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THE MULTI-PHYSICS ANALYSIS OF LEAF RFQ

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Abstract

The 81.25 MHz CW RFQ is designed to accelerate heavy ions with Q/A from 1/7 to 1/2 at 0.5 MeV/u for the Low Energy Accelerator Facility (LEAF) at the Institute of Modern Physics (IMP) of the Chinese Academy of Science (CAS). The four-vane RFQ consists of six modules with a total length of 5.95 meters, For the CW operating mode, thermal management will be a very important issue, Therefore a multi-physics analysis is necessary to ensure that the cavity can stably operate at the high RF power . The multi-physics analysis process includes RF electromagnetic analysis, thermal analysis, mechanical analysis, and the frequency shift, the cooling water system is used for frequency tunning by the temperature adjustment, and also analyze RFQ undercuts, fixed tuners, and pi-mode rods, the results show that the thermal and structural design of this RFQ is reasonable.

INTRODUCTION

The LEAF project is being developed at the Institute of Modern Physics(IMP), composed of superconducting ECR ion source, low energy beam transport line (LEBT), CW radio frequency quadrupole accelerator (RFQ), medium energy beam transport line(MEBT) and an experimental platform [1], the layout of the LEAF project is shown in Fig. 1.

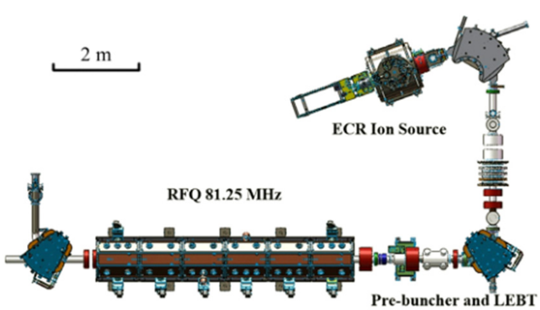

Figure 1: The layout of the LEAF project.

The four-vane RFQ will accelerate heavy ions beams from from 14 keV/u up to 500 keV/u. The operating frequency is 81.25 MHz. The PI-mode rods are used for frequency separation. The cavity will be divided into six segments about 5.95m long. The oxygen-free high-conductivity copper (OFHC) is adopted because of its good heat conduction performance and. An octagon cavity structure is chosen for its structural stability to avoid cavity deformation and convenient design of water cooling system [2].

For high power CW RFQ, the thermal issue will cause structure deformation, frequency shift, and other harmonics. So it's very important to calculate the deformation and evaluate its influence to the electromagnetic field in theory. The thermal and structural distortion of the cavity is calculated by ANSYS code [3], both the temperature rise and the frequency shift can be controlled in an acceptable level according to the optimization of the cooling water design.

The main parameters of the RFQ are listed in Table 1.

Table 1: The Main Parameters of the RFQ

Parameters	Value
Frequency (MHz)	81.25
Injection/Output energy (keV/u)	14/500
Design charge-to-mass ratio	1/7-1/2
Inter-vane voltage (kV)	70
Kilpatrick factor	1.55
Peak current (emA)	2
Transmission efficiency (%)	97.2
Length of the vane (mm)	5946.92
Average radius of the aperture (mm)	5.805

THIN SLICE MODEL SIMULATION

The multi-physics analysis procedure include RF electromagnetic, thermal and mechanical analysis [4], A 1/4 part of the cross section is used for simulation due to symmetry, thin slice model with water cooling channels are shown in Fig. 2.

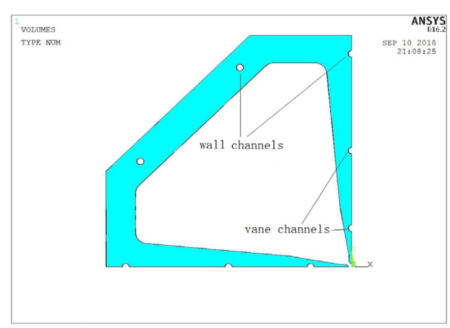

Figure 2: Thin slice model with water cooling channels.

