Rf Measurements and Tuning of the Test Module of 800 MHz Radio-Frequency Quadrupole

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The 800 MHz RFQ (radio-frequency quadrupole), developed and built at KAHVElab (Kandilli Detector, Accelerator and Instrumentation Laboratory) at Bogazici University in Istanbul, Turkey, has been designed to provide protons that have an energy of 2 MeV within only 1 m length. The RFQ consists of two modules and the test module of RFQ was constructed. The algorithm developed by CERN, based on the measurements generated by the tuner settings estimated through the response matrix [1, 2, 3], has been optimized for a single module and 16 tuners. The desired field consistent with the simulation was obtained by bead pull measurements. In this study, we present low-power rf measurements and field tuning of the test module.

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Introduction

At KAHVElab, a serious and unparalleled effort is being made to make key acceleration component operational, which will gain 2 MeV energy to protons with the world's smallest Radio Frequency Quadrupole RFQ, which is an important component of the accelerator structure [4, 5, 6, 7, 8]. The RFQ consists of four vanes, which are connected to each other without any soldering, it designed to be able to be reassembled with screws.

Thanks to the portable and easy installation of the RFQ, it will be easy to material analyses using PIXE analysis method to objects of historical value that are difficult to transported from any museum.

Parameter	Symbol	HF	PIXE	PTAK
Input E (keV)	W_{in}	40	20	20
Output E (MeV)	W_{out}	5	2	2
RF (MHz)	f_0	750	750	800
Number of modules	-	4	2	2
RFQ Length (mm)	-	1964	1073	980
Quality Factor	Q_0	6440	5995	7036
RF Power Loss (kW)	P_0	350	64.5	48.5

Fig. 1: Comparison of PTAK at KAHVElab with similar RFQs.

