DEVELOPMENT AND MEASUREMENTS OF A 325 MHz LADDER-RFQ*

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Abstract

In order to have an attractive 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 GSI-FAIR, Darmstadt, Germany. 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 operating 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, copper-plating and assembly of a 0.8 m prototype RFQ has been finished. We present recent measurements of the rf-field, frequency-tuning, field flatness as well as results from power measurements.

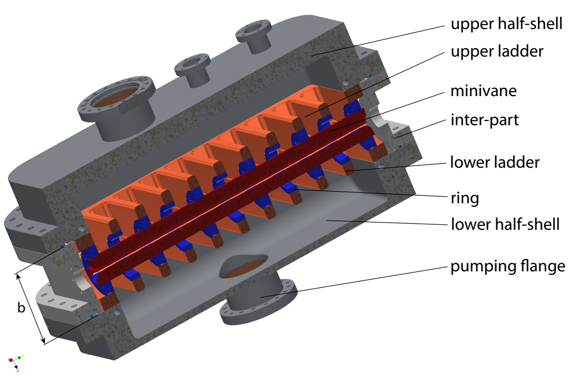

Figure 1: Isometric view of the Ladder-RFQ. The copper carrier-rings (coloured in blue) guarantee the electrode positioning as well as the RF contact. The ladder structure consists of bulk copper components. Any brazing or welding processes were avoided on the copper structure.

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.

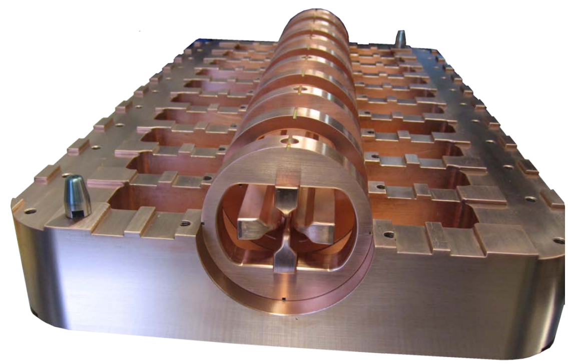

Figure 2: Front view of the Ring-System. The steel-tank and the upper half-shell are removed.

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 results in an homogeneous current flow towards the mini-vanes. The mini-vanes are embedded via precisely machined carrier rings into the copper shells (s. Fig. 2). 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 the realizability of the Ladder RFQ a prototype was designed and built. The results of the measurements are shown in this paper.

MECHANICAL LAYOUT

The mechanical design consists of an inner copper ladder structure mounted into an outer stainless steel tank. The tank is divided into a lower half-shell carrying the inner resonating structure, an inter-part and the upper half-shell (s. Fig. 1). The lower half-shell will carry and adjust the position of the resonating ladder structure. All parts are metal-sealed. The rf features are mainly determined by the resonating structure, while the dimensions of the tank have no significant influence on the frequency. Further details of the mechanical layout can be seen in [9]. Based on the

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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. 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

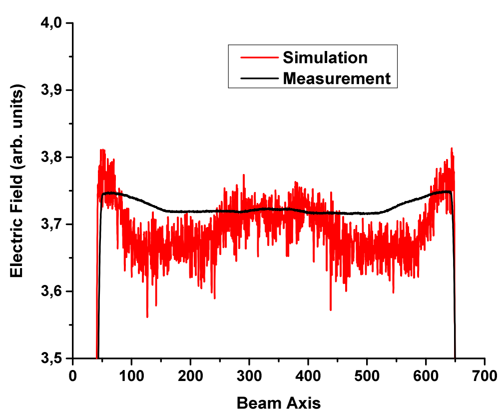

Figure 3: Comparision of the bead pull measurement of the electric field distribution along the beam-axis with the simulations of the model built with CST MWS. The maximum deviation of the electrode voltage is smaller than ±0, 4%.

