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RFQ ELECTRODES CHANGE AND UPGRADE OPTION AT THE UNILAC HSI INJECTOR

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Abstract

In order to meet the beam intensity and quality requirements imposed by FAIR, the HSI-RFQ beam dynamics originally dating from 2009 has been re-designed recently at CERN. Front-to-end simulations demonstrated that the new design meets the FAIR targets. Implementation of the new electrodes, initially planned for 2019, will require re-adaption of the RFQ cavity RF-parameters by re-shaping the stems that keep the electrodes. However, during the beam time 2018 the existing RFQ did not reach its nominal voltage, most likely due to expired lifetime of the electrodes originating from 2009. In order to shorten the RFQ maintenance period and to minimize any risk for upcoming beam time 2019, it was decided to post-pone the implementation of the new design and rather just re-producing the 2009 design electrodes. This contribution is on the reproduction process as short-term solution and on the full implementation of the new design as mid-term solution. CST simulations performed at GSI assure that the resonance frequency with the new electrode geometry is recuperated through corrections of the carrier rings. The status of the exchange of the electrodes and simulations for the adaptation of the new electrode design are presented.

INTRODUCTION

The GSI accelerator facility will be used in future as an injector for FAIR ("Facility for Anti-proton an Ion Research), which is currently under construction, providing numerous experiments with a variety of ion beams. Beam intensity upgrades to the UNILAC [1], a UNIversal Linear Accelerator that can provide up to three different ion species from three different independent ion sources at the same time, are necessary to meet the requirements of FAIR. Figure 1 shows the existing GSI (blue) and the extended FAIR facility (red). FAIR will have two injectors, the existing UNILAC and the planned p-Linac. The real bottleneck of the UNILAC is the front-end system of the high current injector (HSI). The current HSI RFQ electrodes were replaced in 2009. To increase acceptance, the electrode voltage was increased from 125 kV to 155 kV, but by reducing the curvature (rho) of the transverse radius, the maximum surface field was maintained at 31 MV / m to compensate for the higher voltage [2]. In order to meet the requirements of the FAIR project, higher intensities and a better beam quality are necessary, so that after ten years of operation, the electrodes must be replaced again. Corresponding beam dynamics simulations were conducted at CERN with the aim of reducing the electrode voltage according to the design voltage of 123 kV and simultaneous reduction of the mean aperture. CST simulations will check it if the changed resonance frequency can be compensated by adjusting the carrier rings geometry.

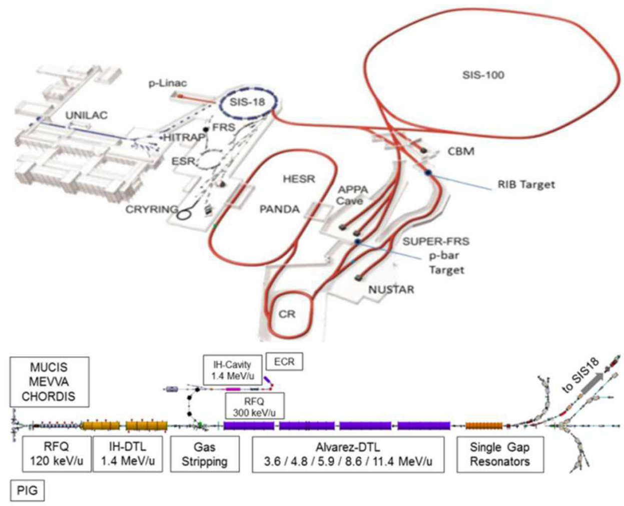

Figure 1: GSI / FAIR facility and the UNILAC injector.

HSI-RFQ

The HSI RFQ [3] was designed in 1996 as a 925 cm long IH cavity and tested with beam in 1999. It consists of ten single modules, with ten stems and carrier rings each. Each ring is alternately attached to two opposite electrodes (see Fig. 2). The rings are also required for frequency matching, because the ring length has an additional capacity acting on the electrodes. During the last 20 years, the matching section of the electrodes was redesigned and since 2009 the RFQ was put in operation with the second redesign of electrodes. This set is currently still in use, the surface is damaged by sparks, especially produced during mixed duty cycle operation with different ion species and high currents. CERN provides the third beam dynamic redesign and the technical design report (TDR) was approved in May 2018. The entire tank should be used again, so exact adjustments to the carrier ring geometry and small changes on the electrode cross section are possible and required. Only with accurate simulations, it will be possible to determine the carrier ring parameters, in order to achieve the correct frequency and a good flatness distribution along the electrodes.