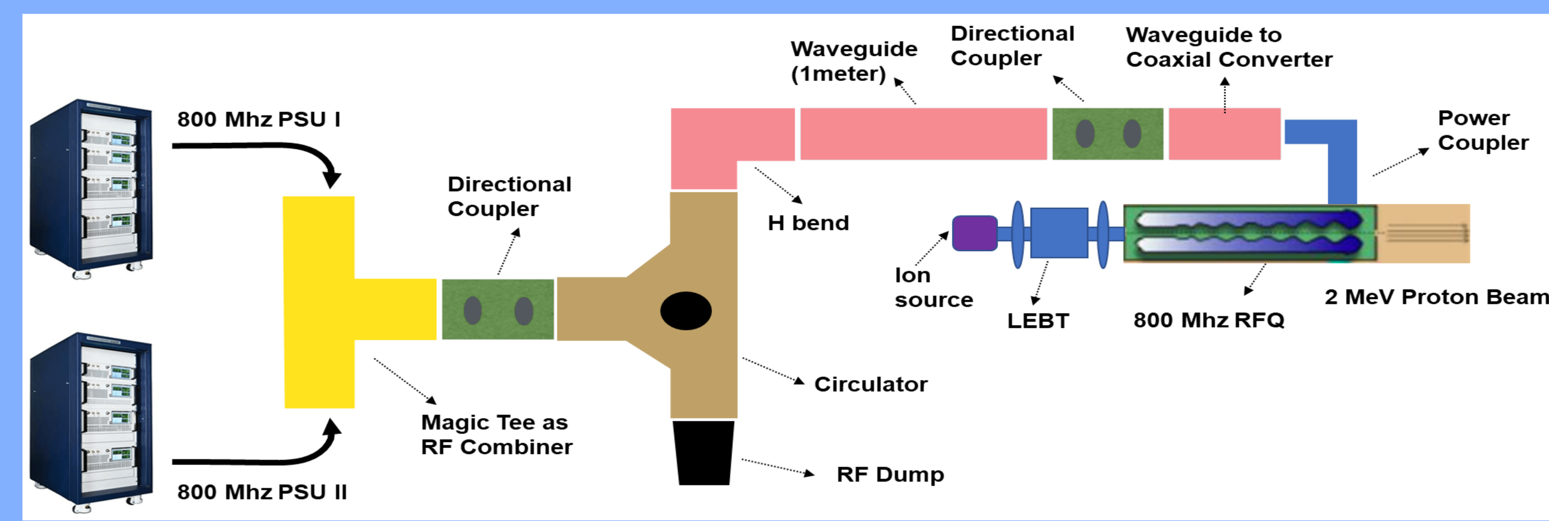


Fig. 2: Layout of 800 MHz Rf System and Proton Accelerator at KAHVElab

The Test Module of the RFQ

The test module of 800 MHz RFQ was manufactured from ordinary copper. Although the test module of the 800 MHz RFQ was manufactured from copper in order to reduce production costs, the RFQ that will be provided protons of 2 MeV for PIXE experiments will been built from oxygen free copper. In order to compensate for the construction errors, a total of 16 tuners were placed, four in each vertical plane to be used for adjustment on the test module.

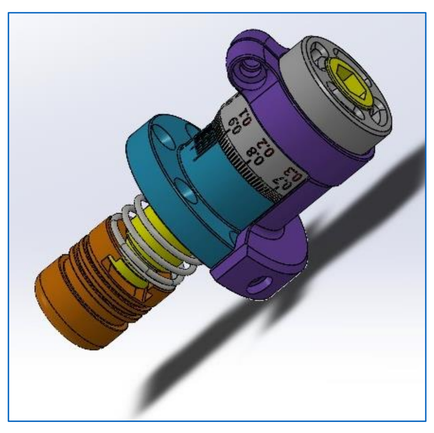


Fig. 3: 3D Solid View of Tuners with locking cap system

Fig. 4: Manufactured Tuners (10 Micrometer Precision)

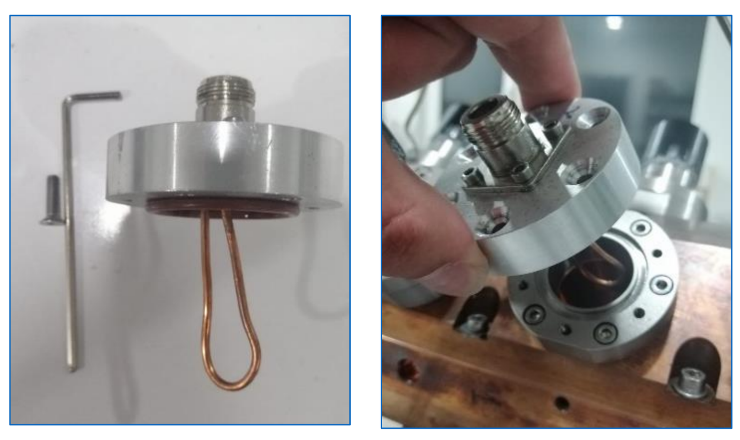


Fig. 5: Homemade Pick-up antenna

The tuners are numbered as T1-T16, starting at quadrant 1 and by locating in a helical orbit.

Two extra tuners on the vertical plane where the pick-up antennas are located are on the module to be used if needed. The two ports with the aforementioned extra tuners are included in the design mainly to be used as vacuum ports.

Measurement Equipment:

*VNA (Vector Network Analyser) (Anritsu)

*Calibration Kit (50Ω)

*N-type (50Ω)

*Temperature Measurement Gauge (Capstone)

*Homemade pick-up antennas.

