Journal of Physics: Conference Series

PAPER • OPEN ACCESS

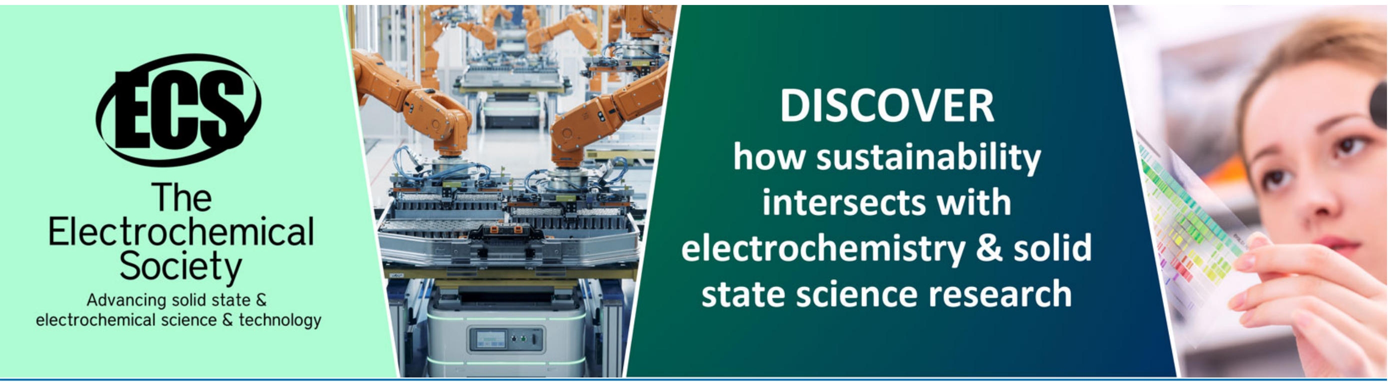
RF measurements and tuning of the 325 MHz Ladder-RFQ

To cite this article: M. Schuett *et al* 2019 *J. Phys.: Conf. Ser.* **1350** 012074

View the article online for updates and enhancements.

You may also like

- Neural networks as effective surrogate models of radio-frequency quadrupole particle accelerator simulations
Joshua Villarreal, Daniel Winklehner, Daniel Koser et al.
- CW RFQ design and investigation for multi-charge-state acceleration of radioactive beams from BISOL
P.P. Gan, H.P. Li, Z. Wang et al.
- Design study of a radio-frequency quadrupole for high-intensity beams
Jungbae Bahng, Eun-San Kim and Bong-Hyuk Choi



This content was downloaded from IP address 3.128.198.60 on 16/05/2024 at 11:46

RF measurements and tuning of the 325 MHz Ladder-RFQ

M. Schuett[1], U. Ratzinger, M. Syha and H. Wang

Institute for Applied Physics, Goethe University, Frankfurt, Germany

E-mail: schuett@iap.uni-frankfurt.de

Abstract. Based on the positive results of the 0.63 m unmodulated 325 MHz Ladder-RFQ prototype from 2013 to 2016 [1, 2], a modulated 3.3 m Ladder-RFQ (s. Fig. 1) has been designed and built for the acceleration of up to 100 mA protons from 95 keV to 3.0 MeV at the FAIR p-Linac [3, 4]. In this paper, we will show the results of manufacturing as well as low level RF measurements of the Ladder-RFQ including flatness and frequency tuning.

1. Introduction

The idea of the Ladder type RFQ came up in the late 1980s [5, 6] and was realized successfully for the CERN Linac3 operating at 101 MHz [7] and for the CERN antiproton decelerator ASACUSA at 202 MHz [8].

Due to its higher symmetry against a classical 4-Rod-RFQ, this Ladder-RFQ development allows to realize high RF frequencies at very low dipole field contributions across the aperture. The Ladder-RFQ prototype was high power tested at the GSI test stand [9]. It accepted three times the RF power level needed in operation[10, 2]. That level corresponds to a Kilpatrick factor of 3.1, tested 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 for 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 technical design and tendering of the RFQ have been successfully completed in 2016 [10]. Manufacturing and copper-plating of the tank have been succeeded in September 2018. We will show the finalization of assembly after manufacturing as well as low level RF measurements. The final machining step for both flatness and frequency tuning has been finished in April 2019.