The upper and lower half shell of the RFQ were copper plated until 12/2015. Measurements have confirmed that HOMs 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 (for details s. [11]). The quality factor increased from 3000 [9] to 4670 after copper plating the upper and lower half-shells of the tank. After the adjustment

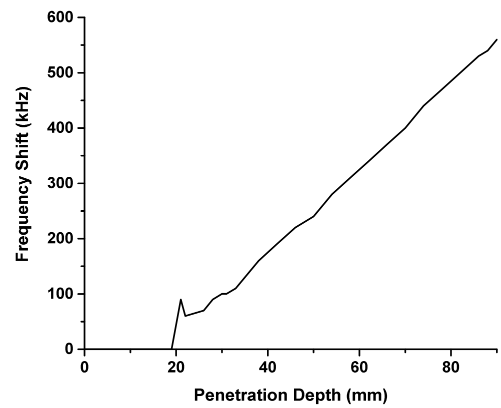

Figure 4: The RFQ is tuned with a static and a moveable motor plunger. The frequency shift is plotted in dependence of the penetration depth of the moveable plunger.

of the height of each cell of the ladder RFQ the flatness of the electric field could be minimised to a maximum deviation of 0, 4% (s. Fig. 3) 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 by a static plunger in the ninth 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. 4).

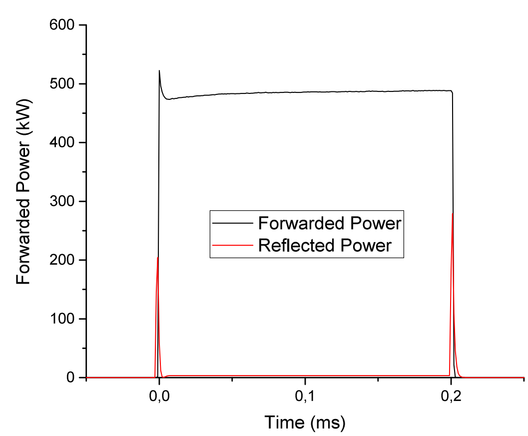

Figure 5: The forward power of 487 kW is shown in black. The RFQ accepted the power as the reflected power is stable along the flat top being lower than 3.34 kW. The RFQ is slightly over-coupled with $S_{11} = -15.6$ dB.

POWER MEASUREMENT

At the GSI 3 MW klystron test stand the RFQ was tested with a power up to 487 kW at a repetition rate of 2 Hz and a pulse duration of 200 µs (s. Fig. 5) [12]. This exceeds the

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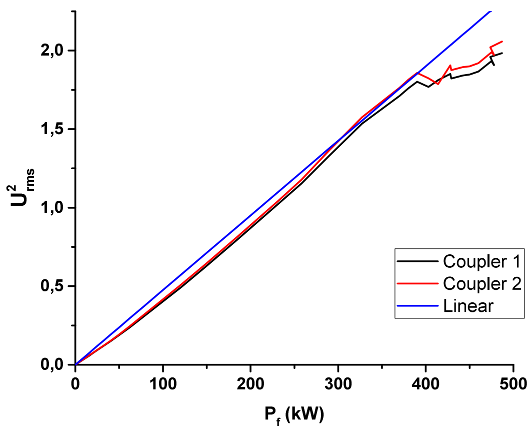

Figure 6: Stored energy of the RFQ in dependence of the forward power.

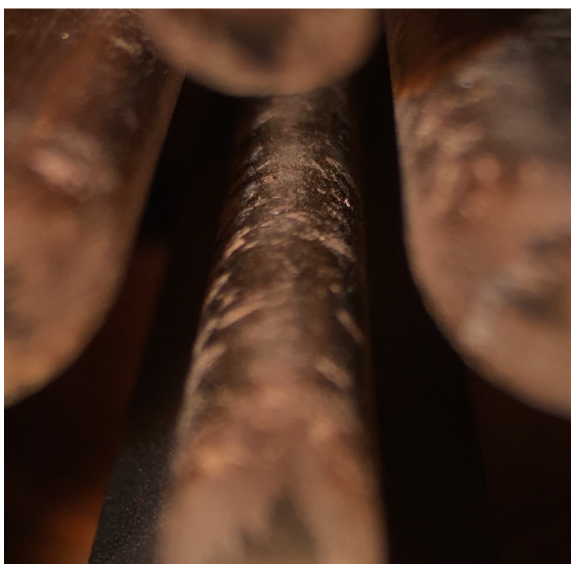

Figure 7: Photo of the electrodes after the power measurement. The surface is slightly discoloured yet it is still very smooth.

