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DEVELOPMENT OF A 325 MHz LADDER-RFQ OF THE 4-ROD-TYPE*

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Abstract

For the research program with cooled antiprotons at FAIR a dedicated 70 MeV, 70 mA proton injector is required. In the low energy section, between the Ion Source and the main linac an RFQ will be used. The 325 MHz RFQ will accelerate protons from 95 keV to 3 MeV. This particular high frequency for an 4-ROD type RFQ creates difficulties, which are challenging in developing this cavity. In order to define a satisfactory geometrical configuration for this resonator, both from the RF and the mechanical point of view, different designs have been examined and compared. Very promising results have been reached with a ladder type RFQ, which has been investigated since 2013 [1, 2]. We present recent 3D simulations of the general layout and of a complete cavity demonstrating the power of a ladder type RFQ as well as measurements of a 0.8 m prototype RFQ, which was manufactured in late 2014 and designed for RF power and vacuum tests. The prototype manufacturing was completed and first measurements are shown.

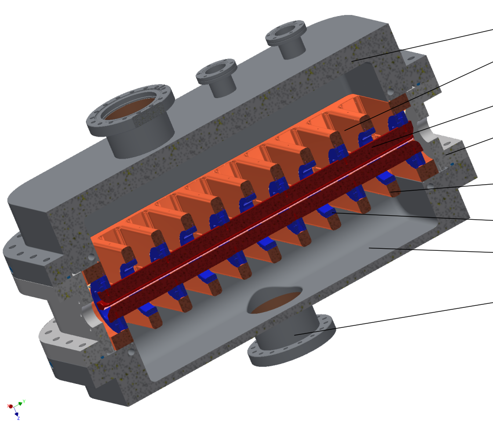

Figure 1: Isometric view of the Ladder-RFQ. The cooper carrier-rings (for a better view coloured in blue) guarantee the electrode positioning as well as the RF contact. The ladder structure consists of bulk copper components. Any brazing or welding processes are avoided.

INTRODUCTION

The idea of the Ladder-RFQ firstly came up in the late eighties [3,4] and was realized successfully for the CERN Linac3 operating at 101 MHz [5] and for the CERN antiproton decelerator ASACUSA at 202 MHz [6]. 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 complexity as well as the challenging RF tuning procedure of that structure: The dipole modes tend to overlap with the quadrupole mode. Safe beam operation conditions result in ambitious mechanical vane tolerances. In the proposed ladder-RFQ version, the spokes show an extended width 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 built. The results of the simulation and comparision with the measurement are shown in this paper.

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MECHANICAL LAYOUT

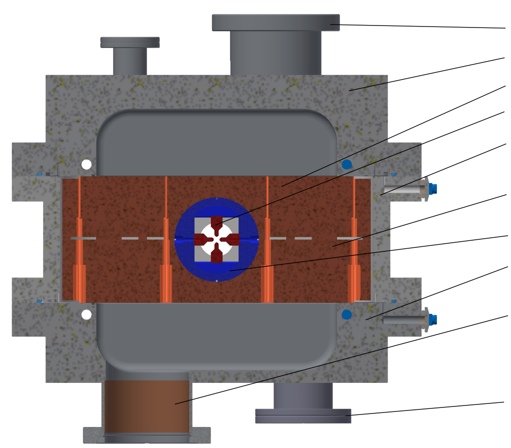

Figure 2: Sectional front view of the Ladder-RFQ.

The mechanical design consists of an inner copper ladder structure mounted into an outer stainless steel tank. The tank is divided into a base plate carrying the inner resonating structure, an intermediate part and the cover plate. The base will carry and adjust the position of the resonating structure. All parts are metal-sealed. 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 made of massive copper. They press and grout the carrier-rings in between. The

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diameter of the precisely thrilled hole is slightly shmaller than the carrier-rings ensuring an optimal rf-contact. Both half shells have significantly reduced contact surface areas (see Fig. 4) to improve the pumping speed and the operating pumping pressure. Indium seelings between the tank and the copper-structure provide a good heat and rf contact.

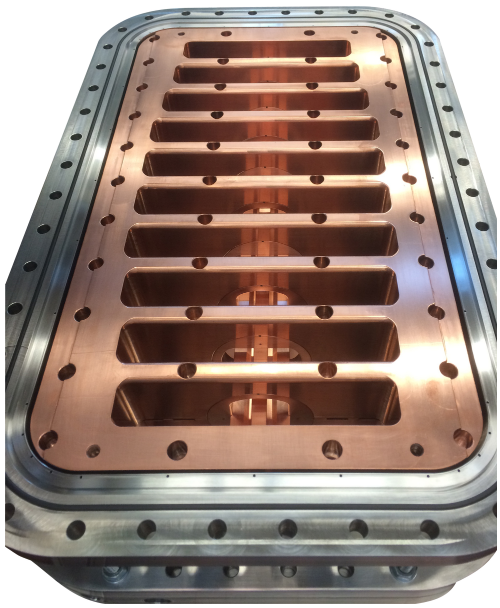

Figure 3: Photography of the Ladder-RFQ as-built. The upper steel-tank was removed for a better view on the inner ring-ladder structure.

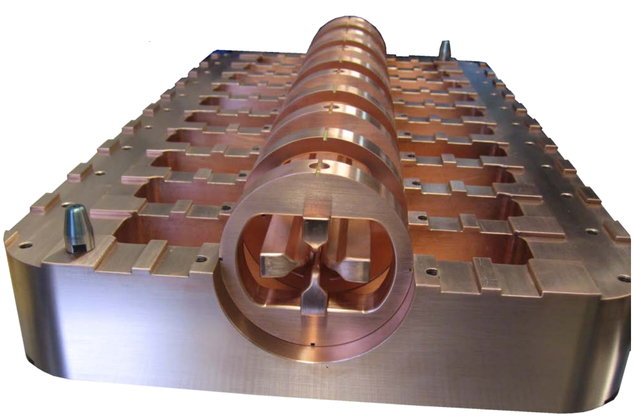

Figure 4: Front view of the Ring-System. The steel-tank and the upper half-shell are removed.