2. 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

[1] Present address: Institute of Applied Physics, Goethe University Frankfurt, Max-von-Laue-Str. 1, 60438 Frankfurt, Germany.

Content from this work may be used under the terms of the Creative Commons Attribution 3.0 licence. Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.
Published under licence by IOP Publishing Ltd

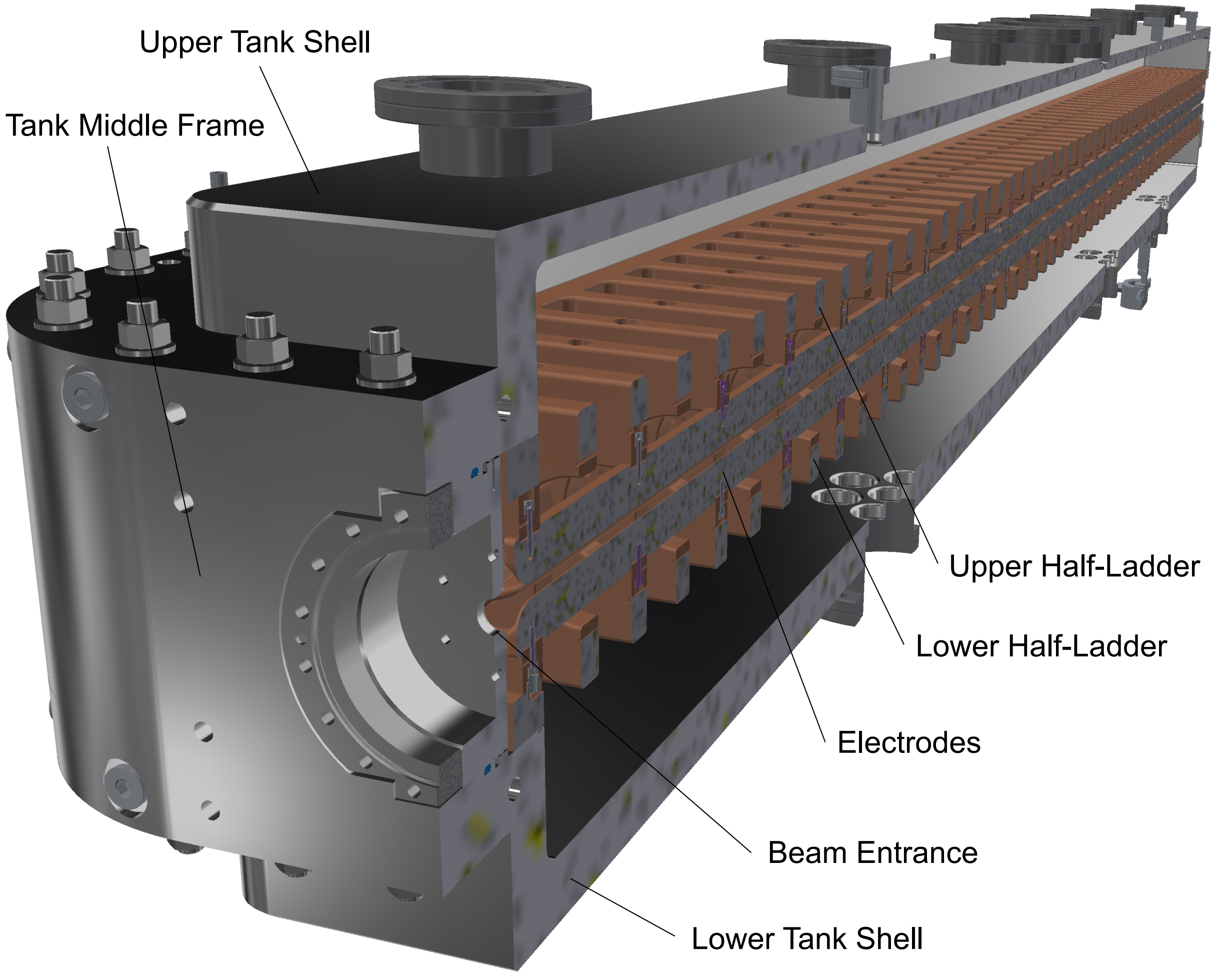


Figure 1. Isometric view of the 3.3 m modulated Ladder-RFQ. Solid copper carrier-rings guarantee the electrode positioning as well as the RF contact. The ladder structure consists of bulk copper components. Any brazing or welding processes were avoided for the assembly of the main components.