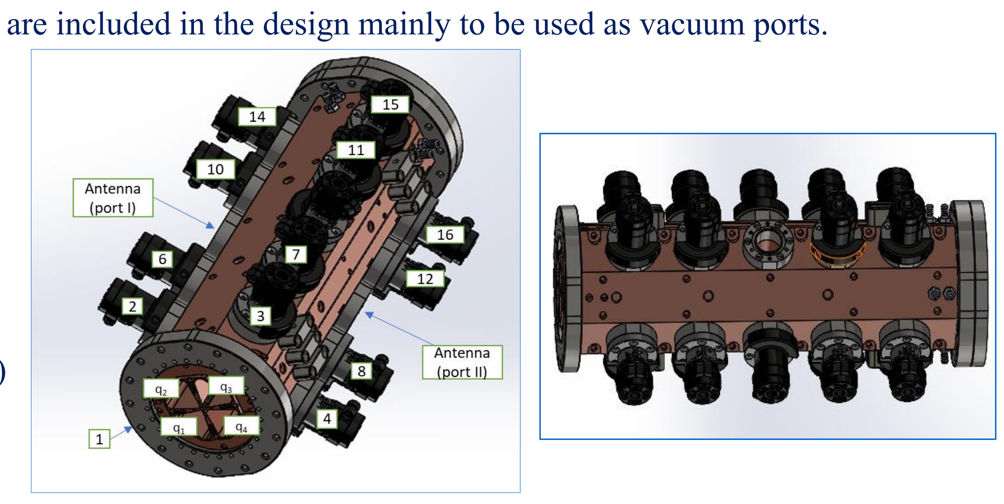
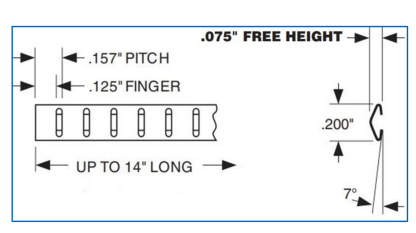


Fig. 6: Layout of Quadrant and Tuner Numbering on the Test Module

The VNA and calibration kit were always used unchanged for all measurements N-type cables are connected with 2 antennas to distribute and collect the signal generated by the VNA into the cavity.

Pick-up antennas were handmade using 2.5 mm thick copper wire. After the antennas were mounted on the test module, antenna calibration was performed. The antennas are in the middle of the RFQ, but are also located on two opposite quadrants.



Boundary conditions were applied at the module ends by means of a cylindrical tube made of aluminum material at one end and an aluminum cap at the other end. All tuners were placed on the module in the flush position with a precise measurement. Rf finger was used to prevent rf leaks.

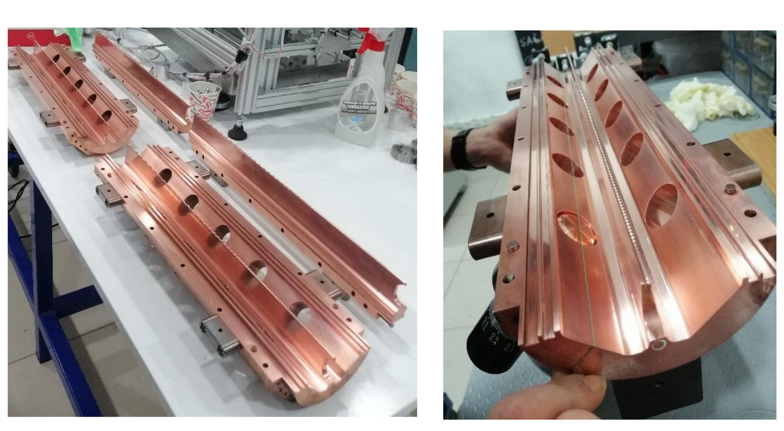


Fig. 7: View of 4-vanes of test module (right) and view of flush positioning of tuners on module (left)

