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TUNING AND RF MEASUREMENTS OF THE LILAC RFQ*

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Abstract

A new linac for the NICA ion collider is under construction for JINR at BEVATECH GmbH. As first cavity the 2.5 m long RFQ was manufactured. Within this length it accelerates particles with a mass to charge ratio up to three to an energy of 600 keV/u. The operation frequency is 162.5 MHz and the 4-Rod structure consists of 23 RF cells that need to be adjusted using tuning blocks in order to provide the required field distribution along the electrodes. The status of the manufacturing and the upcoming tuning process including the overall RF setup of the RFQ are summarized in this paper.

INTRODUCTION

The NICA collider will be fed with various ion beams accelerated in the Nuclotron [1]. Heavy particles with A/Q=6.25 will use the HILAC (Heavy Ion Linac) [2] as injector and will be injected into the booster synchrotron before they will be finally accelerated by Nuclotron. Light ions with A/Q=3 will use the Light Ion Linac (LILAC) [3] and directly injected into the Nuclotron. LILAC will be fed with ions from two different ion sources, the SPI (Special Polarized Ion Source) for protons and deuterons, and LIS – a Laser Ion Source for ions such as C^{3+} for example [1]. Between the ion sources and the LILAC RFQ a LEBT will transport and focus proton beams with 50 keV from the ion source. In addition deuterons with only 25 keV/u beam energy from the ion source will be post-accelerated and matched to the RFQ acceptance. A solution to match the carbon beams is under investigation.

The emittance of the beam from the ion source is limited to 0.3 mm mrad which was measured as worst case for the SPI. Larger emittances can be transported by the LEBT, but will not be accepted by the RFQ.

RFQ DESIGN

Based on the measured output from the SPI and LIS, the LEBT beam dynamics design and the required matching to the following IH Drift Tube Linac, the LILAC RFQ beam dynamics design parameters are listed in Table 1. The design plots in Figure 1 show a stable output emittance against changes of the input emittance for an injected C^{3+} beam with maximum 15mA of beam current. For the worst case input emittance of 0.3 mm mrad (rms), the LILAC RFQ design provide transmissions of around 89%. The LILAC RFQ is chosen to be of the 4-Rod type RFQs.

The RF design parameters of the RFQ resonant structure have been simulated in CST. The RF design was performed taking the longitudinal end fields [4] as well as dipole correction [5] into consideration. The RF design parameters are listed in Table 2.

Table 1: LILAC RFQ Beam Dynamics Design Parameters

Parameter	Value	Unit
Input energy	25	keV/u.
Output energy	600	keV/u.
Input emittance $\varepsilon_{n,rms,xy}$	0.3	mm mrad
Output emittance $\varepsilon_{n,rms,xy}$	0.31	mm mrad
Energy spread (@15 mA, A/Q=3)	1.8	%
Transmission[1]	89	%

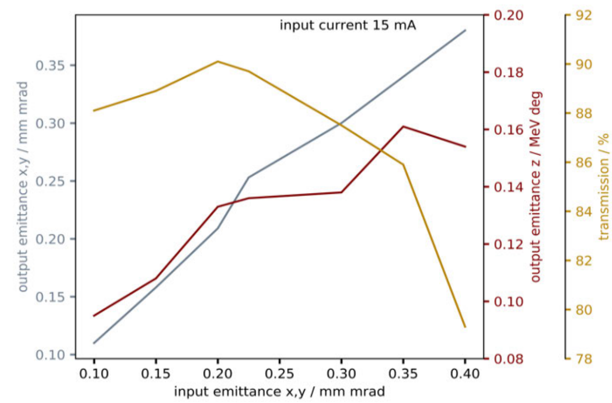

Figure 1: Output emittance and transmission as a function of the input emittance for a beam current of 15mA.

Table 2: LILAC RFQ Design Parameters

Parameter	Value	Unit
Operating frequency	162.5	MHz
Shunt impedance Z_{eff} (CST)	116	kΩ*m
Recommended RF power (Amplifier)	300	kW
Quality factor (CST)	5800	
Flatness	±3.5	%
Kilpatrick	1.60	

TECHNICAL DESIGN

The base of the technical design of this RFQ is derived from a well established and successful design of rectangular RFQ tanks [6,7] which have water cooling feedthroughs realised in the ground plate. In the case of the LILAC RFQ only the stems will be cooled. In addition, the rectangular tank has a cover plate allowing for easy access to the 4-rod structure and tuning plates. The tuning plates are mounted

[1] For input emittances 0.3 mm mrad

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with screws to the stems and offer advanced electrical and thermal conductivity, see Figure 2.

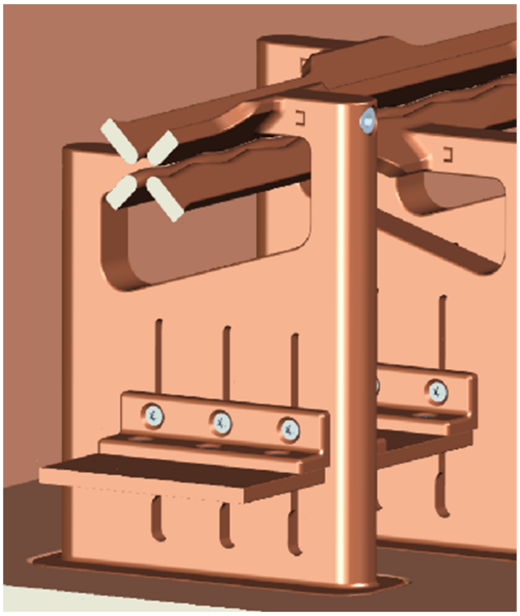

Figure 2: Mounting of tuning plates via screws.