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 [11]. 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 beam dynamics for a vane-vane voltage of 88 kV. For details of the final beam dynamics and error studies, see [12, 13]. 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 has 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 additional drifts. Additionally, the effect of gap fields between the electrodes and tank wall has been studied to improve the overall beam dynamics [14].

Manufacturing of the tank components, consisting of an upper tank shell, middle frame and

Table 1. Main RF and geometric parameters of the modulated Ladder-RFQ.

No. of RF cells	55
Q-Value (simulated)	6800
Loss (with sim. Q)	675 kW
Shunt Impedance (sim.)	40 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

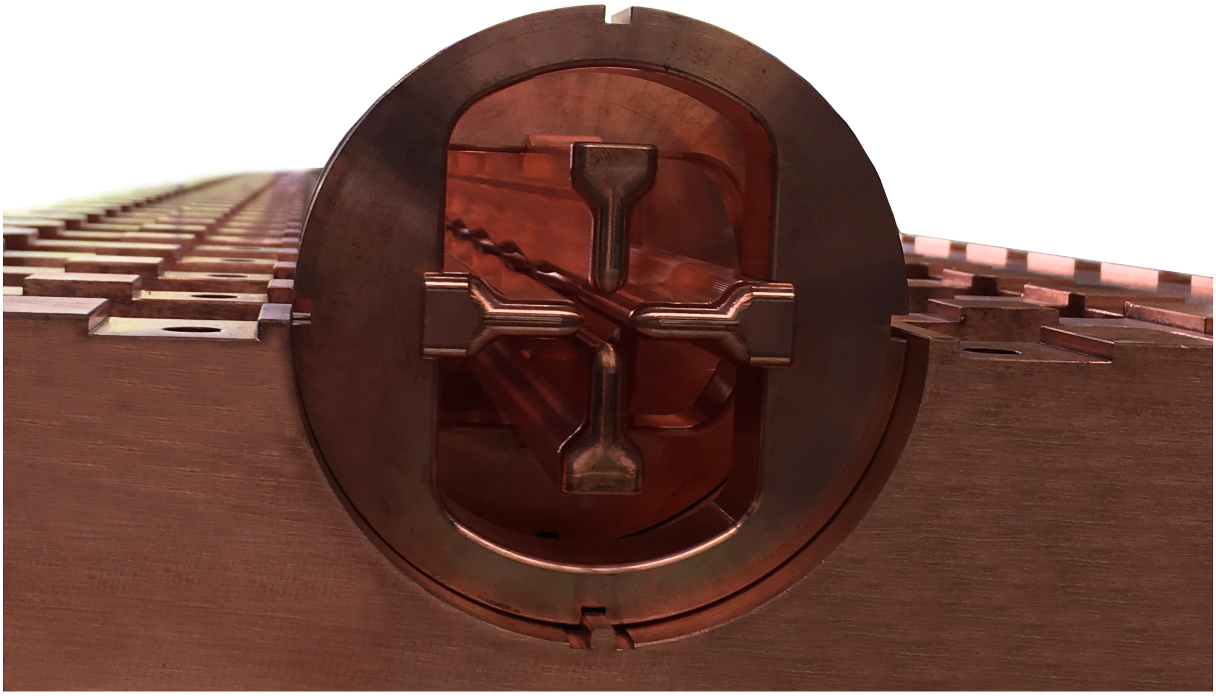


Figure 2. Electrodes mounted into the carrier-rings on the lower half-ladder structure.

lower tank shell, started in September 2017. The tank components have been completed in April 2018 [15]. The copper structure has been machined in parallel and finalized in 08/2018 (s. Fig. 2). The electrodes have been completed in September 2018. Fig. 3 depicts the Ladder-RFQ during assembly, after installation of the electrodes and rings, prior to closing the tank.

