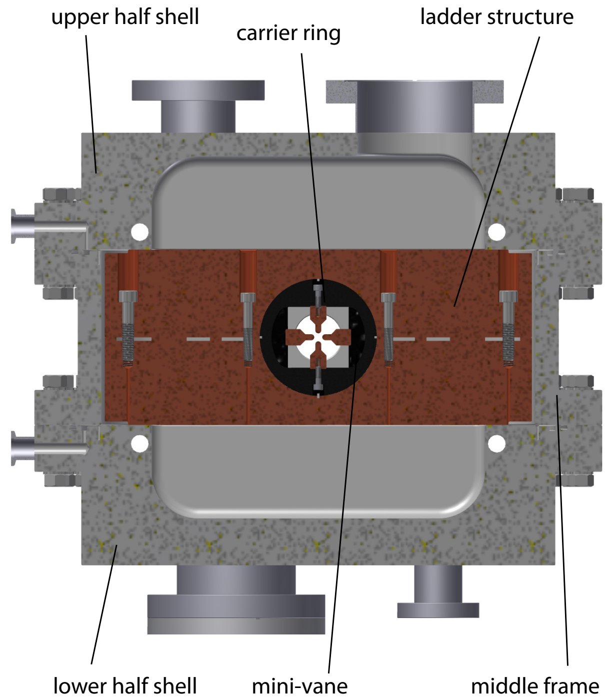

Figure 1: Sectional view through the ladder-structure. The copper carrier-rings (for a better view coloured in black) guarantee the electrode positioning as well as the RF contact.

MECHANICAL LAYOUT

The mechanical design consists of an inner copper ladder structure mounted into an outer stainless steel tank. The tank is devided into a base plate carrying the resonating inner structure, an intermediate part and the cover plate. The base will carry and adjust the position of the resonating structure. Furthermore its task is to provide a vacuum at the level of 10^{-8} mbar. The rf is mainly determined by the resonating structure, while the dimensions of the tank have no significant influence to the frequency.
To lower the wall losses it is foreseen to copperplate the lower and upper half shells. The inner resonating structure consists of two symmetric half shells (see fig.4) made of massive copper. They press and grout the carrier-rings in between. The diameter of the precisely thrilled hole will be slightly shmaller than the carrier-rings ensuring an optimal rf-contact. Both half shells have significantly reduces contact surface areas to imporve the pumping speed and the

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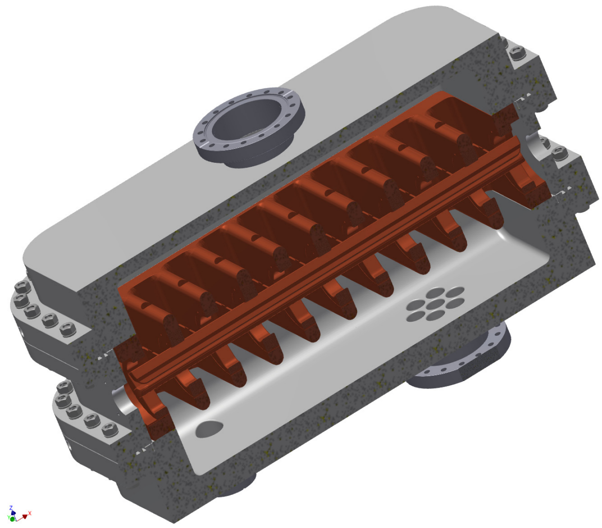

Figure 2: Isometric drawing of the Prototype RFQ. The ladder structure consists of bulk copper components. Any brazing or welding processes are avoided.

operating pumping pressure. Indium seelings between the tank and the copper-structure provide a good heat and rf contact.
The mini-vanes are screwed onto the carrier-rings (see fig.3). This design guarantees a simple and precise assembling as well as access onto the mini-vanes for maintenance. It is even possible to exchange the ring-mini-vane-structure completely by an improved system as demonstrated succdessfully at the GSI High Current RFQ [7]. Guide pins between the rings and the lower structure prevent a contortion of the ring system and ensure

Figure 3: 3D view of the carrier-ring.

To reach the desired frequency of 325.224 MHz the following strategy will be applied: In the first production step the inner copper structure is machined with a reduced ladder width. That results in a decreasing inductance and respectively a higher frequency. The next step is to compare the measured frequency with the simulation. In a second machining step the wight is increased accordingly, to obtain a frequency slightly below 325.244 MHz. The last step is the fine tuning with plungers (see chap. Tuning) to match the exact frequency.

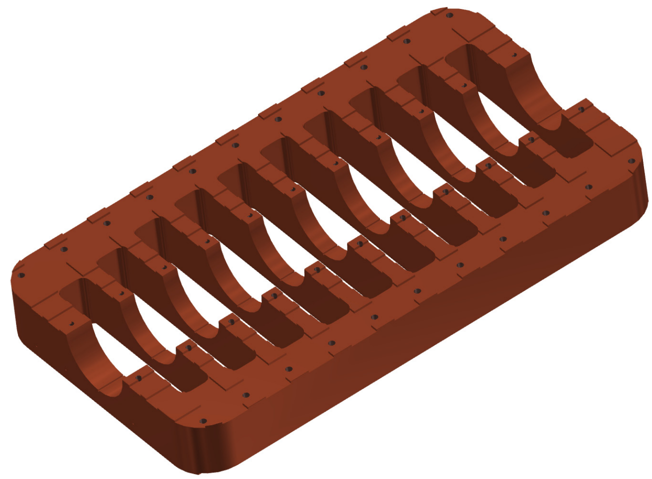

Figure 4: Isometric view of the lower copper shell.