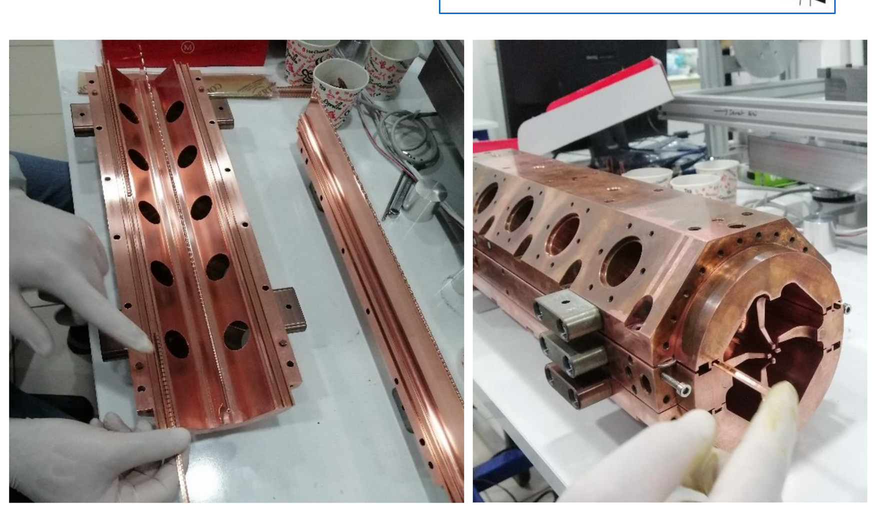


Fig. 8: Rf Fingers Placed in the Slots on the RFQ Test Module

Bead-pull Measurements and Tuning Code

The bead pull measurements [2, 6, 8] were performed both to make sure of the manufacturing quality and to tune the field of the cavity.

Field tuning via bead pull measurements is done by inserting or removing at a certain length of every single of tuners in each quadrant of the four quadrant space.

As the output of the bead pull measurements, raw data of phase were obtained. The field components of all quadrants was aligned after a few data process [2] and smoothed using Kernel regression [9].

The field flatness that expressed by quadrupole (Q) and dipole components (Ds, Dt) are based on relative quadrant amplitudes(q1, q2, q3, q4). The relative quadrant amplitudes are calculated by taking the square root of the phase [2].

Fig. 9: View of Bead-pull Measurement Setup at KAHVElab

$$Q = \frac{q1 - q2 + q3 - q4}{4}, \quad D_s = \frac{q1 - q3}{2}, \quad D_t = \frac{q2 - q4}{2}$$

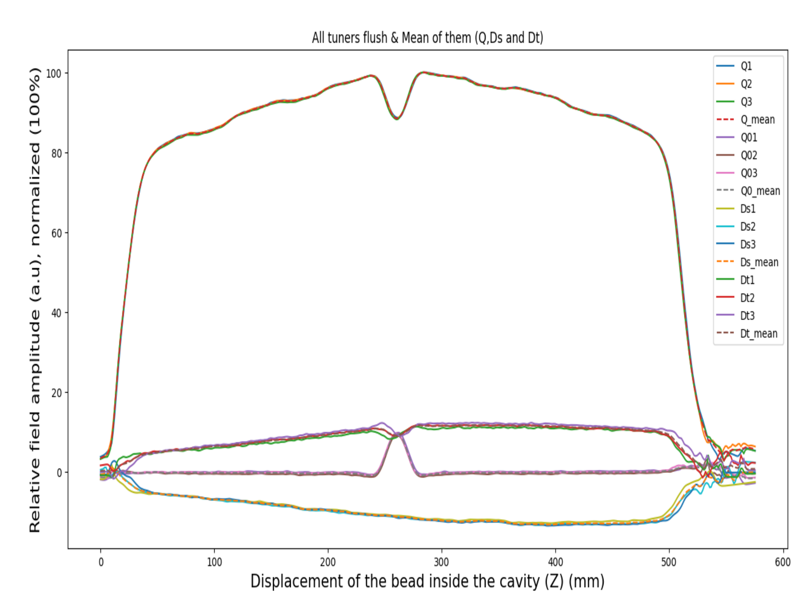


Fig. 10: Comparison of Measurements and Their Average (Q,Ds, Dt Components)

