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

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Abstract

In order to have an inexpensive alternative to 4-Vane RFQs above 200 MHz, we study the possibilities of a Ladder-RFQ. The 325 MHz RFQ is designed to accelerate protons from 95 keV to 3.0 MeV according to the design parameters of the p-Linac for the research program with cooled antiprotons at FAIR. Therefore 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 operated at 325.224 MHz. This particular high frequency for an RFQ creates difficulties, which are challenging in developing a cavity. In order to define a satisfying 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]. Due to its geometric size the manufacturing as well as maintenance is not that complex compared with brazed cavities. The manufacturing, coppering and assembling of a 0.8 m prototype RFQ has been finished. We present recent measurements of the rf-field, frequency-tuning, field flatness and the mode spectrum.

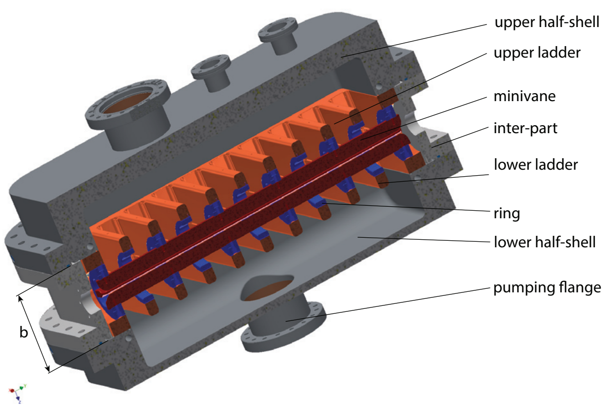

Figure 1: Isometric view of the Ladder-RFQ. The cooper carrier-rings (coloured in blue) guarantee the electrode positioning as well as the RF contact. The ladder structure consists of bulk copper components. Any brazing or welding processes were avoided on the copper structure.

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.

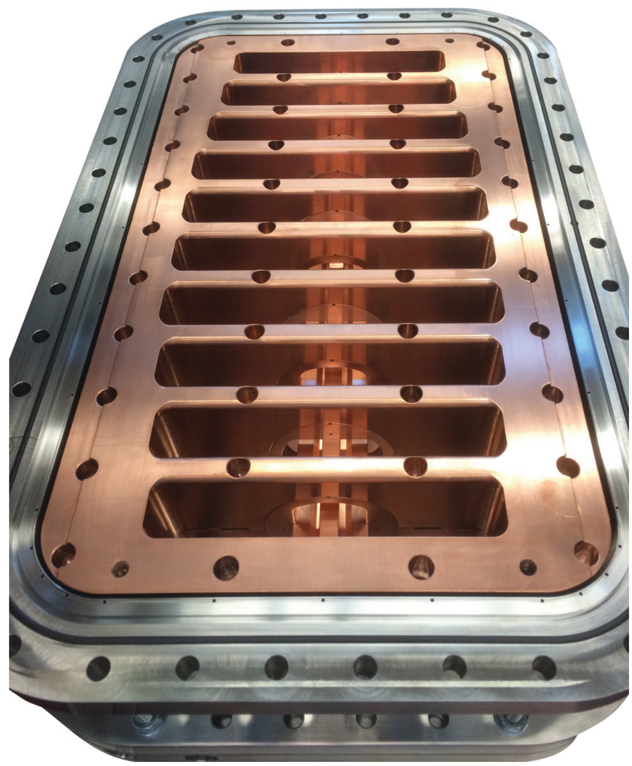

Figure 2: Photography of the Ladder-RFQ as-built. The upper steel-tank was removed for a better view on the inner ring-ladder structure.

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 ladder spokes show an extended width *b* 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. 1). It is even possible to exchange the ring-mini-vane-structure completely by an improved electrode system as demonstrated successfully at the GSI High Current RFQ [7, 8]. To proof the mentioned advantages and

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realizability of the Ladder RFQ a prototype was designed and built. The results of the measurements are shown in this paper.

