ISBN: 978-3-95450-184-7 doi:10.18429/JACoW-IPAC2018-TUPAL050

PROGRESS WORK ON A CW DEUTERON RFQ WITH MAGNETIC COUPLING WINDOWS*

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Abstract

A new 162.5 MHz RFQ has been built for a joint 973 project between Peking University (PKU) and Institute of Modern Physics (IMP). It is designed to deliver 50-mA deuteron beams to 1 MeV in CW mode, with an inter-voltage of 60 kV and a length of 1.809 m. Due to its window-type structure, the RFQ has compact cross-section, sufficient mode separation and high specific shunt impedance. It consists of two segments fabricated and installed at IMP. The assembling error of the cavity is less than 0.05 mm. The RF measurements show good electrical properties of the resonant cavity with a measured unloaded quality factor equal to 96.4% of the simulated value. After tuning, we obtained the nominal frequency and field unbalance within ±1.0%. Preparation of high-power test of this RFQ is underway. This paper will cover the fabrication details and RF measurements, as well as the progress of high-power test.

INTRODUCTION

High-current continuous-wave (CW) RFQ is greatly needed for basic research, energy, medicine, etc., but also a great challenge. Since 2013, PKU and IMP have been collaborating on a new 973 project, which aims to build a 50-mA CW deuteron RFQ. The design of beam dynamics and RF structure has been completed [1-2]. Main parameters of this RFQ are listed in Table 1. As shown in Fig. 1, the RFQ adopts a window-type structure [3-4], with low power consumption and sufficient mode separation, with no stabilizing rods required. At present, the RFQ has been fabricated, assembled and tested at IMP.

Table 1: Main Parameters of the Window-Type RFQ

Parameter	Value
Operating frequency [MHz]	162.5
Particle	D^+
Beam current [mA]	50
Duty factor	100%
Input/output energy [MeV]	0.05/1.01
Average radius [mm]	3.88
Vane tip radius [mm]	2.57~3.32
Inter-vane voltage [kV]	60
Length of the vanes [m]	1.809
Cavity radius [mm]	170.00
Mode separation between TE_{210} and TE_{110} [MHz]	3.144
Power loss [kW]	46.532
Peak power density [kW/m²]	3.846×10^5
Quality factor	9300
Shunt impedance [kΩ·m]	139.982

* Work supported by NSFC, Grand No. 2014CB845503
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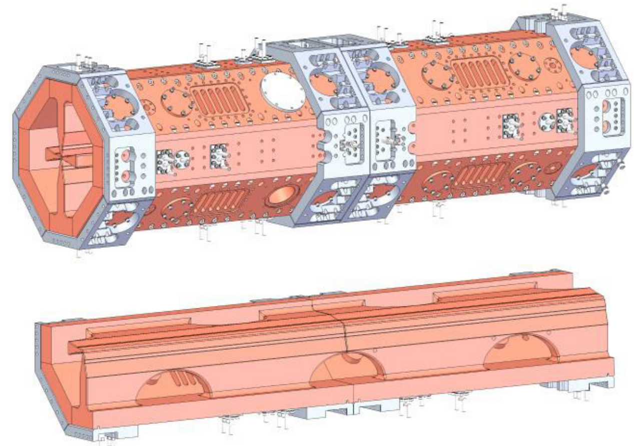

Figure 1: 3D model of the window-type RFQ.

FABRICATION

The RFQ cavity consists of two nearly identical segments of 904.50-mm length and input/output flanges, which are all made of oxygen-free copper (OFC). Each segment is divided into four vanes and four cavity walls for manufacturing. The RFQ is also equipped with 28 60-mm-diameter tuners, 2 couplers, 8 vacuum ports, 8 pick-ups and 56 cooling connectors. The fabrication procedure passed the following steps:

1. All the components went through the rough machining, deep-hole processing, semi-finishing and fine machining in turn. Ball-end milling tools were used during processing the vane modulations, as the transvers radius of the vane tip was designed to change along the RFQ. As shown in Fig. 2, the maximal machining error was measured to be 0.0317 mm, located at the vane tip.

2. The RFQ components were vertically assembled together. After properly adjusting the vanes, the assembling errors were measured to be within 0.05 mm at both ends of each segment.

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3. The two segments were brazed and post-processed successively (see Fig. 3). Their vacuum degrees reached 1×10^{-5} Pa.

4. A laser tracking system was used to collimate the two segments. Influenced by various factors, the total collimation error was between 0.12 mm and 0.16 mm.