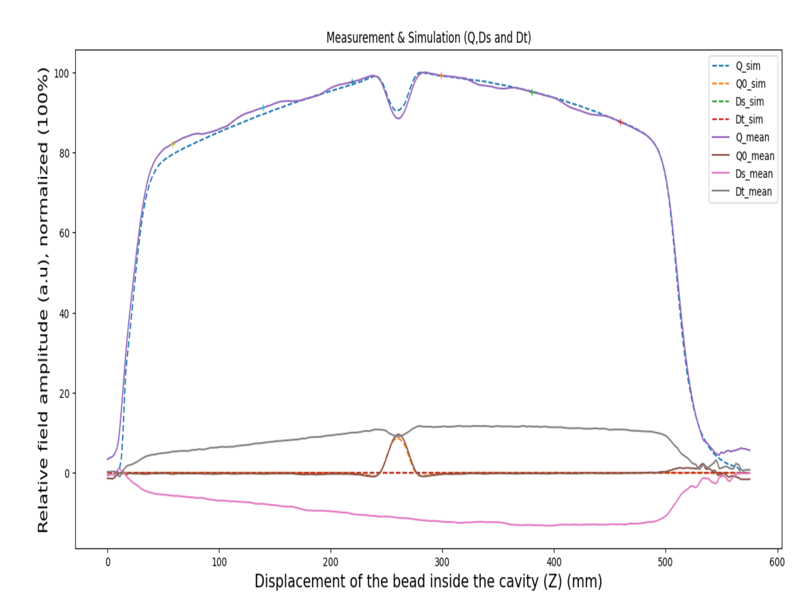


Fig. 11: The Results of Simulation- Average of Measurements for Q,Ds, Dt Components

We decided to use 6 points to run the code based we use Singular Value Decomposition [1, 2, 3] to get the inverse of the matrix. The code that previously created at CERN [2] was optimized for 6 points and 16 tuners, then 18x16 response matrix was created to estimate tuner lengths required for a flat field distribution.

$$\begin{bmatrix} 80{,}2 - V1 \\ 89{,}8 - V2 \\ 97{,}1 - V3 \\ 99{,}1 - V4 \\ 95{,}1 - V5 \\ 87{,}8 - V6 \\ 0 - V7 \\ 0 - V8 \\ 0 - V9 \\ 0 - V10 \\ 0 - V11 \\ 0 - V12 \\ 0 - V13 \\ 0 - V14 \\ 0 - V15 \\ 0 - V16 \\ 0 - V17 \\ 0 - V18 \end{bmatrix} = \begin{bmatrix} \frac{\partial Q1}{\partial T1} & \frac{\partial Q1}{\partial T2} & \cdots & \cdots & \cdots & \frac{\partial Q1}{\partial T16} \\ \vdots & \ddots & & & & \vdots \\ \frac{\partial Q6}{\partial T1} & \frac{\partial Q6}{\partial T2} & \ddots & & & \frac{\partial Q6}{\partial T16} \\ \frac{\partial Ds1}{\partial T1} & \frac{\partial Ds1}{\partial T2} & \ddots & & & \frac{\partial Ds1}{\partial T16} \\ \vdots & \ddots & & & & \vdots \\ \frac{\partial Ds6}{\partial T1} & \frac{\partial Ds6}{\partial T2} & \ddots & & & \frac{\partial Ds6}{\partial T16} \\ \frac{\partial Dt1}{\partial T1} & \frac{\partial Dt1}{\partial T2} & \ddots & & & \frac{\partial Dt1}{\partial T16} \\ \vdots & \ddots & & & & \vdots \\ \frac{\partial Dt6}{\partial T1} & \frac{\partial Dt6}{\partial T2} & \cdots & \cdots & \cdots & \frac{\partial Dt6}{\partial T16} \end{bmatrix} * \begin{bmatrix} T1 - 0 \\ T2 - 0 \\ T3 - 0 \\ T4 - 0 \\ T5 - 0 \\ T6 - 0 \\ T7 - 0 \\ T8 - 0 \\ T9 - 0 \\ T10 - 0 \\ T11 - 0 \\ T12 - 0 \\ T13 - 0 \\ T14 - 0 \\ T15 - 0 \\ T16 - 0 \end{bmatrix}$$

Final Tuner Lengths and Field Components

A few measurements were taken as a result of applying the tuner length estimates given by the code to the tuners. Despite the results of more than one iteration, it was observed that the field distribution of the dipole components could not reach the desired level.

