RF MEASUREMENTS AND TUNING OF THE TEST MODULE OF 800 MHz RADIO-FREQUENCY QUADRUPOLE

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Abstract

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.

INTRODUCTION

At KAHVELab, there is an ongoing effort to make the proton beamline operational. It will attain 2 MeV exit energy using the world's smallest Radio Frequency Quadrupole (RFQ, see Table 1 for a quick comparison), which is an important accelerator structure [4, 5, 6, 7, 8] (Fig. 1).

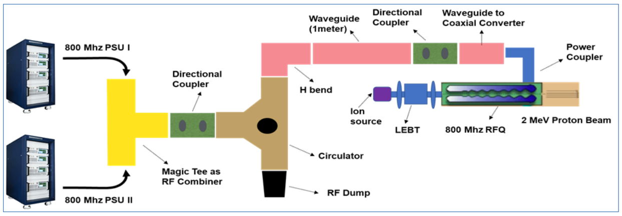

Figure 1: Layout of 800 MHz rf system and proton accelerator at KAHVElab.

The RFQ consists of four vanes, which are connected to each other without any soldering. It is designed to be reassembled with screws, a 3-D O-ring and RF guards. Thanks to the portable and easy installation nature of the RFQ, it will be easy to do material analysis using PIXE technique on the objects of historical value that are difficult to transport from museums.

Table 1: Comparison of PTAK at KAHVElab with similar RFQs

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	800	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

THE TEST MODULE OF RFQ

General Layout

The test module of 800 MHz RFQ was manufactured from ordinary copper to reduce production costs. Naturally, the final 2 MeV RFQ will be built from OFE-Cu (Oxygen-free electric copper) material.

The bead-pull measurements [2, 6, 8] were performed to ensure of the manufacturing quality and to tune the EM field in the cavity. The construction errors are compensated with a total of 16 tuners with micrometer precision, four in each quadrant of the test module (Fig. 2).

The tuners are numbered as T_1-T_{16} starting at quadrant-1 and moving 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 as vacuum ports.

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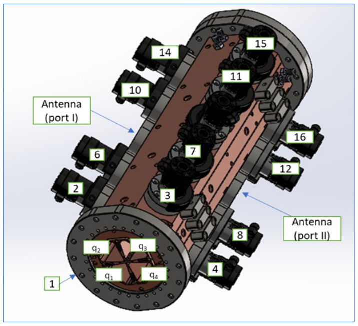
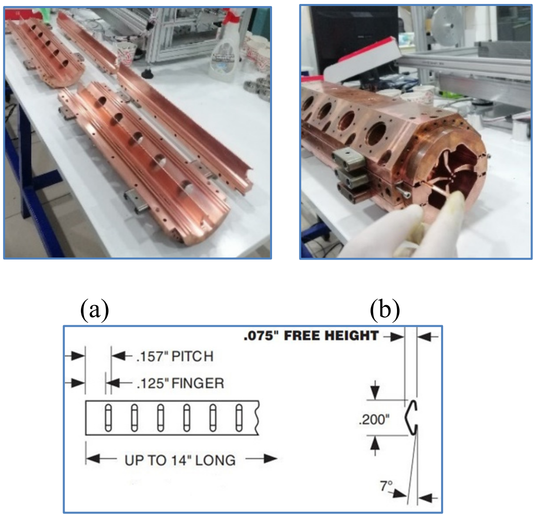


Figure 2: Layout of quadrant and tuner numbering on the test module.

C-shaped RF guards (fingers) from copper are selected and installed to prevent RF leaks (Fig. 3).



(a) (b)

(c)

Figure 3: (a) View of 4 vanes of test module, (b) RF fingers placed in the slots on the RFQ test module and (c) dimensions of the RF finger.