Find below in Table 3 the technical design parameters of the 4-Rod structure and the tank dimensions.

Table 3: RFQ Technical Design Parameters

Parameter	**Value**	**Unit**
Electrode length	2422	mm
Tank inner length	2440	mm
Tank outer length	2540	mm
Tank height	400	mm
Tank width	400	mm

The RFQ vacuum will be generated using a combination of an ion-getter pump together with a turbo molecular pump sitting each on DN 160 CF flanges located on both ends of the RFQ tank. The beam entrance and exit flanges realised as DN 200 CF are shaped as lids housing each an ACCT for current transmission measurements during operation.

The power coupler for the RFQ consists of a hollow, optionally water-cooled, loop yoke made of copper and a 6 1/8" (EIA) transmission line connector for the connection to the rigid line. Detection of the transmitted signal in the cavity will be done with one of three available pick-up antennas oriented along the side of the tank. Power coupler and antennas have rotatable flanges for optimisation of the loop positions. During operation the RF tuning of the LILAC RFQ will be performed by a MTCA based LLRF control system [8] which is developed in co-operation with DESYs Tech Lab. The tuner algorithm implemented in this MTCA control system stabilises small amplitude and phase deviations. Frequency stabilisation is realised through a dynamic piston tuner with perturbation body which is coupled to the MTCA system over ModBus. The tuner can be optionally water cooled.

MANUFACTURING

During manufacturing the tank was welded from stainless steel parts, machined and polished before sent to copperplating. In Figure 3 one can see the LILAC RFQ tank and the cut-outs for the stems in the ground plate. One can easily see the alternating displacement of the stems which is simulated and used to counteract dipole components on-axis.

Figure 3: RFQ stainless steel tank with cut outs for the stems.

The tank was copperplated in Q4 2021 while the machining of the electrodes and stems had to be partially postponed into Q1 of 2022 due to difficulties in supply of raw materials. After a test mounting of the 4-rod structure followed by precision measurements the procedure of precission milling of the stems to allow precise alignment of the rods was performed in May 2022, see Figure 4.

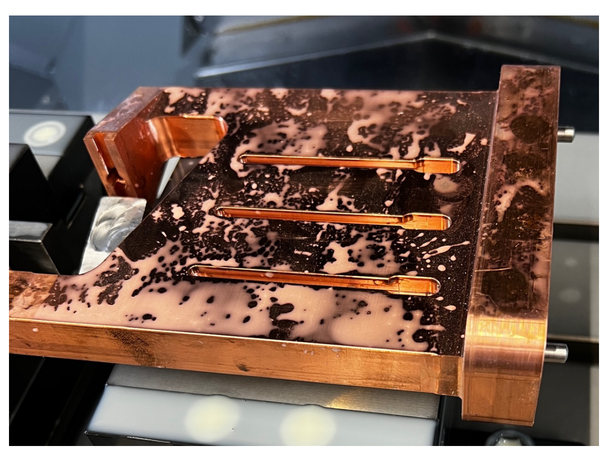

Figure 4: RFQ Stem during precision milling.

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First vacuum tests with power coupler and pickup loops showed a leak in the delivered power coupler which is currently under repair. It is expected to be fixed by beginning of July which will then be followed by the tuning and RF measurements of the LILAC RFQ.

TUNING AND RF MEASUREMENTS

After successful FAT and basic tests such as vacuum and cooling water tests, the RFQ will be investigated and set up in regard to low level RF. All measurements will be performed using appropriate equipment (mostly using a vector network analyzer and corresponding cables). The LLRF setup comprises mainly the following steps.

- Measurement of the resonant frequency and the mode spectra of the RFQ
- Adjustment of the field flatness with the tuning plates
- Setup of the power coupler in terms of coupling beta and its corresponding angular position
- Determination of quality factors (Q_0, Q_L, Q_{ext})
- Setup and adjustment of pickup antennas
- Measuring and optimisation of the tuning range of dynamic tuner

In a first step, it must be guaranteed that the nominal frequency of the RFQ is matched. At 162.5 MHz only a medium sensitivity of the RFQ on manufacturing inaccuracies, with no significant offset of the nominal frequency is expected. Nevertheless, a backup plan is foreseen to be able to adjust the frequency in a worst-case scenario.

A mode spectra and mode identification by comparing with higher order modes (HOMs) found in simulations assures a proper operation of the cavity. Also, possible other modes introduced by the piston tuner can be investigated and suppressed during the RF setup.

The voltage distribution of the RFQ will be measured using the perturbation capacitor technique.

The objective of the power coupler setup is a proper matching of the coupling loop, a determination of the coupling β and the different quality factors. This enables an efficient power transfer towards the cavity and compensates the additional losses caused by beam loading.

The pickup antennas provide the feedback signals for the LLRF system. The desired attenuation can be adjusted by the loop size and angle of the pickup antenna during the RF setup.

The tuning and RF measurement processes will be followed by a low power conditioning of up to 100 W cw to eliminate the most critical multipacting barriers.

CONCLUSION

The production of the LILAC RFQ is completed. A leak in the power coupler led to a delay in the tuning and RF measurements which were planned for end of May/beginning of June 2022. These measurements will now be performed in July and August in 2022.

The experience with the technical layout of this 4-rod RFQ design inside the square shaped stainless steel tank which is galvanically copper plated is well known and well proven and we do not expect major surprises in the final measurements.

With the introduction of concepts such as the inclusion of longitudinal end fields and dipole correction, which led to significant improvements of the role of 4-rod RFQs in the linear accelerator community, we expect a very well performing RFQ.

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