Tuner length estimates obtained with the code were applied to the tuners and the measurements obtained were examined in detail.

As a result of the analysis, the field distribution of the dipole components were set to the desired level by applying the lengths of all tuners 1 and 4, which gave the best results for the field distribution of the dipole components, to all other tuners.

The frequency is set to 799.980 MHz after bead pull-measurement. All tunners were inserted 0.1 mm and the frequency was adjusted to 800.010 MHz.

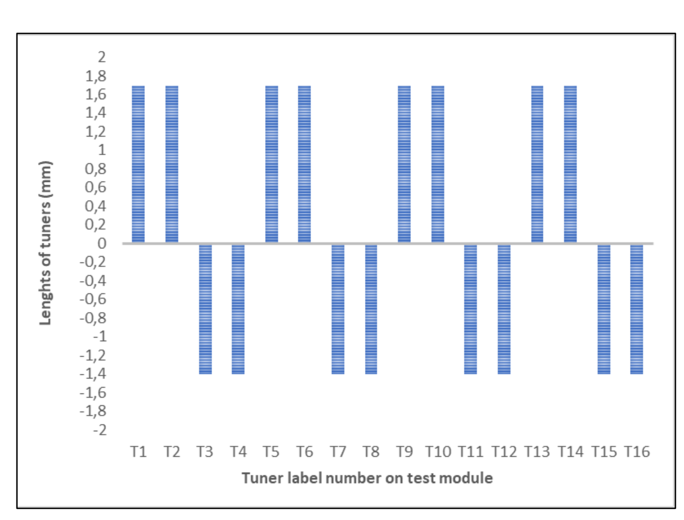


Fig. 12: Final Lenghts of Tuners on the Test Module

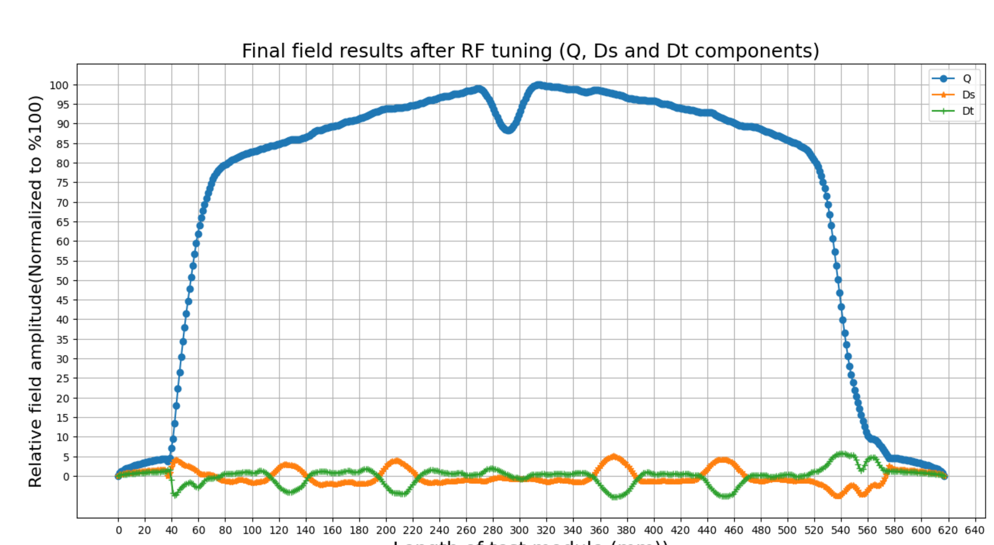


Fig. 13: Final Field Results for Q,Ds, Dt Components

Conclusion

Thanks to the facilitating solutions revealed during the trial production, the production of the module to be produced from Oxygen-free copper (OFC) material will be completed quickly.

The code will be easily optimized again for the response matrix used by the code that will adjust the RFQ field distribution with 2 modules and 32 tuners.

It is also expected that the quality factor of RFQ, whose production will be completed with OFC material, will improve.

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