TUNING OF THE NEW 4-ROD RFQ FOR FNAL*

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Abstract

For the injector upgrade at FNAL a 4-rod Radio Frequency Quadrupole (RFQ) with a resonance frequency of 201.25 MHz has been built. With this short structure of only 1.3 m a very compact injector design has been realized. Simulations with CST Microwave Studio® were performed for the design. Their results leading to the RF characterizations of the RFQ and the final RF setup which has been accomplished at IAP of the Goethe-University Frankfurt are presented in this paper.

CHARACTERISTICS OF THE FNAL-RFQ

The new injector at FNAL was planned to replace the old Cockcroft-Walton Accelerator. This modernization of the complex, which is similar to other projects realized in the last years [1], will lead to a high reliability of the injector to serve the increasing demand for protons.
As part of this project the 4-rod RFQ will accelerate the ions from a 35 keV magnetron source to 750 keV, operating at 201.25 MHz. A very compact RFQ was designed with a length of only 1.3 m and an intervane voltage of 72 kV. Fig. 1 shows the RFQ during the preparation at the Institute of Applied Physics (IAP) and more details of the setup values are summeriezed in table 1.

Table 1: Design Parameters of the FNAL-RFQ

Parameter	FNAL-RFQ Value
Frequency	201.25 MHz
Input Energy	35 keV
Output Energy	753 keV
Beam Current	50 mA
Apertur (mean)	4.17 mm
Modulation Factor	1 - 2.1
Electrode Length	1.18 m
Intervane Voltage	72 kV
RF cells	11
Beam Height in Tank	130 mm
Stem Thickness	20 mm
Stem Distance	100 mm
Tank Diameter (inside)	260 mm
Tank Length	1.29 m
Wall Thickness	45 mm

* Work supported by BMBF

Figure 1: The 4-rod RFQ for FNAL during preparation at IAP.

Simulation Model

For the RF design of the RFQ simulations with CST Microwave Studio® were performed. These simulations were especially concentrated on the cross shape of the electrodes. Some examples of the different models are shown in fig. 2. The geometry of the electrodes on the left side is comparable with the one used for the ReA3-RFQ at NSCL [2]. But in combination with the very small mean aperture of the FNAL-RFQ these electrodes are to big as they carry to much capacitance for the high frequency in the region of 200 MHz. For that reason it is interesting to consider a more slender shape like for example on the right side of fig.2. This model fits much better to the specifications which finally led to the construction presented in fig.3.

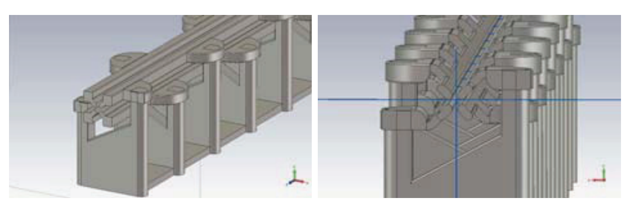

Figure 2: Examples of RFQ simulation models with different electrode cross shape. On the left nearly square ones, carrying a high capacitance. On the right an example of more slender electrodes, leading to a higher resonance frequency.

TUNING PROCESS

The tuning process accomplished at IAP includes the adjustment of the longitudinal voltage distribution along the electrodes, the so called flatness, going hand in hand with the adaption of the resonance frequency.

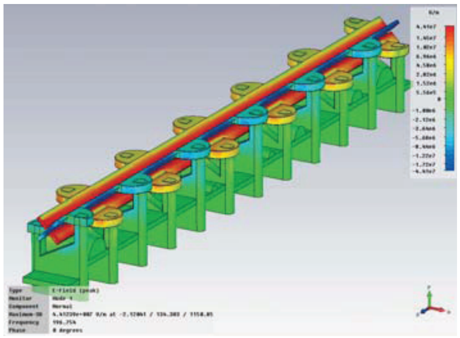

Figure 3: The final 4-rod RFQ setup with its electric field distribution.

The calibrations of the power coupling loop, the pick ups and the piston tuners were done as well as leak tests and a low power RF test.

Tuningplates

As shown in fig.4 the original measured flatness is tilted with a higher voltage on the high energy end of the RFQ and an minimal voltage in the middle RF-cell.

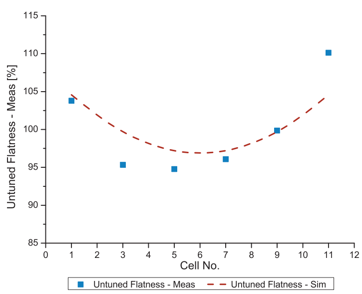

Figure 4: The Measurement of the untuned flatness (dots) compared to its simulation with MWS (line).

