

PROGRESS OF A 162.5 MHz HIGH-CURRENT RFQ WITH COUPLING WINDOWS *

Qi Fu, Kun Zhu[†], Yuanrong Lu[†], Zhi Wang, Shuli Gao, Fangjian Jia, Pingping Gan, Haipeng Li, State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing, China

Abstract

A 162.5 MHz, four-vane RFQ with magnetic coupling windows has been designed by the RFQ group of Peking University. Clear frequency separation of the resonant modes and smaller transverse dimension are the advantages of the window-type RFQ. The electromagnetic simulations have shown that the average power loss of this 1.809 m long RFQ is about 50 kW in continuous wave mode. Consequently, a water cooling system was designed via the multi-physics analysis. The mechanical design and assembling technology were also presented in this paper.

INTRODUCTION

The copper prototype of a four-vane RFQ with coupling windows, which combines the characteristics of traditional four-vane RFQ and that of four-rod [1], is ready to be manufactured. It will accelerate deuteron from 50 keV to 1 MeV, and operate at 162.5 MHz of mode TE₂₁₀ with Δf of 3.144 MHz from mode TE₁₁₀ [2]. At present, the aircraft aluminium model has been finished and tested. It confirmed the results calculated by either CST MWS or HFSS [3].

The multi-physics analysis is a complete loop of coupled numerical simulations, as shown in Fig. 1 [4]. Surface current induced by magnetic field is simulated in CST MWS, and it is used to calculate the thermal losses, which can be imported to MPS for thermal analysis. Then, the structure stresses and deformation field can be obtained by coupling the optimized temperature field to the Mechanical Solver. Finally, sensitive analysis in CST MWS realizes the estimate for frequency shift caused by structure deformation.

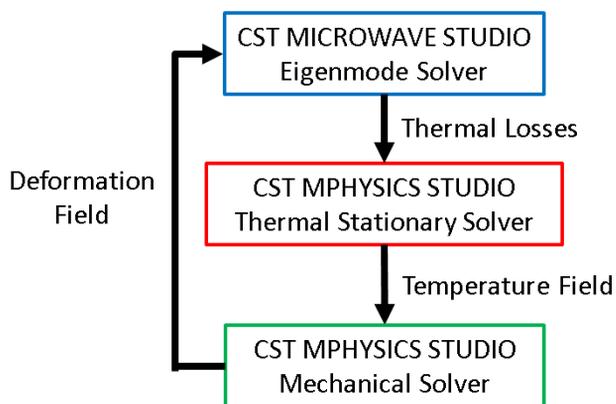


Figure 1: The multi-physics analysis scheme based on CST.

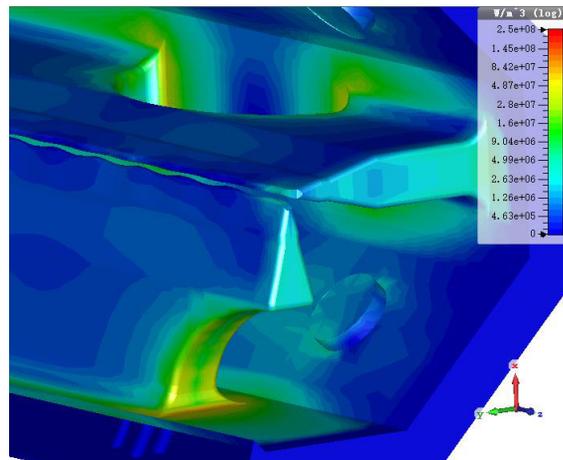


Figure 2: Power loss distribution.

RF ANALYSIS

The electromagnetic performance of this RFQ, calculated by CST MWS, has been shown in earlier paper. For improving the field flatness affected by the vane modulation, the tuners and some optimizations of the coupling windows were considered in recent RF study. The new parameters of this RFQ are summarized in Table 1. The resonant frequency of the RFQ was tuned to 162.522 MHz and Q value nearly 9000 with electric conductivity of 5.0×10^7 S/m. The total power losses of the cavity were 46.5kW, while the inter-vane voltage was normalized to 60 kV.

Table 1: The Main Parameters of the RFQ

Parameters	Value
Frequency [MHz]	162.522
Nearest mode (TE ₁₁₀) [MHz]	165.666
Mode separation [MHz]	3.144
Quality factor	8999.0
Power loss [kW]	46.523
Special shunt impedance [kΩ·m]	69.991
Inner cavity diameter [mm]	340.00
Length of the RFQ vanes [m]	1.809

Loss distribution indicated that the maximum loss appears in the corners of the windows on both cavity ends, as shown in Fig. 2. Thus, a water cooling system was needed to control the temperature in the cavity, especially around the coupling windows.