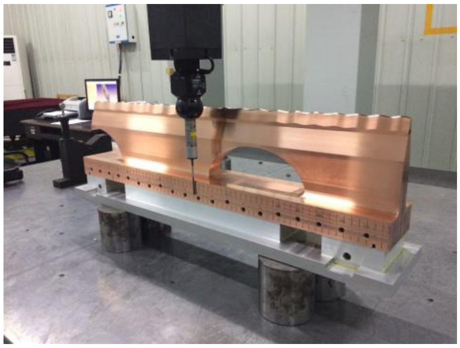

Figure 2: Three-coordinate measurement of a modulated vane.

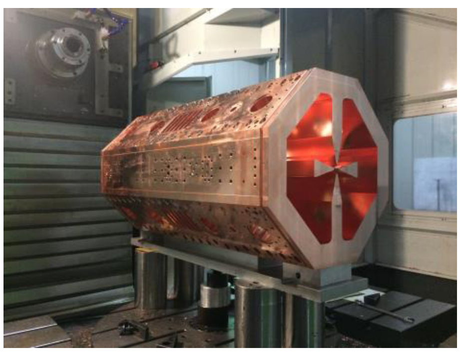

Figure 3: Post-processing of the brazed segment #2.

RF MEASUREMENTS

Before and after the segments were jointed together, the RF characteristics of each segment and the whole RFQ cavity were measured by two pick-ups in transmission mode with very weak coupling. As can be seen in Table 2, the obtained results are very closed to that predicted by CST [5] simulations. The operating frequency of the whole RFQ without tuning or power-input loops installed is 0.233 MHz below the simulated value. The measured Q_0 of the operating mode is 96.4% of the simulated value. Figure 4 shows the first five modes of the whole RFQ.

Table 2: Main RF Parameters of the RFQ Cavity

Parameter		Segment #1	Segment #2	Whole cavity
TE_{210} /MHz	Simulated	161.578	161.976	161.930
	Measured	161.465	162.185	161.697
TE_{110} /MHz	Simulated	178.115	176.940	164.922
	Measured	-	-	164.664
Q_0 of TE_{210}	Simulated	8768	8899	9300
	Measured	8148	8306	8962

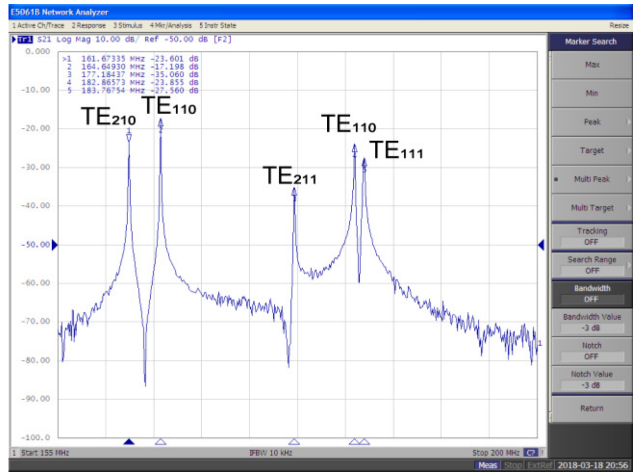

Figure 4: Measured mode spectra of the window-type RFQ.

The field measurement adopted the common bead-pull perturbation method. By guiding a 3-mm-diameter bead along the axis, the field in the aperture was measured. Due to the non-zero volume of the bead, the obtained field is actually the integral of the field inside the bead. Thus, a 1-mm-off-axis field calculated with CST EM is used for comparison. Figure 5 shows a good consistency between the two field distribution curves, which confirms the accuracy of the vane modulation. It also can be carefully observed that there is a tiny step change (circled by blue line) at both ends of the curves. They are the longitudinal field components in the gaps between the end plates and the vanes, caused by the asymmetry structure at the cavity ends, which is inherent for window-type RFQs and four-rod RFQs. As confirmed by beam dynamics simulations, these field components have no serious impact on beam transmission [2].

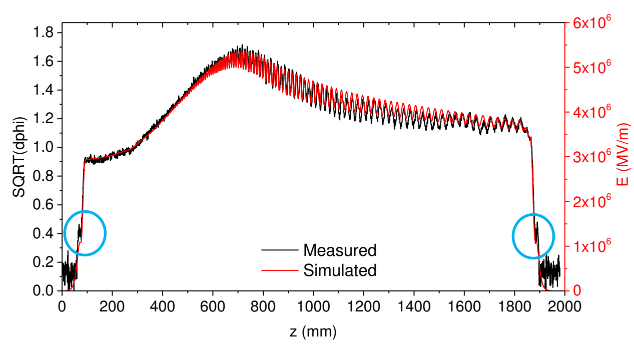

Figure 5: Comparison of simulated and measured fields in the aperture.