Measurements and calculations:

- As the output of the bead pull measurements, raw data of phase are recorded.
- The field components of all quadrants were aligned after a few data process [2] and smoothed using Kernel regression [9].
- The field flatness, expressed by quadrupole (Q) [Eq. (1)] and dipole components (D_s, D_t) [Eq. (2)], is based on relative quadrant amplitudes (q_1, q_2, q_3, q_4). The relative quadrant amplitudes are calculated by taking the square root of the phase [2] obtained from the bead-pull measurements.

$$Q = \frac{q1-q2+q3-q4}{4} \tag{1}$$

$$Ds = \frac{q1-q3}{2}\ ,\ Dt = \frac{q2-q4}{2} \tag{2}$$

To control the reliability of the data, a series of measurements were taken for the case that all tuners were flush. The Q, D_s, D_t components were measured multiple times and no large deviations from the mean values were observed (Fig. 4).

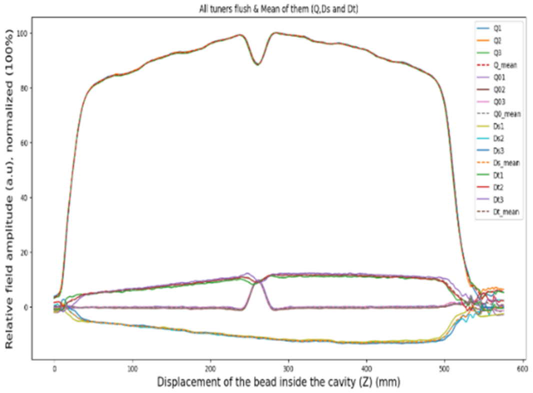


Figure 4: The comparison of the results of measurements and their average (Q, D_s, D_t components).

The comparison between the mean values of the Q, D_s, D_t components and their simulations are shown in Fig. 5. It is seen that the Q component from the measurement is rather compatible with the simulation results.

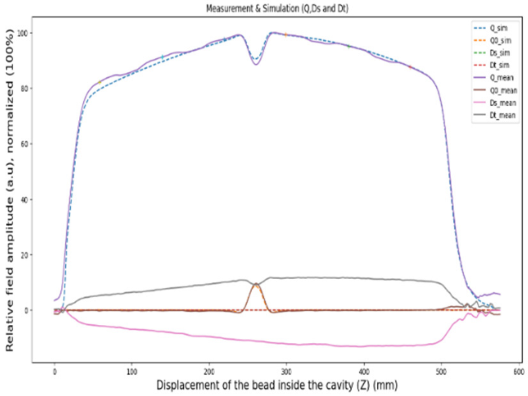


Figure 5: The comparison of the results of simulation and average of measurements for Q, D_s, D_t components.

As seen in Fig. 5, it is seen that the D_s and D_t components based on the measurement result are far from the target level when compared with the simulation results. The fact that these components are close to zero due to the flatness of the field is very important for the proper operation of the RFQ.

The matrix-based code developed by CERN [2] was used to bring dipole components to the desired values and to keep them in the same level as the Q component. In the test setup, 6 test points were used for optimization and the Singular Value Decomposition to get the inverse [Eqs. (1), (2) and (3)] of the matrix.

The response matrix on which the code previously created at CERN [2] is based is optimized as an 18x16 matrix for 6 test points and 16 tuners. With the help of equation (3), the code that estimates the tuner lengths required for a uniform field distribution is run. Field flatness could not be obtained from the result of initial prediction. The measurement data taken after predictions applied to the tuners were again included in the calculation by the code as input. This process was repeated until the field flatness was obtained.