MECHANICAL LAYOUT

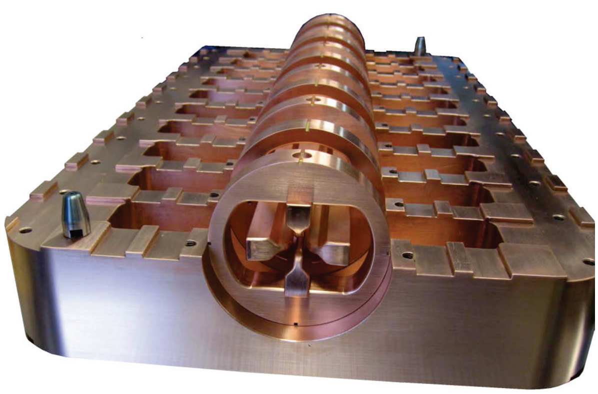

Figure 3: Front view of the Ring-System. The steel-tank and the upper half-shell are removed.

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 (see Figs. 2 and 3). The base will carry and adjust the position of the resonating structure. All parts are metal-sealed. The rf is mainly determined by the resonating structure, while the dimensions of the tank have no significant influence to the frequency. Further details of the mechanical layout can be seen in [9]. Based on the parameters resulting from the beam dynamics [10], such as aperture, vane radius and intervane voltage, the ladder sizes were adjusted to match the frequency of 325 MHz (see Figs. 4 and 5). The results are shown in Table 1 for the prototype cavity which has no electrode modulation.

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

No. of cells	10
Q Value (sim. / meas.)	7200 / 4600
Loss (measured Q)	160 kW
Thermal Loss (measured Q)	130 W
Shunt Impedance (sim. / meas.)	42 kΩm / 29 kΩm
Voltage	80 kV
Frequency	325.224 MHz
Pepetition Rate	4 Hz
Pulse Duration	200 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

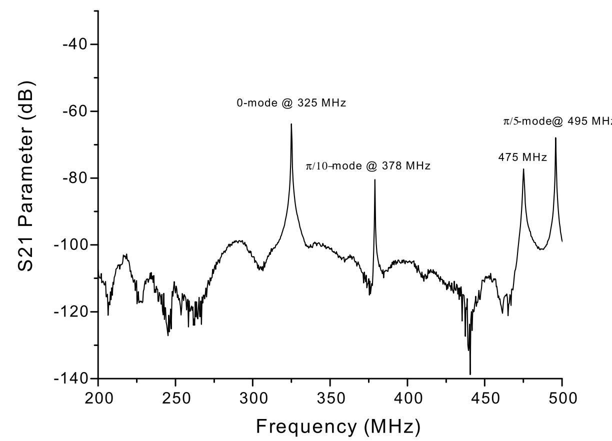

Figure 4: Measured frequency spectrum. The resonance is at 324.94 MHz resp. 325.04 MHz in vacuum after tuning.

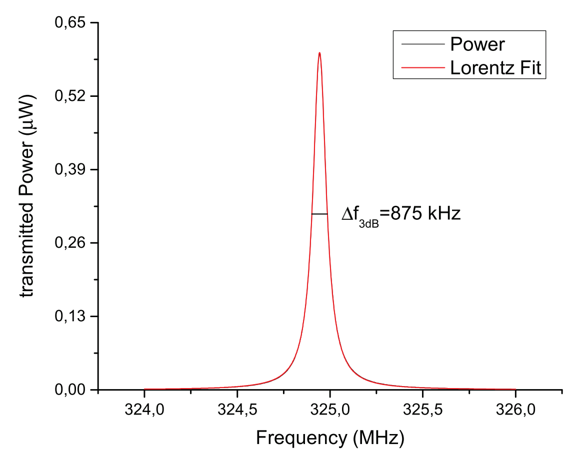

Figure 5: Measured spectrum of the resonant mode. The quality factor increased from 3000 to 4670 after copper-plating of the steel-tank.

