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FIRST RF MEASUREMENTS OF THE 325 MHz LADDER-RFQ

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Abstract

Based on the positive results of the 0.63 m unmodulated 325 MHz Ladder-RFQ prototype from 2013 to 2016 [1], a modulated 3.3 m Ladder-RFQ (see Fig. 1) has been designed and built. In this paper, we will show the results of manufacturing as well as first low level RF measurements of the Ladder-RFQ.

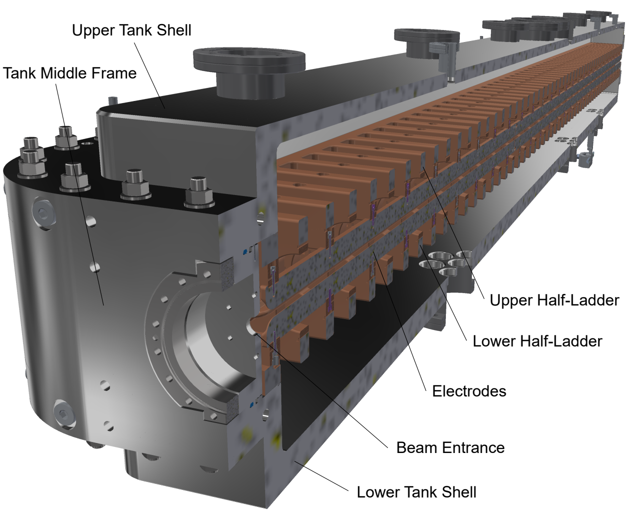

Figure 1: Isometric view of the 3.3 m modulated Ladder-RFQ. Copper carrier-rings guarantee the electrode positioning as well as the RF contact. The ladder structure consists of bulk copper components. Any brazing or welding processes were avoided for the assembly of the main components.

INTRODUCTION

The idea of the Ladder type 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].

Due to its high symmetry, this Ladder-RFQ features a very constant voltage along the axis. The Ladder-RFQ prototype was high power tested at the GSI test stand. It accepted 3 times the RF power level needed in operation [6]. That level corresponds to a Kilpatrick factor of 3.1 with a pulse length of 200 µs. The 325 MHz RFQ is designed to accelerate protons from 95 keV to 3.0 MeV according to the design parameters of the proton linac within the FAIR project. This particular high frequency creates difficulties for a 4-ROD type RFQ, which triggered the development of a Ladder-RFQ with its higher symmetry. The results of the unmodulated prototype have shown, that the Ladder-RFQ is a suitable candidate for that frequency. For the present design duty cycles are feasible up to 5%. The basic design and tendering of the RFQ has been successfully completed in 2016 [7]. Manufacturing of the large components has been completed in September 2018.

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

Parameter	Value
No. of RF cells	55
Q-Value (simulated)	6800
Loss (with sim. Q)	675 kW
Shunt Impedance (sim.)	45 kΩm
Vane-Vane Voltage	88.43 kV
Frequency	325.224 MHz
Repetition Rate	4 Hz
Pulse Duration	200 µs
Total Length	3410 mm
Cell Length	40 mm
Spoke Height	280 mm
Spoke Width	150 mm
Electrode Length	3327 mm

DESIGN AND MANUFACTURING

The mechanical design consists of an inner copper ladder structure mounted into an outer stainless steel tank. The tank is divided into three parts - the lower and upper shells and a middle frame.

The lower shell of the tank carries and fixes the position of the inner resonating ladder structure. Due to manufacturing reasons, the ladder structure is divided into two lower and two upper half-ladder elements, which are precisely aligned via guide pins. The half-ladders themselves are machined from solid copper blocks. Between the half-ladder elements, the electrodes are precisely fixed via carrier-rings [8]. Those carrier-rings furthermore guarantee a seamless RF connection between the electrodes and the ladder structure.

The RF features are mainly determined by the resonating structure, while the dimensions of the tank have no significant influence on the frequency. Based on the successful high power tests of the unmodulated prototype, we decided to develop a new beam dynamics for a vane-vane voltage of 88.4 kV [9]. For details of the final beam dynamics see [10]. The basic physical and mechanical parameters of the Ladder-RFQ results are shown in Table 1. Furthermore, the thickness of the tank walls inside the entrance and exit flange of the RFQ have been reduced to 10 mm within the flange diameter of 100 mm (CF100). That allows an integration of preceding and following components like a cone or steerer to reduce an emittance growth caused by an additional drift. The next step, beginning in 2019, is the development of