The water cooling is provided by water channels around the lower and upper half shell. The simulation have shown that, due to the low duty factor of just 2/1000, the total thermal losses over the total length of 700 mm are 20 W. As a consequence a direct water cooling of the ladder stems or mini-vanes can be avoided. The temperature difference between the mini-vanes and the copper shells is expected to stay well below 1 K, thus guaranteeing the mini-vane alignment during operation.

RF DESIGN

Based on the parameters resulting from the beam dynamics [8], such as aperture, vane radius and intervane voltage, the ladder sizes were adjusted to match the frequency of 325 MHz. The results are shown in tab.1 for the prototype cavity which has no electrode modulation.

Simulations have shown that a width variation of the outer three ladder widths is sufficient to flatten the electric field distribution. This is also true for the original RFQ structure with an expected length slightly above 3 m. After the completion of the prototype the simulations will be compared with the bead pull mearsurements.

TUNING

The dynamic tuning of the frequency will be realized by two motor driven plungers in the second (see fig.6) and ninth cell. Displacing the magnetic field leads to an increase of the frequency due to the slater theory of pertubated fields. Fig.6 shows the functionality of the tuner penetrating a cell. With

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Table 1: Main Parameters of the Prototype Ladder RFQ

No. of cells	10
Q Value (sim.)	7200
Loss (cw,calc.)	100 kW
Thermal Loss (calc.)	200 W
Shunt Impedance (calc.)	40 kΩm
Voltage	80 kV
Frequency	325.224 MHz
Pepetition Rate	4 Hz
Pulse Duration	50 μs
Cell Length	40 mm
Ladder Thickness	20 mm
Ladder Clear Width	285 mm
Ladder Height	150 mm
Aperture	3.42 mm
Vane Radius ρ	2.56 mm
Vane Length	630 mm

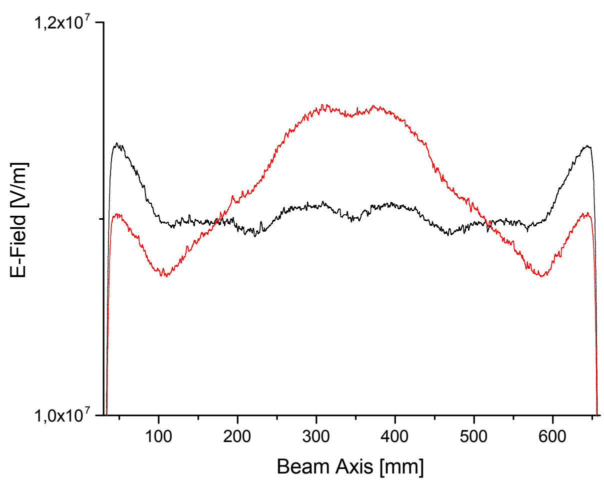

Figure 5: Simulated electric quadrupole field distribution along the beam axis. The red curve shows the distribution with 10 identical ladder cells and the black curve after the adjustment of the width of the end cells. The maximum relative difference of the electric field can hereby be optmized to less than 5%.

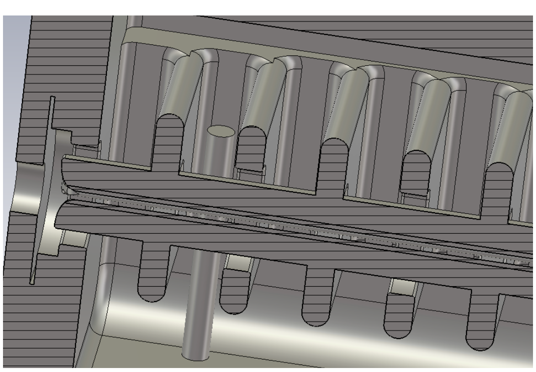

Figure 6: Inductive plunger penetrating the second cell.

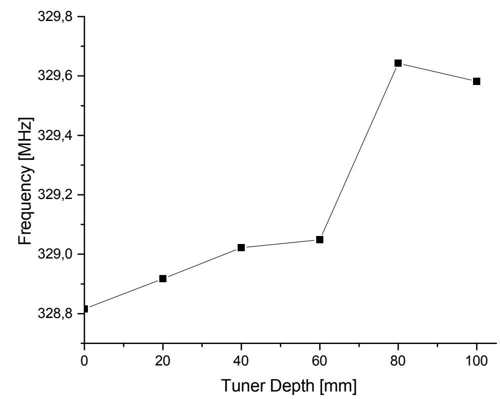

Figure 7: Frequency in dependence of the penetration depth of both parallel driven plungers into cell two and nine.

this method it is possible to vary the resonance frequency over a range of 800 kHz (see fig.7).

CONCLUSION

It was shown that the Ladder-RFQ seems to be a good candidate for the acceleration of protons, at typical frequencies above 250 MHz. Simulations showed that a comfortable tuning and the achievement of a flat voltage distribution áre possible.

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