The upper and lower half shell of the RFQ were copper plated until 12/2015. Fig. 4 shows the final frequency spectrum. Higher Order Modes, like the $\pi/10$-mode are at least 50 MHz apart from the operating 0-mode at 325 MHz. Simulations for a ladder structure with a length of 3 m have shown that the next higher order mode is still at least 4 MHz apart. The quality factor increased from 3000 [9] to 4670 after copper plating the upper an lower half shells of the tank (s. Fig. 5).After the adjustment of the height of each cell of the ladder rfq the flatness of the electric field could be minimised to a maxmimum deviation of 0, 4% (see Fig. 6) and even 0, 01% along 70% of the beam-axis. The dynamic fine tuning of the frequency will be realized by a motor driven plunger in the second and a static plunger in the ninth

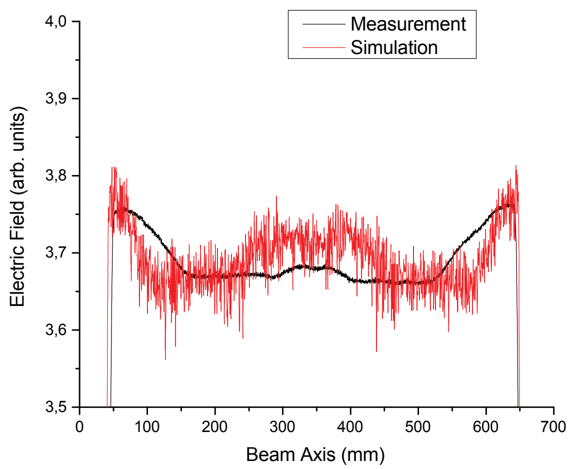

Figure 6: Comparision of the bead pull measurement of the electric field distribution along the beam-axis with the simulations of the model built with CST MWS. The maximum deviation of the electrode voltage is smaller than $\pm 0,4\%$.

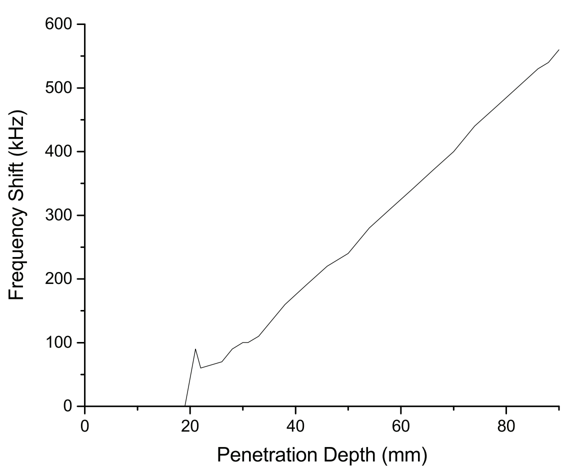

Figure 7: The RFQ is tuned with a static and a moveable motor plunger. The frequency shift is plotted in dependence of the penetration depth of the electrical plunger.

cell. Displacing the magnetic field leads to an increase of the frequency due to the slater theory of perturbed fields. Measurements showed that the frequency can be varied in a range of 560 kHz resp. from 325.14 MHz to 325.7 MHz (s. Fig. 7). Furthermore, the RFQ was tested with an RF power up to 380 W cw. The RFQ accepts the power and the vacuum remains in the 10^{-8} mbar range. Multipacting barriers could easily be overcome during the conditioning, which effectively took about 2 days. Afterwards the RFQ was tested up to 95 kW with 2 Hz and 200 μs at the GSI klystron test stand. The RFQ accepted this power level within a few hours without any propblems and we expect to reach the maximum power of 160 kW within two more days.

CONCLUSION

All measurements of the Ladder-RFQ such as frequency, tuning, field-flatness, vacuum are in good agreement with the simluation and it seems to be a good candidate for the acceleration of protons, at typical frequencies above 250 MHz. The next important step in the next weeks are rf power measurements up to 160 kW peak power.

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