The mini-vanes are screwed onto the carrier-rings (see Figs. 3 and 4). This design guarantees a simple and precise assembling as well as access to the mini-vanes for maintenance. It is even possible to exchange the ring-mini-vane-structure completely by an improved system as demonstrated successfully at the GSI High Current RFQ [7,8]. Guide pins between the rings and the lower ladder prevent a contortion of the ring system.

Table 1: Main RF and Geometric Parameters of the Prototype Ladder RFQ

No. of cells	10
Q Value (sim.)	7200
Loss (cw,calc.)	94 kW
Thermal Loss (calc.) peak/av.	75 W
Shunt Impedance (calc.)	42 kΩm
Voltage	80 kV
Frequency	325.224 MHz
Pepetition Rate	4 Hz
Pulse Duration	50 µs
Cell Length	40 mm
Spoke Thickness	20 mm
Spoke Height	285 mm
Spoke Width	150 mm
Aperture	3.42 mm
Vane Radius ρ	2.56 mm
Vane Length	630 mm

MEASUREMENT RESULTS

Based on the parameters resulting from the beam dynamics [9], such as aperture, vane radius and intervane voltage, the ladder sizes were adjusted to match the frequency of 325 MHz (see Figs. 5 and 6). The results are shown in Table 1 for the prototype cavity which has no electrode modulation.

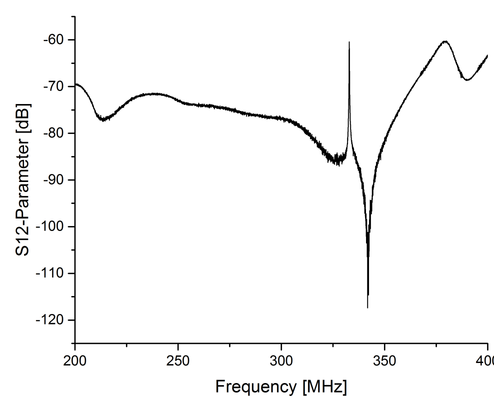

Figure 5: Measured frequency spectrum. The resonance is at 332.85 MHz. The simulated frequency was 332 MHz.

The frequency was designed to be slightly above 325.224 MHz. By comparing the measurement with the simulations it is possible to adjust and optimize the frequency as well as the field flatness in a following machining step by varying the ladder cell heights.

Simulations have shown that a variation of the clear height of the outer three cell heights 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. The measurement of the electric field distribution of the prototype complies with the simulations (see Figs. 7 and 8)

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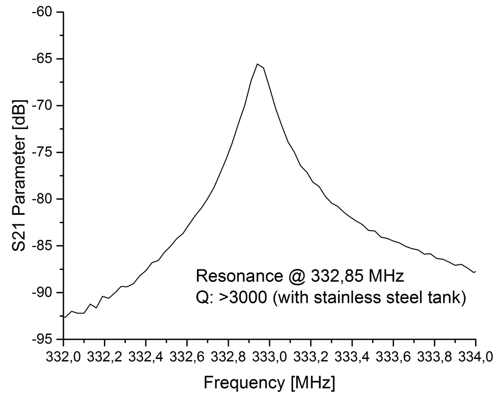

Figure 6: Measured spectrum of the resonant mode. The quality factor is 3000 and should increase after copper-plating of the steel-tank.

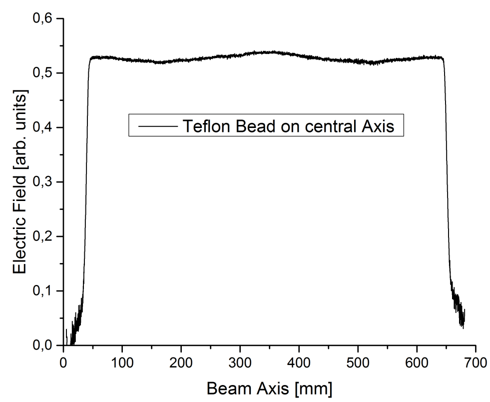

Figure 7: Bead pull measurement of the electric field distribution along the beam-axis. The teflon bead was pulled along the central beam-axis. The relative difference in the electric field is smaller than 4% and can still be reduced to be < 3% in the next and final mechanical treatment.

The final dynamic fine tuning of the frequency will be realized by two motor driven plungers in the second and ninth cell. Displacing the magnetic field leads to an increase of the frequency due to the slater theory of perturbed fields. With this method it is possible to vary the resonance frequency over a range of at least 800 kHz.

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. The measurements are in a good agreement with the simulations. A next important step are rf power measurements at the GSI klystron test stand.

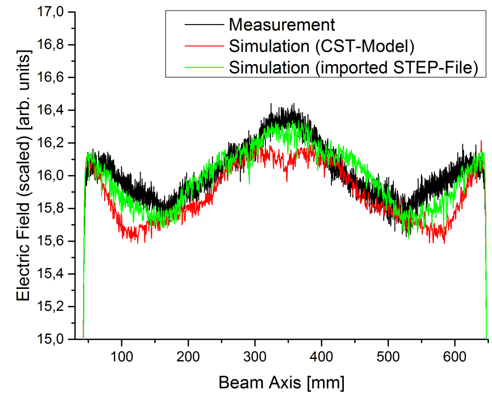

Figure 8: Comparision of the measurement of the electric field distribution (from Fig. 7) with the simulations of the model built with CST MWS and an imported CAD-Model.

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