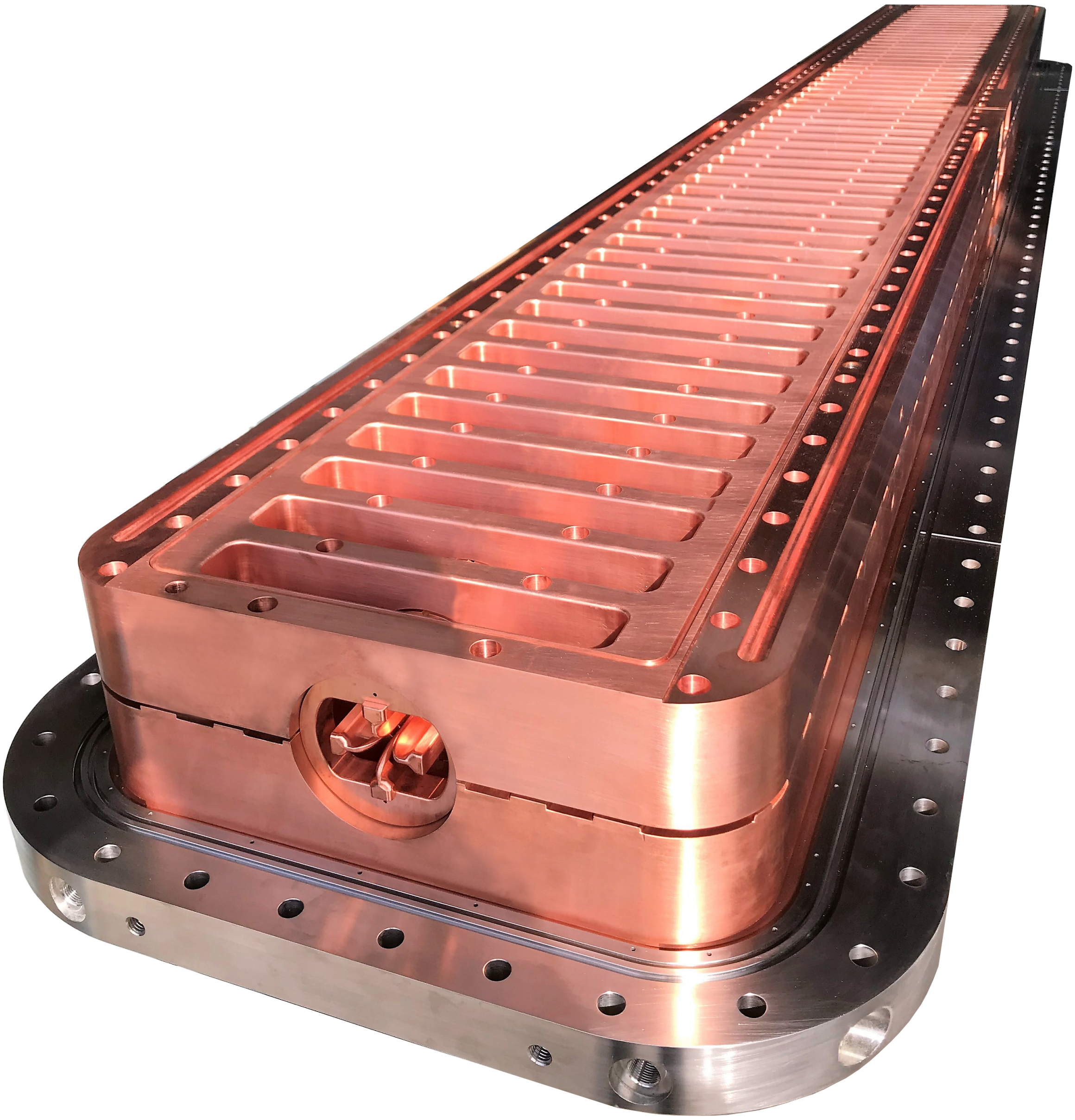


Figure 3. Assembly of the electrode and carrier rings mounted into the lower and upper half-ladders. The ladder structure itself is aligned and placed onto the lower tank shell.

3. RF Measurements

Manufacturing and first RFQ assembly have been completed in September 2018. The measured resonance frequency was 338.04 MHz, which is 0.1% above simulations. Before using aluminum wires as an RF sealing, the Q-Value reached 4600, which is 65% [16]. After inserting RF sealings and tightening the tank, the quality factor increased to 5700 (approx. 81% of the simulation). The screws between the half ladders as well as rings and electrodes have not been silver-plated yet. The bead pull measurements before tuning the flatness have been compared with simulations. Subsequently, the final cell heights of the ladder structure were determined by simulations including the modulation at a very high precision level and mesh number. By increasing the heights of the ladder structure in cells No. 5 to 51 the frequency is matched to