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[†] Corresponding author: zhukun@pku.edu.cn; yrlyu@pku.edu.cn

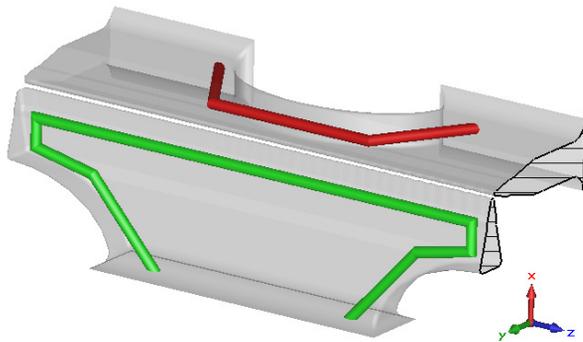


Figure 3: The initial cooling channels.

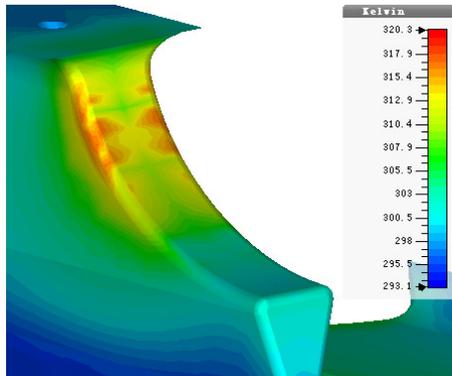


Figure 4: The initial temperature map of RFQ cavity.

THERMAL ANALYSIS

The initial cooling channels around the windows are shown in Fig. 3. There are some ways to improve the cooling efficiency, such as increasing the diameter or making the water channel closer to the vane surface. Within the mechanical limitation, each channel diameter has been expanded to 12 mm and the channel positions have also been optimized. By previous experience, the flow velocity was set to 2.3 m/s, the temperature of cooling water 18 °C and background temperature 22 °C. In order to simplify the thermal analysis, the average heat transfer coefficient of the channel surfaces was adopted, which can be obtained from the formulas [5]. The simulation results shown in Fig. 4 indicated that a single channel cannot provide enough capacity to control the temperature on the two edges of the windows corners.

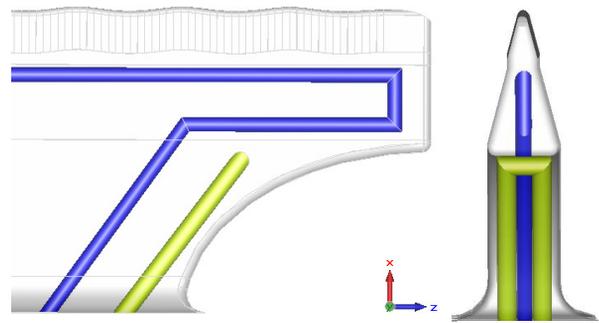
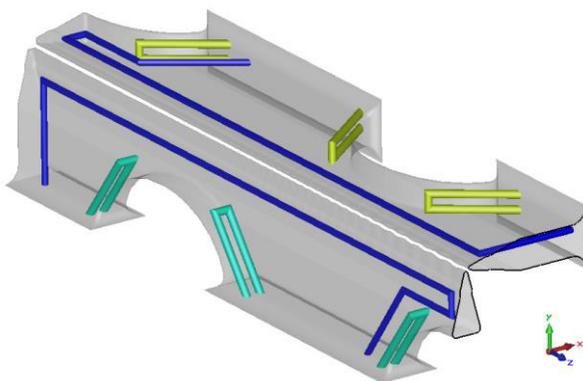


Figure 5: Multi-view of optimized cooling channels.

Therefore, a new layout of cooling channels was designed, as shown in Fig. 5. Compared to the initial design, the short channels near coupling windows not only increased the cooling area but also reduced the temperature rise through long path. The diameter of the channels for windows cooling was 10 mm and that for vane tips cooling was 8 mm. The corresponding simulation results shown in Fig. 6 indicated that the maximal temperature rise was reduced by 5.5 °C after optimizations.

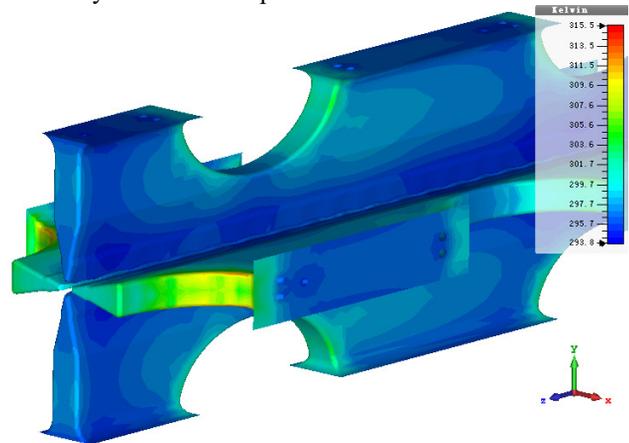


Figure 6: The optimized temperature map of RFQ cavity.