The RF analysis has been carried out with ANSYS code, the result gives RF power losses in cavity in order to obtain a temperature map.

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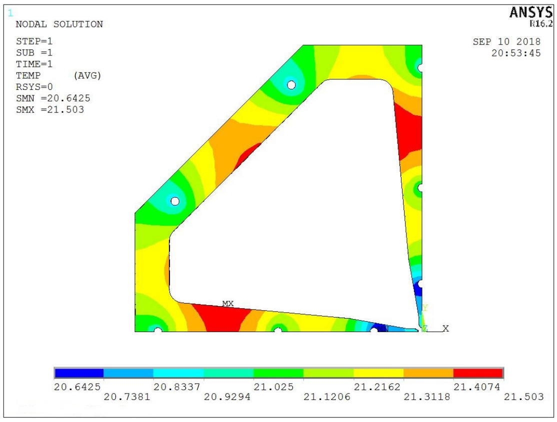

Figure 3: The temperature distribution of the RFQ.

The tempreture distribution from the thermal analysis is shown in Fig. 3, the heat load is produced by the RF power losses which is applied to the inner cavity wall surfaces, according to the optimization for channel position, channel diameter, fluid and velocity temperature, the maximum temperature is 21.5℃ and is located at the vanetips, the RFQ cavity temperature only rises 2℃ above initial water temperature. This temperature rise causes deformation and resonant frequency shift of the cavity.

The water cooling channels parameters are listed in Table 2.

Table 2: The Water Cooling Channels Parameters

	vane/wall
Diameter (mm)	12
Flow speed (m/s)	2.29
Number of Channels (/unit)	4/4
Heat transfer coefficient (W/m2.K)	9723

The final heat flux is coupled to a mechanics structrue to estimates the stress and deformation due to thermal expansion. The frequency shift is obtained through a new RF simulate of the deformed structure.

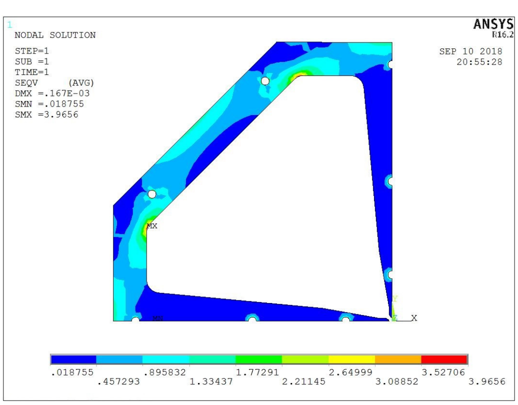

Figure 4: The von-Mises stress distribution of the RFQ.

The von-Mises stress distribution is shown in Fig. 4, the maximum stress is 3.9656 MPa at the corners of cavity, the displacement distribution is given in Fig. 5, the maximum displacement is 0.167mm around the external wall.

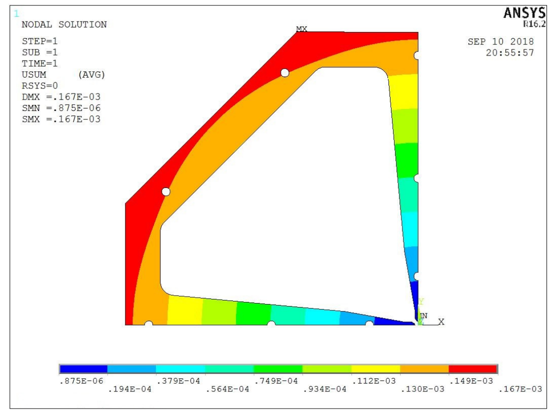

Figure 5: The displacement distribution of the RFQ.