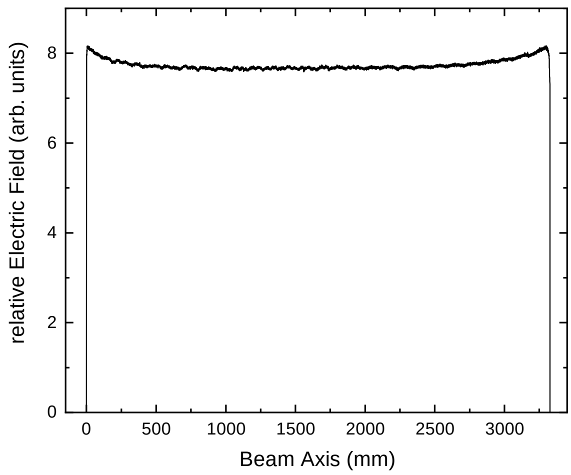


Figure 4. Flatness after tuning. The relative on-axis flatness is 1%.

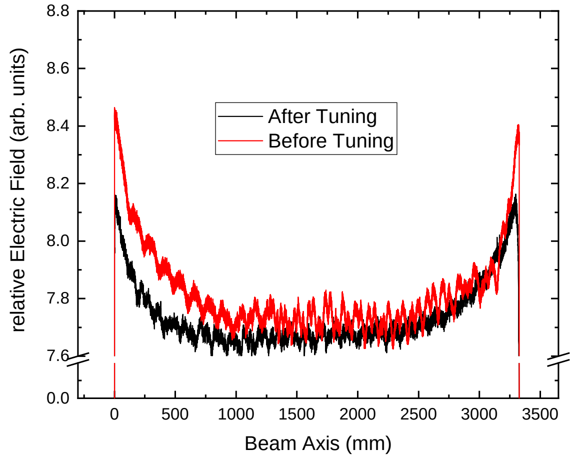


Figure 5. Detailed comparison of the flatness before and after tuning.

its final value of 325.224 MHz for operation. Furthermore, the flatness is optimized by adjusting the heights of the outer ladder cells at the low and high energy end (cells No. 1-4 and 52-55) individually. The relative deviation of the electric field along the beam axis is $< \pm 2.5\%$ including peaks at the entrance and exit. Along the mid beam-axis the flatness remains below $\pm 0.5\%$ (s. Fig. 4). A comparison of the flatness before and after tuning is shown in Fig. 5. In

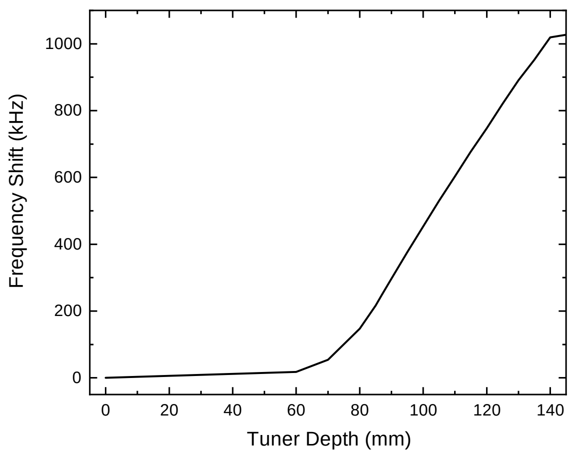


Figure 6. Tuning Range of 10 static tuners.

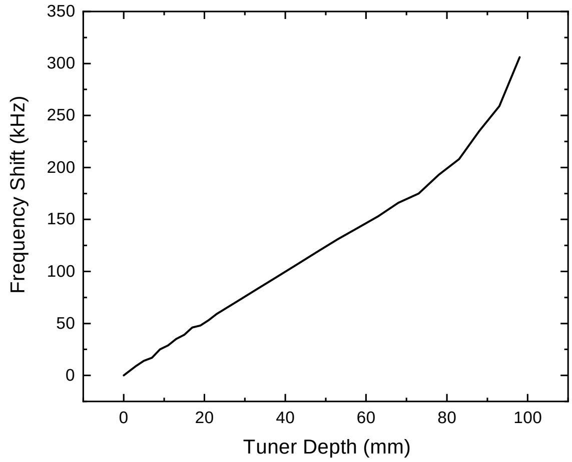


Figure 7. Tuning Range of 2 movable tuners.