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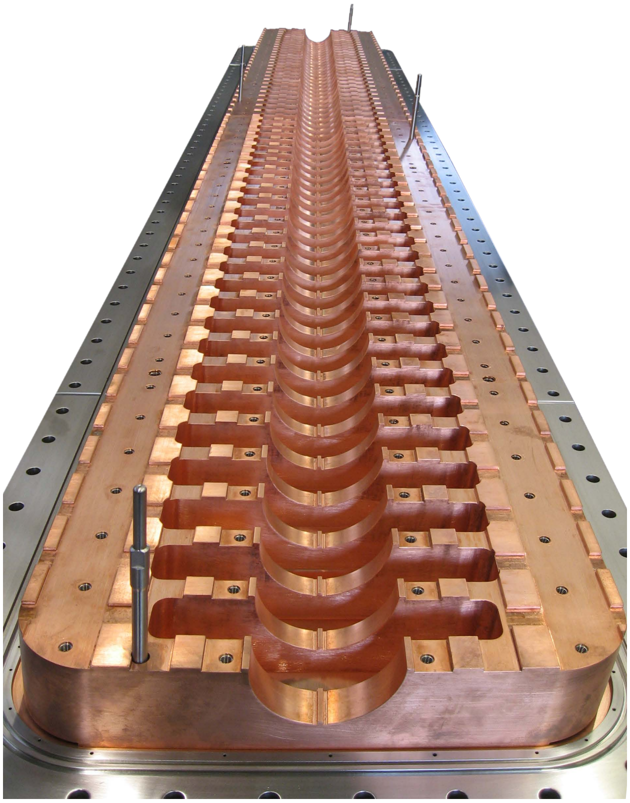

Figure 2: Lower half-ladder structure after finalization of surface treatment and assembly on the lower tank shell.

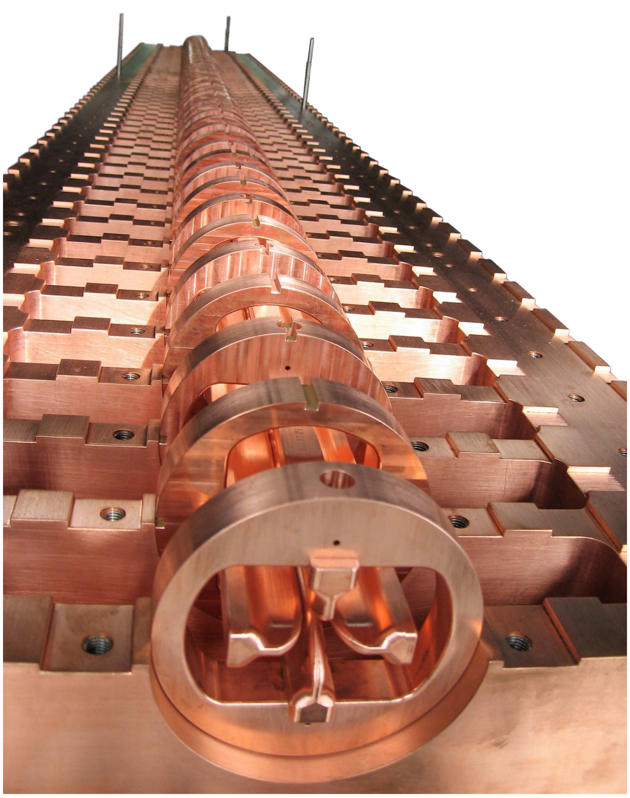

Figure 3: Assembly of the electrodes and carrier rings.

a new loss cone for the chopped beam integrated into the entrance flange of the RFQ.

Manufacturing of the tank components, consisting of an upper tank shell, middle frame and lower tank shell started in September 2017. The middle frame had been completed in November 2017 and was copper-plated by GSI in December 2017. The upper and lower tank shell followed in March and April 2018, respectively. Copper-plating of all components has been finished within Q2/2018. The copper structure has been machined in parallel from 02-04/2018 (see Fig. 2) and finalized in 08/2018. The electrodes have been completed in September 2018. The whole assembly was accomplished within two day. Figure 3 depicts the Ladder-RFQ during assembly after installation of the electrodes and rings prior to closing the tank.

MEASUREMENTS

As manufacturing and first assembly of the RFQ has finished on 10.09.2018, the frequency and first bead pull measurements could be performed prior to LINAC conference. The measured resonance frequency is 338.04 MHz which is 0.1% above simulation. The Q-Value reached up to 4600 which is 65% of the simulated value. During the measurements, tank parts were not screwed on tightly. The screws between the half ladders as well as rings and electrodes have not been silver-plated yet. No RF sealing has been used. Therefore, an increase of the quality factor is expected as conductivity increases. The flatness prior to any tuning process is shown in Fig. 4. The relative deviation of the electric field along the beam axis is $< \pm 3\%$.