TUNING

Figure 6 shows the measured frequency shift caused by inserting tuners in quadrant I. One can see that the tuning capabilities fall into three degrees (1.48, 2.38, 2.88 kHz/mm). This is because the magnetic field varies periodically with the coupling windows and the tuners in different longitudinal positions correspond to different magnetic field values.

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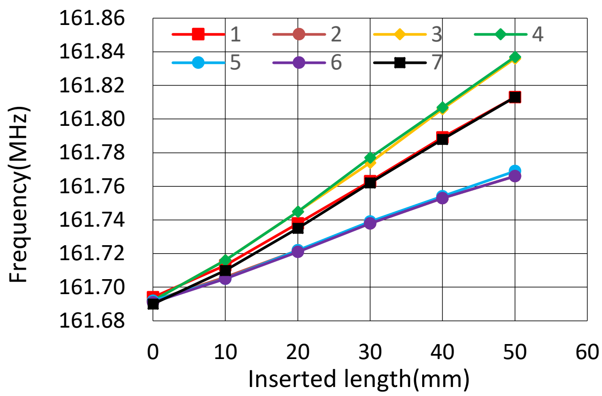

Figure 6: Frequency shift as a function of inserted length of each tuner in quadrant I.

Before tuning, the electric field along the RFQ in one quadrant had a maximal deviation of 3.0%, and the field unbalance among four quadrants was within ±3.0%. These measurements indicate that the fabrication errors of the cavity are small. So, our tuning strategy is adjusting the resonant frequency to the target value first, and then improving the field distribution while keeping the frequency unchanged. The coupling effect unique to the window-type RFQ was considered during the field tuning. As shown in Fig. 7, the half windows exist in the horizontal vanes' ends powerfully couple the two adjacent quadrants, leading to their fields varying together. After tuning, the maximal deviation of the field in one quadrant is 2.2%, and the field unbalance among four quadrants is reduced to below ±1.0%.

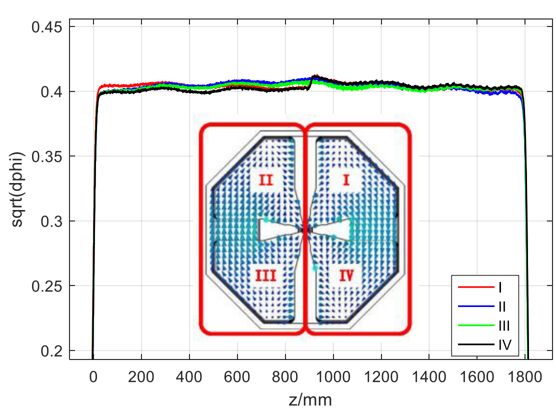

Figure 7: Tuned electric field along the RFQ for four quadrants.

EXPERIMENTAL SETUP

The experimental setup intended for high-power test and beam commissioning of the RFQ is shown in Fig. 8. It consists of an ECR ion source, an LEBT system including two solenoids and a 90° bending magnet, two water-cooled Faraday cups (FC), the RFQ, a fast current transformer (FCT), a beam position monitor (BPM), and a water-cooled beam dump (BD). The RFQ will be driven by two solid-state RF amplifiers of 80 kW through two couplers.

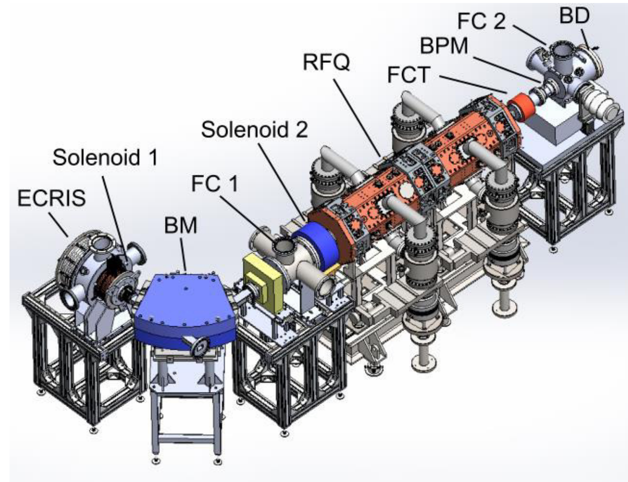

Figure 8: Schematic view of the RFQ test system.

CONCLUSION

The window-type RFQ has been successfully fabricated, and the RF measurements showed good agreements with the simulations. Now, we are preparing for the experimental setup. High-power test and beam commissioning will be performed soon in May and June of 2018.

ACKNOWLEDGEMENT

Authors would like to thank the engineers of the machining factory of IMP for high level RFQ fabrication. This work was supported by the National Basic Research Program of China (Grant No. 2014CB845503).

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