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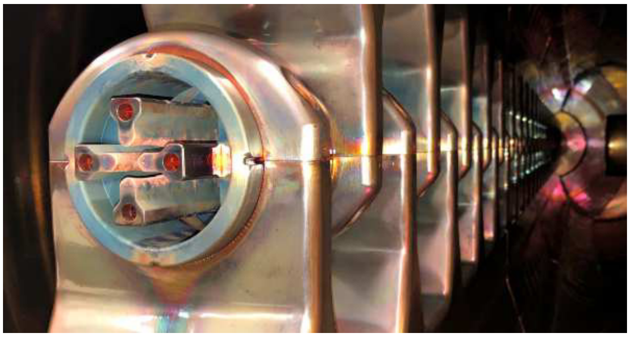

Figure 2: Picture inside the HSI RFQ with the electrodes, carrier rings, stems and one of the tuners.

Each module is 92.5 cm long and separately simulated with its special parameters for the length of the carrier ring nose, the electrode base rounding, the angle and the height of the electrode shoulder. With the IH-RFQ, adjusting the frequency is not trivial. In total, there are three dynamic tuners that can change the frequency by 45 kHz during operation. There are also five static tuners to adjust the frequency and flatness along the electrodes. It is possible to install up to five additional static tuners. Otherwise, the frequency must be hit by adjusting the carrier ring lengths. Opening the individual tank sections to work on the accelerator structure is not easily possible in comparison to a 4-rod RFQ. Re-fitting the ring lengths requires complete removal of the electrode structure and thus is very time consuming. A new set of electrodes is re-designed with moderate changes in acceptance and voltage to match the requirements for FAIR, some parameters are shown in Table 1.

Table 1: Electrode Parameters

	Design 2009	**CERN Design**
design ion	238 U4+	238 U4+
design voltage	155 kV	123 kV
max. surface field strength	31.2 MV/m	32 MV/m
average aperture	6.0 mm	5.1 to 6.0 mm
min. aperture	4.1 mm	5.1 to 3.4 mm
max. modulation	1.93	2.0
Number of cells	394	372
Input emittance (20mA)	200 mm mrad 50 mm mrad rms	200 mm mrad 50 mm mrad rms
Output emittance (20mA)	31.7/30 mm mrad (95%, hor. / vert.)	31.2 mm mrad
transmission	80%	78% (Toutatis)

After a nearly two years long shutdown, during re-commissioning for the beam time 2018, the existing RFQ did not reach its nominal voltage, most likely due to the expired lifetime of the electrodes originating from 2009. The forward RF power and reflected RF power depending on the normalized cavity voltage are shown in Fig. 3. For uranium beam, a GSI internal scaled tank voltage of 8.3 V is required.

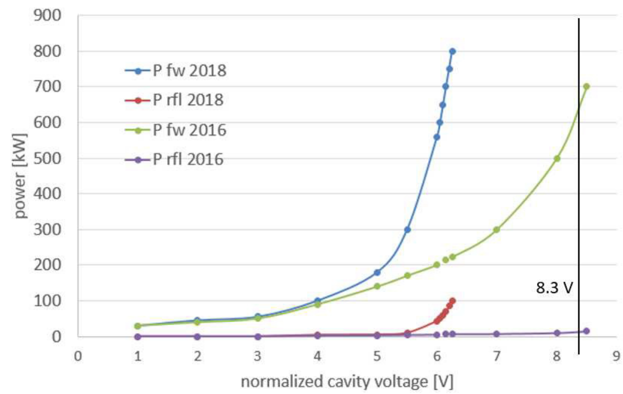

Figure 3: Forward and reflected power 2016 and 2018 as functions of the normalized cavity voltage.

During the shutdown, the HSI section was disassembled and the RFQ was kept under atmospheric pressure for about 11 month [4]. Table 2 shows several investigations that were performed during the re-commissioning to understand and eliminate the misconduct and to achieve the desired status of the RFQ, as it was the case in 2016.

Table 2: Investigations on RFQ Voltage Drop [4]

Investigations during re-commissioning 2018
• voltage limit imposed by reflected power, not by sparking or vacuum
• classical “conditioning behaviour” not observed, situation did not changed for two weeks
• several tank temperatures and tuner positions tested
• residual gas spectrum does not reveal masses >44, i.e, no hydro-carbonites
• independent dust probe indicates no oil
• visual inspection without special findings
• RF-power amplifier, power lines, RF-coupler ok
• network analyser measurements of higher modes
• several external experts consulted
• Q and Rs ok at norm. voltages ≤ 5V

Figure 4: Current RFQ-electrodes originating from 2009.