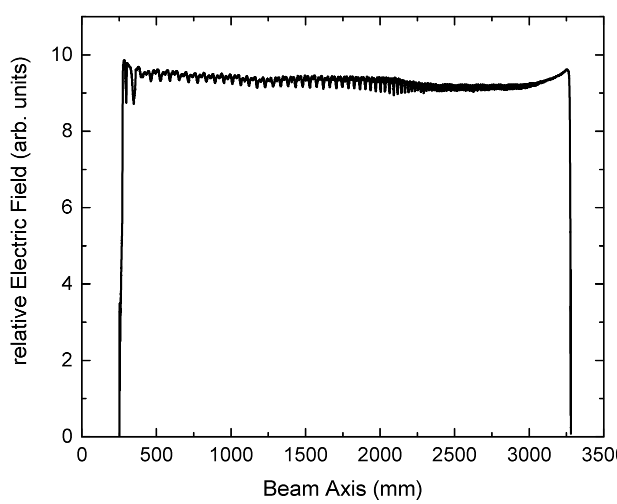

Figure 4: Field flatness of the Ladder-RFQ along the beam axis before tuning procedures.

BEAMMATCHING BETWEEN LEBT AND RFQ

As adjacent electrodes of 4-ROD RFQ's do have a floating potential along the beam axis, there will be a non distinguishable longitudinal fringe field between the

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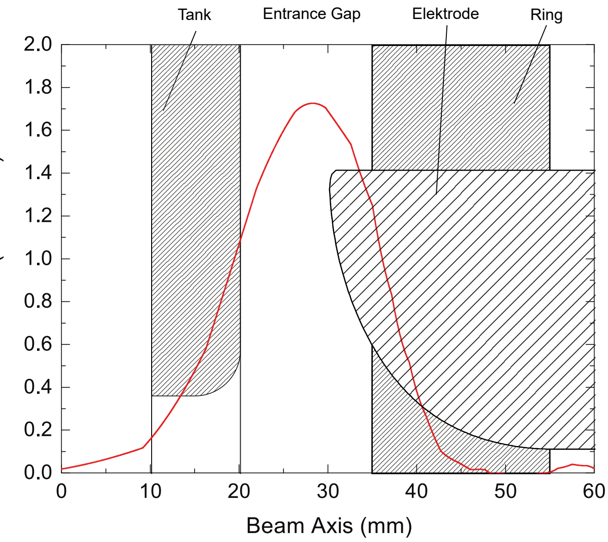

Figure 5: Longitudinal fringe field in the entrance gap/radial matching section of the RFQ.

grounded tank and the net potential of the electrodes at the RFQ entrance and exit gap (see Fig. 5). Depending on the distance between the walls and the electrodes as well as on the actual electrode potential the field may reach up to 50% of the incoming particle energy. In case of the Ladder-RFQ and regarding the time-transient factor, this field causes an energy modulation of up to ±2 eV.

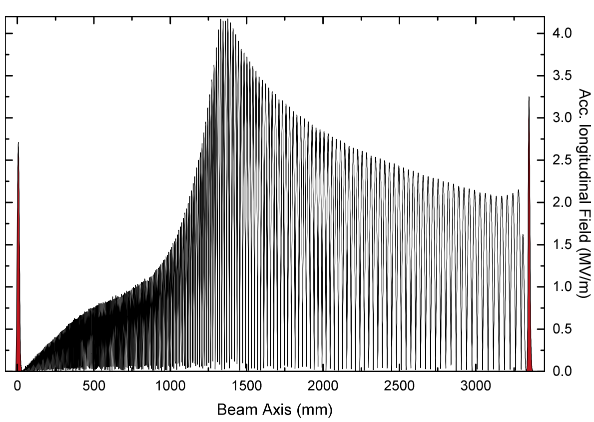

Figure 6: Longitudinal electric field on the beam axis. Simulation result of a complete 3D EM eigenmode simulation considering the entire final modulation of the electrodes. The entrance and exit fields are colored in red.

That longitudinal electric field in the entrance gap of the RFQ (see Fig. 6) will now be beneficially used to pre-bunch the incoming cw beam. According to simulations, the bunching effect is comparable to that within the first five RFQ cells after the radial matcher. Therefore, the phase of the incoming synchronous particle, which is the zero-crossing on the rising edge of the energy modulated cw beam, has to pass the center of the first RFQ cell after the radial matcher at a phase of $\varphi_s = -90°$. By adding a focusing quadrupole drift channel, i.e. a non modulated extension of the electrodes with a constant mean aperture between the end of the radial matcher and the first modulated RFQ cell, the relative phase of the synchronous particle referred to the RF is shifted. After that additional drift, the synchronous particle is centered within the phase space of ±180°.

OUTLOOK

The next steps within 2018 are further bead pull measurements with different methods and beads. Afterwards, the measurements will be compared to the simulations to define the individual ladder cell height needed for the final machining and tuning procedure. Furthermore, the inductive coupling strength will be measured to define the final coupling loop. Beginning late 2019, conditioning and high power tests are envisaged. Additionally, in 2019, a new cone after the chopper, which shall be integrated into the RFQ flange to avoid any additional drift length, will be designed and build.

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