MECHANICAL ANALYSIS

The vane base was considered to be fixed in the mechanical simulations. Based on the optimized temperature map, simulations of deformation field were carried out and showed in Fig. 7.

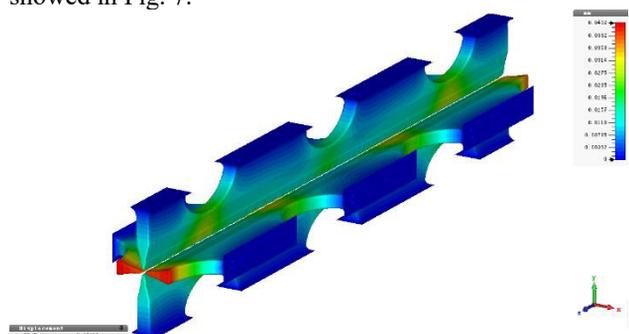


Figure 7: Deformation field on the vanes.

The lack of support structure and high temperature at the windows led to the vane tip deformation and the maximal temperature in the ends of the two horizontal vanes, which

resulted in the beam aperture decrease and frequency change. The results of multi-physics analysis are given in Table 2. The frequency shift of optimized design is nearly 40 kHz lower than that of the initial design.

Table 2: Comparison of the multi-physics analysis between the initial and optimized designs.

Parameters	Initial design	Optimized design
Inter-vane voltage [kV]	60	
Cooling water velocity [m/s]	2.3	
Cooling water temperature [°C]	18	
Maximal temperature rise [°C]	27.2	21.7
Maximal equivalent stress [MPa]	161.6	84.5
Maximal absolute deformation [µm]	61.5	43.2
Frequency shift [kHz]	-248.1	-209.9

MECHANICAL DESIGN

The whole RFQ cavity is assembled by two sections and each consists of four vanes and four cavity walls, as shown in Fig. 8. The total 28 tuners of 60 mm diameter equally placed in four quadrants will provide a maximal 2.5 MHz frequency tuning with 60 mm depth. Four vacuum pumps with eight vacuum ports are set to fulfil the high vacuum. A general view of the RFQ (without cooling and power coupling system) is shown in Fig. 9.

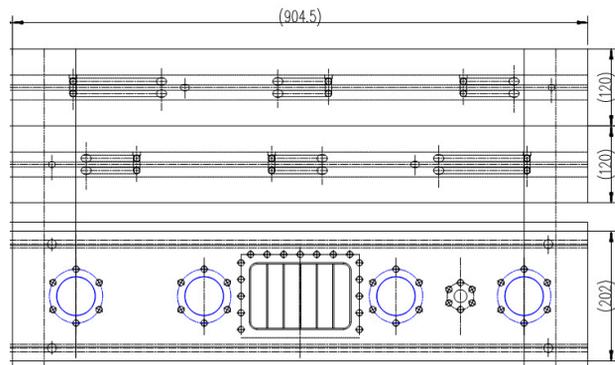


Figure 8: The external view of one section of vanes and cavity walls.

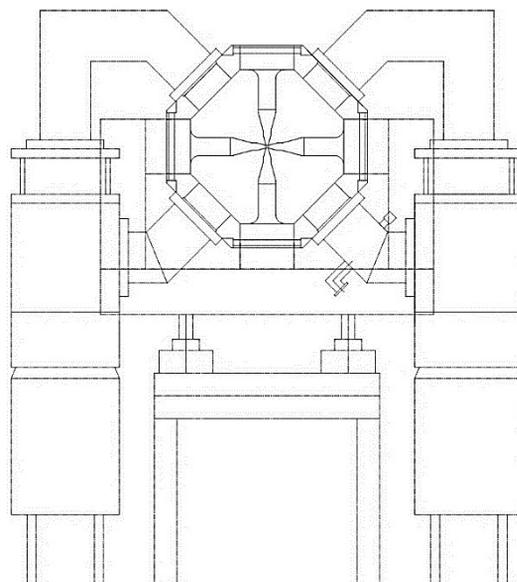


Figure 9: The schematic of RFQ cavity, support and vacuum system.

CONCLUSION

By using CST, we carried out the multi-physics analysis for the window-type RFQ and obtained the optimized cooling system, which dramatically decreases the frequency shift of the initial design. The mechanical design was also accomplished and will be manufactured soon. The design for power coupling system is under progress.

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