The third revision of the electrodes, planned for FAIR operation was suspended due to the 2018 problems. The cause for performance loss of the existing RFQ is still not

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understood, but most likely due to the expired lifetime of the electrodes originating from 2009. Figure 4 shows a view inside the HSI RFQ after the beam time 2019. To minimize the risk for operation 2019 and 2020 a short-term solution was needed and it was decided to re-produce the RFQ-rods (2009 design) instead of the improved but not tested new CERN design.

The fabrication of the 2009 design electrodes finished, at GSI workshop, in February 2019. For all tank sections completion of electrode „baskets"(with carrier rings) finished in April 2019. Figure 5 shows the electrode basket of the second tank section. The removal of the old electrodes and the adjustment of the new ones will start in the middle of May. The follow up of the original strategy (CERN design) was postponed to 2020. The material for the rods and carrier rings of the new design is already ordered.

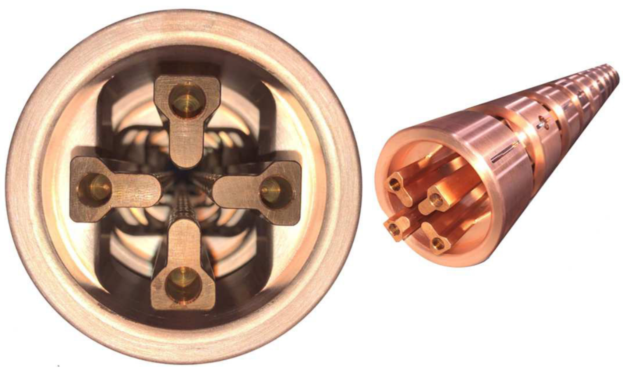

Figure 5: Electrode "basket" of the re-produced electrodes for the second tank section.

RF-SIMULATIONS

All simulations were done with the CST software Microwave Studios [5]. Figure 6 shows a part of the created model with electrode modulation used for the simulations. The individual modules of the 10 m long RFQ were simulated separately. A mesh sweep was used to determine the minimum number of mesh cells needed to minimize the difference between model and real tank simulation.

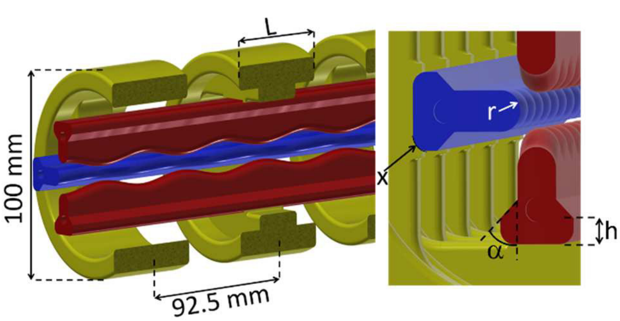

Figure 6: Electrodes and carrier rings of the simulation model with the changeable parameters for the RF simulations.

Modelling of the cavity with electrode modulation requires significantly more mesh cells, is very time consuming and limited by the computers RAM, therefore exact simulations of the whole HSI RFQ are almost impossible.

Several preliminary simulations for the RF adaption were performed and show the boundary conditions especially for the minimum average aperture and the total length of the electrodes, so the beam dynamic parameters of the CERN design was crosschecked [6].

The results of the simulations showed that the total length of the electrodes should just change minimally in comparison with the current design, so that the existing tank can be set to operation without additional changes to the geometry. The examination of the allowable electrode aperture showed that a minimum average aperture of 5.3 mm is necessary to achieve the resonance frequency [6]. The main parameter for the frequency adjustment is the length of the carrier rings. These must be determined individually for each tank section to compensate the changing aperture along the electrodes. Similarly, the ring length should also adjust the voltage distribution along the electrodes. In order to prepare the planned upgrade as well as possible, further simulations are in progress. The exact ring lengths for the single cavity sections must be determined and small changes made to the electrodes so the resonance frequency and the flatness are hit as well as possible.

CONCLUSION

To meet the requirements of FAIR, a third revision of the HSI RFQ electrodes is planned. Although the design is completed, this revision has been suspended. The cause of the performance loss is still not understand, but most likely lifetime of the electrodes is exceeded. The last user beam time (beginning 2019) with limited amplitudes was successful. New electrodes are produced, applying the 2009 design, to cure the cavity performance loss and will be mounted immediately. In addition, new rods will be produced, applying the CERN design for the FAIR requirements. Modifications of the electrodes and the carrier rings were simulated, to show that the RF requirements could be fulfilled with the beam dynamic design from CERN. Boundary conditions for the average aperture and the total length of the electrodes were investigated and determined. Simulations with electrode modulation are possible for a certain length of the structure, but in comparison with unmodulated electrodes, there are just small changes in RF properties. An electrode exchange always requires a lead of time for development of the new geometry of the electrodes and a prolonged shutdown for installation, conditioning, tuning and commissioning.

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