designed rf power at 80 kV of operation by a factor of three. The average power reached 192 W which is 50% more than the thermal loss during normal operation. The Kilpatrick factor was 2.8 compared to 1.6 under normal operation. As anticipated, the stored energy increases linearly with the forward power up to 400 kW. At higher energies up to 487 kW the stored energy begins to rise slower due to field emission (s. Fig. 6). During the measurements it could be clearly seen that more time for conditioning can reduce the dark current levels. In nine days of high power measurements the surface of the copper structures has changed its colour slightly but it is not damaged. The surface remained smooth and non abrasive (s. Fig. 7).

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. Based on this results, the next step is the designand construction of a full legth RFQ which will be tested with beam at GSI.

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REFERENCES

[1] R. Brodhage, U. Ratzinger, and Ali Almomani, "Design Study of a high frequency proton LADDER RFQ", in *Proc. IPAC'13*, Shanghai, China, p. 3788.

[2] M. Schuett, U. Ratzinger, and R. Brodhage, "Proposal of a 325 MHz Ladder-RFQ for the FAIR Proton-Linac", in *Proc. LINAC'14*, Geneva, Switzerland, p. 1016.

[3] A. Fabris, A. Massarotti, and M. Vretenar, "A Model of 4-Rods–RFQ", Seminar on New Techniques for Future Accelerators, Erice, Sicily, 1986, New York, Plenum, p. 265.

[4] M.J. Browman, G. Spalek, P.B. Friedrichs, and T.C. Barts, "Studies of the Four-Rod RFQ Using the MAFIA Codes", in *Proc. LINAC'88*, Newport, Virginia, p. 119.

[5] G. Bezzon, A. Lombardi, G. Parisi, A. Pisent, and M. Weiss, "Construction and Commissioning of the RFQ for the CERN Lead Ion Facility", in *Proc. LINAC'94*, Tsukuba, Japan, p. 722.

[6] Y. Bylinsky, A.M. Lombardi, and W. Pirkl, "RFQ - a Decelerating Radiofrequency Quadrupole for the CERN Antiproton Facility", in *Proc. LINAC'00*, Monterey, California, p. 554.

[7] U. Ratzinger, K. Kaspar, E. Malwitz, S. Minaev, and R. Tiede, "The GSI 36 MHz High-Current IH-Type RFQ and HIIF-relevant Extensions", *Nucl. Instr. and Meth.* A 415 (1998), p. 281-286.

[8] A. Kolomiets, S. Minaev, W. Barth, L. Dahl, H. Vormann, and S. Yaramyshev, "Upgrade of the UNILAC High Current Injector RFQ", in *Proc. LINAC'08*, Victoria, BC, Canada, p. 136-138.

[9] M. Schuett, U. Ratzinger, and R. Brodhage, "Development of a 325 MHz Ladder-RFQ of the 4-ROD Type", in *Proc. IPAC'15*, Richmond, USA, p. 3745.

[10] C. Zhang and A. Schempp, "Design of an Upgradeable 45-100 mA RFQ Accelerator for FAIR", *Nucl. Instr. and Meth.* A, 609(2009), p. 95-101.

[11] M. Schuett, U. Ratzinger, and C. Zhang, "Development of a 325 MHz Ladder-RFQ of the 4-ROD-Type", Proceeedings of IPAC2016, Busan, Korea, p. 899.

[12] G. Schreiber *et al.*, presented at LINAC'16, East Lansing, MI, USA, paper MOPLR067, this conference.