April 2019 the cell heights of the ladder structure have been CNC machined to their final value. The frequency after that tuning process is 324.87 MHz. Considering an increase of 100 kHz in vacuum a frequency jump of approx. 250 kHz is needed to match the operation frequency. The possible frequency tuning range has been studied with prototype tuners made of aluminum. In total up to ten static plungers and two movable motor plungers are used. All tuners act as inductive plungers. The static plungers are able to increase the frequency up to 1 MHz linearly without affecting the quality factor (s. Fig. 6). During operation the movable plungers may correct the frequency by up to +300 kHz within their maximum stroke of 100 mm (s. Fig. 7).

4. OUTLOOK

The next steps in 2019 are further measurements studying the influence of the plungers on the flatness. Furthermore, the inductive coupling strength will be measured to define the final coupling loop. In mid 2019 the water cooling channels of the ladder structure will be finalized and the FAT is envisaged in the third quarter of 2019. Afterwards, the Ladder-RFQ can be completely assembled to start conditioning of the RFQ and high power RF tests. After completion of the p-Linac building and installing the source together with LEBT the Ladder-RFQ can be tested with beam.

5. ACKNOWLEDGEMENTS

We acknowledge the efficient cooperation with the GSI p-Linac team, especially Klaus Knie and Carl Kleffner. Many thanks to Kress Maschinenbau GmbH for successfully manufacturing the Ladder-RFQ. The authors would also like to thank the galvanic workshop of GSI, Darmstadt, for copper plating the tank.

References

[1] Schuett M, Ratzinger U and Zhang C 2016 *P*roc. of IPAC 899-901 URL `https://doi.org/10.18429/JACoW-IPAC2016-MOPOY024`
[2] Schuett M, Obermayer M and Ratzinger U 2016 in *Proc. of LINAC* 578-580 URL `https://doi.org/10.18429/JACoW-LINAC2016-TUPLR053`
[3] Kleffner C 2018 *Proc. of LINAC* 787-789 URL `https://doi.org/10.18429/JACoW-LINAC2018-THPO046`
[4] Kleffner C et al. 2019 *Proc. of IPAC* MOPTS020
[5] Fabris A, Massarotti A and Vretenar M 1987 *Seminar on New Techniques for Future Accelerators* 265-269 URL `https://doi.org/10.1007/978-1-4684-9114-2_17`
[6] Browman M J, Spalek G, Friedrichs P B and Barts T C 1988 *Proc. of LINAC* 119-121
[7] Bezzon G, Lombardi A, Parisi G, Pisent A and Weiss M 1994 *Proc. of LINAC* 722-724
[8] Bylinsky Y, Lombardi A M and Pirkl W 2000 *Proc. of LINAC* 554-556 URL `https://arxiv.org/ftp/hep-ex/papers/0008/0008030.pdf`
[9] Schreiber G, Plechov E, Salvatore J, Schlitt B, Schnase A and Vossberg M 2016 *Proc. of LINAC* 287-289 URL `http://dx.doi.org/10.18429/JACoW-LINAC2016-MOPLR067`
[10] Schuett M, Ratzinger U, Schnase A, Syha M and Obermayer M 2017 *J. Phys.: Conf. Series* **874** 012048 URL `https://doi.org/10.1088/1742-6596/874/1/012048`
[11] Ratzinger U, Kaspar K, Malwitz E, Minaev S and Tiede R 1998 *Nucl. Instrum. Meth.* A **415** 281-286 URL `https://doi.org/10.1016/S0168-9002(98)00395-7`
[12] Syha M, Ratzinger U and Schuett M 2018 *Proc. of LINAC* 521-523 URL `https://doi.org/10.18429/JACoW-LINAC2018-THPO046`
[13] Syha M, Haehnel H, Ratzinger U and Schuett M 2019 *Proc. of IPAC* MOPTS032
[14] Schuett M, Syha M and Ratzinger U 2019 *Nucl. Instrum. Meth.* A **9258** 58-64 URL `https://doi.org/10.1016/j.nima.2019.02.071`
[15] Schuett M, Ratzinger U and Syha M 2018 *J. Phys.: Conf. Series* **1067** 052004 URL `https://doi.org/10.1088/1742-6596/1067/5/052004`
[16] Schuett M, Ratzinger U and Syha M 2018 *Proc. of LINAC* 826-829 URL `https://doi.org/10.18429/JACoW-LINAC2018-THPO060`