The process of adjusting the flatness follows the method described in [3]. Using tuning plates between the stems the current path and with it the inductivity is changed to decrease the voltage in a RF-cell. As described in [8] this effect is linearly dependent to the height, which leads to the following equation for the tuned flatness UF_T .

$$UF_T(z,h) = UF_U(z) \times \prod_{k=1}^{N} [h_k \cdot EC_k(z) + 1] \qquad (1)$$

As presented in fig.5 measurements on the FNAL-RFQ showed, that this linear approximation, which works well with RFQs around 100 MHz [3], is not able to predict the behaviour of the RF-cells good enough for an 4-rod-RFQ with a high resonance frequency. A exponential description fits much better, so the theory had to be corrected in that way.

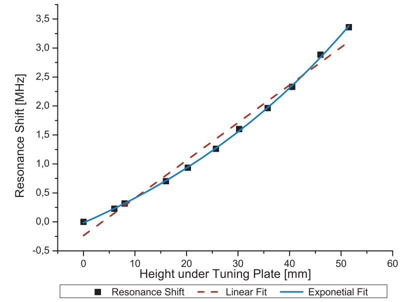

Figure 5: Dependency of the resonance frequency on the hight of the tuning plates. The dots show the measured resonance shift, while the dashed line represents the linear approximation and the blue one an exponential fit.

Additional Tuning Possibilities

In addition to the tuning plates some half cylinders were used as pictured in fig.6. They work similar to piston tuners by perturbation of the magnetic field between the stems, so a higher flexibility could be aimed for the tuning.

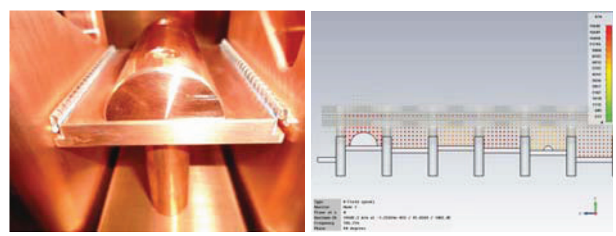

Figure 6: The half cylinders used for tuning the flatness of the FNAL RFQ. They are fixed on the tuning plates and work mainly by suppressing the magnetic field in the RF Cell.

For the operation of an RFQ, there has to be an opportunity to tune the frequency of the structure while running the accelerator to compensate thermal effects. This is done with piston tuners, which can be drawn between the stems. For this very short and high frequency RFQ it is enough to insert only one tuner. Simulations of the shift in the flatness of the electrodes caused by the tuner are shown in fig.7. It is very small compared to the other variations in the voltage distribution, so there is no problem in using just one tuner.

RESULTS

A resonance frequency of 201.6 MHz was adjusted with a deviation in the longitudinal voltage distribution of under ±3%. Measured with a perturbation capacitor a shunt impedance of about 63 kΩm was ascertained for the final setup.

The final flatness is presented in fig.8 together with the distribution of the tuning plates and half cylinders. They have been inserted in three different sizes as shown in fig.3.

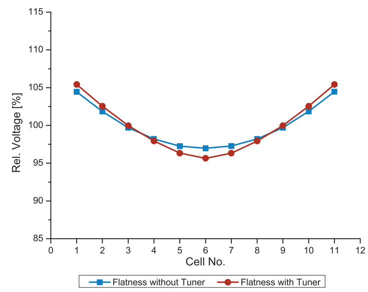

Figure 7: Comparison of the simulated flatness with and without piston tuner in the middle RF Cell. The tuner causes just a minimal decrease of the voltage in the middle of the structure.

Even if they draw some marginal part of the electric field into their direction, the RFQ benefits a lot of the additional tuning possibilities they offer.

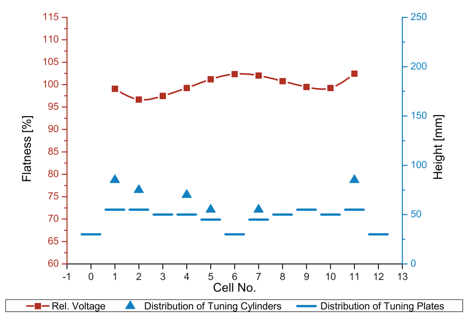

Figure 8: Final results of the flatness tuning. The flatness curve is represented by the blue line above the distribution of the tuning plates (bars) and the half cylinders (triangles).

The piston tuner will allow to regulate the resonance frequency during operation in the range of approximately up to 1 MHz. All the RF parameter of the FNAL-RFQ are summarized in table 2.

Table 2: RF Parameters of the FNAL-RFQ

Parameter	**Value**
Frequency	201.06 MHz
Quality Factor Q_0	2200
Voltage Distribution	$< \pm 3\%$
Shunt Impedance	63 kΩm
Reflection Power Coupler	-25 dB
Transmission Pick Up 1	-43 dB
Transmission Pick Up 2	-44 dB

Outlook

The 4-rod-RFQ for FNAL has been delivered in July 2011. The next steps are low power RF tests to prepare the RFQ for conditioning and operation.

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