The displacement of the cavity will cause the frequency shift. The final frequency were calculated with the ANSYS code according to the new cavity geometry which represents the steady-state operating condition, The frequency shift is -26.3 kHz compared with the initial frequency.

RFQ UNDERCUTS SIMULATION

The RFQ undercuts are simulated by a similar mean as the thin slice model with the ANSYS code, the tempreture result is shown in Fig. 6. The maximum temperature occurs at the tips of the cutbacks, where the water cooling channels can't distribution.

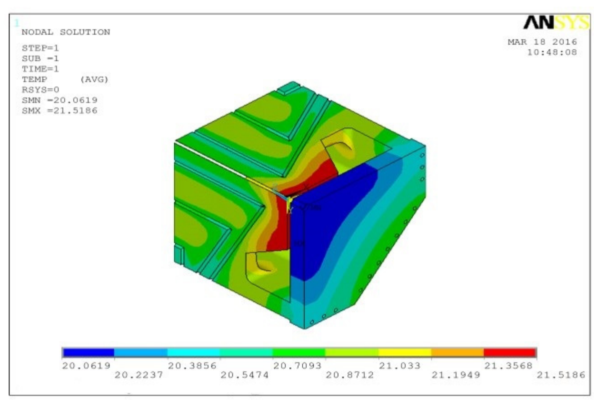

Figure 6: The temperature distributions of the RFQ undercuts.

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RFQ TUNERS AND PI-MODE RODS SIMULATION

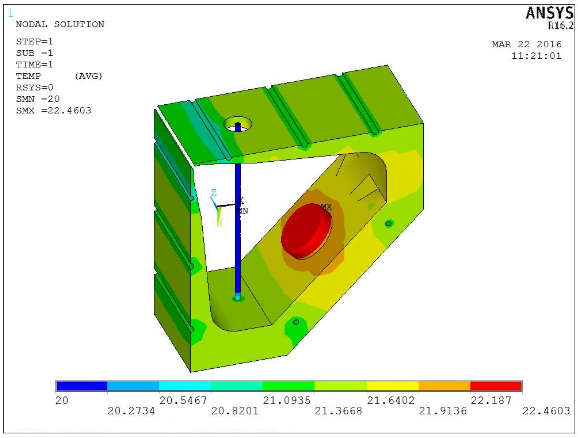

Figure 7: The temperature distributions of the tuners and Pi-mode rods.

There are totally twenty water cooling channels distributed over of the RFQ and one water cooling channel per Pi-rod. The temperature distributions of the RFQ tuners and Pi-mode rods is shown in Fig. 7, the maximum temperature of the RFQ is 22.46°C which is located in the tuners. The tuners will work safely without water cooling.

CONCLUSIONS

The multi-physics analysis of the LEAF RFQ has been accomplished including the RF, thermal and structural simulations using thin slide model, undercuts model, tuners and Pi-mode rods model. The results show that the cooling water system can meet the requirements of RFQ operating at CW full power. The multi-physics results provide the data for RFQ frequency tuning strategy.

REFERENCES

[1] W. Ma, L. Lu, T. Liu *et al.*, "Three-dimensional multiphysics analysis and commissioning frequency tuning strategy of a radio-frequency quadrupole accelerator", *Nucl. Instrum. Methods Phys. Res.*, vol. 866, pp. 190–195, 2017.

[2] W. Jing, H. Long, H. Yuan *et al.*, "Multi- Physics analysis of the RFQ for the injector scheme II of CADS driver linac", *Chinese Physics C*, vol. 38 , pp. 97-101, 2014.

[3] ANSYS, `http://www.ansys.com`

[4] A.K. Orduz, C. Bontoiu, A. Berjillos *et al.*, "Thermal and structural analysis of the 72.75 MHz lince RFQ", in *Proc. 6th Int. Particle Accelerator Conf. (IPAC'15)*, Richmond, VA, USA, May 2015, pp. 3857-3860.