$$\begin{bmatrix} 80{,}2 - V1 \\ 89{,}8 - V2 \\ 97{,}1 - V3 \\ 99{,}1 - V4 \\ 95{,}1 - V5 \\ 87{,}8 - V6 \\ 0 - V7 \\ 0 - V8 \\ 0 - V9 \\ 0 - V10 \\ 0 - V11 \\ 0 - V12 \\ 0 - V13 \\ 0 - V14 \\ 0 - V15 \\ 0 - V16 \\ 0 - V17 \\ 0 - V18 \end{bmatrix} = \begin{bmatrix} \frac{\partial Q1}{\partial T1} & \frac{\partial Q1}{\partial T2} & \cdots & \cdots & \cdots & \frac{\partial Q1}{\partial T16} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \frac{\partial Q6}{\partial T1} & \frac{\partial Q6}{\partial T2} & \ddots & \ddots & \ddots & \frac{\partial Q6}{\partial T16} \\ \frac{\partial Ds1}{\partial T1} & \frac{\partial Ds1}{\partial T2} & \ddots & \ddots & \ddots & \frac{\partial Ds1}{\partial T16} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \frac{\partial Ds6}{\partial T1} & \frac{\partial Ds6}{\partial T2} & \ddots & \ddots & \ddots & \frac{\partial Ds6}{\partial T16} \\ \frac{\partial Dt1}{\partial T1} & \frac{\partial Dt1}{\partial T2} & \ddots & \ddots & \ddots & \frac{\partial Dt1}{\partial T16} \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \ddots & \ddots & \vdots \\ \frac{\partial Dt6}{\partial T1} & \frac{\partial Dt6}{\partial T2} & \cdots & \cdots & \cdots & \frac{\partial Dt6}{\partial T16} \end{bmatrix} * \begin{bmatrix} T1 - 0 \\ T2 - 0 \\ T3 - 0 \\ T4 - 0 \\ T5 - 0 \\ T6 - 0 \\ T7 - 0 \\ T8 - 0 \\ T9 - 0 \\ T10 - 0 \\ T11 - 0 \\ T12 - 0 \\ T13 - 0 \\ T14 - 0 \\ T15 - 0 \\ T16 - 0 \end{bmatrix} \quad (3).$$

FINAL TUNER LENGTHS AND FIELD COMPONENTS

A few measurements were taken after applying the tuner length estimates given by the code to the tuners. Despite using 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.

The lengths of tuner number 1 and tuner number 4 which gave the best results for the field distribution of the dipole components (Fig. 6) were applied to number 2 and number 3 respectively. Then these lengths were applied to each set of four tuners on the vertical plane, respectively.

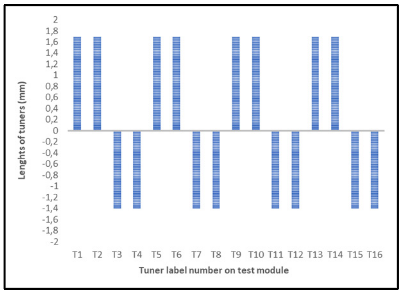


Figure 6: Final lengths of tuners on the test module.

The field distributions of the dipole components also have been set to the desired level after final tuner settings (Fig. 7).

The frequency is set to 799.980 MHz after bead pull-measurement. All tuners were readjusted inwards by 0.1 mm and the frequency was therefore set to 800.010 MHz.

ACKNOWLEDGEMENTS

This project is supported by The Scientific and Technological Research Council of Turkey (TUBITAK) Project no: 118E838.

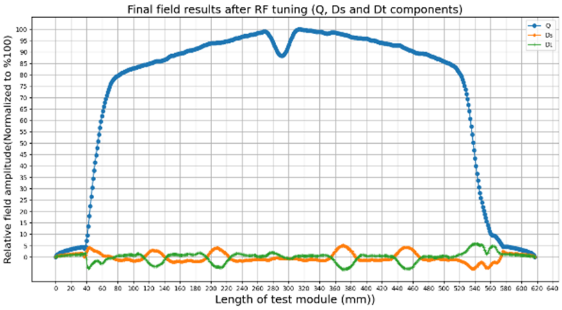


Figure 7: Final field results for Q, D_s, D_t components.

CONCLUSION

Thanks to the facilitating solutions revealed during the trial run, the final two modules, to be produced from OFE-Cu material, will be completed quickly. It is expected that the quality factor of OFE-Cu RFQ, will improve compared to the test module.

The tuner adjustment code will be optimized again for the response matrix for the final RFQ field distribution with 2 modules and 32 tuners.

For the test module, the effects of temperature and humidity on the phase were observed and all data were recorded during the measurement. However, their effects on working-frequency of the RFQ was not considered in the final frequency setting for the test module.

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