STRUCTURAL ANALYSIS OF THE NEW-SHAPED QWR FOR HIAF IN IMP*

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Abstract

Since the QWR cavity is very successful for the operation with frequency of 48 to 160 MHz and beta value of 0.001 to 0.2, a new-shaped QWR is being designed for the low energy superconducting section of HIAF in the Institute of Modern Physics [1]. The cavity will work at 81.25 MHz and beta of 0.085，with an elliptical cylinder outer conductor to better its electro-magnetic performance and keep limited accelerating space. Structural design is an important aspect of the overall cavity implementation, and in order to minimize the frequency shift of the cavity due to the helium bath pressure fluctuations, the Lorentz force and microphonics excitation, stiffening elements have to be applied. In this paper, structural analyses of the new-shaped QWR are presented and stiffening methods are explored.

INTRODUCTION

A stable resonant frequency for the superconducting cavity is desired, because excessive frequency fluctuations require extra power to control the RF amplitude and phase. The reasons that lead to frequency fluctuations include the fluctuations in the liquid helium pressure, Lorentz force detuning, mechanical vibration modes and the etching effect from the cavity surface treatment. Since the operating temperature for the QWR cavities is 4.5 K, the helium pressure stability will be determined by the extent to which the cryogenic plant can be controlled. The stiffening measures were intended primarily to reduce the pressure sensitivity.

MECHANICAL SIMULATION

When the EM design has been completed, the mechanical performance of the cavity should be evaluated. We tried to figure out the cavity's helium pressure sensitivity, severity of Lorentz Force Detuning plus the vibration frequency of mechanical modes, and further, to minimize the instabilities using different stiffening measures. Simulations and optimizations have been done by the 3D Multiphysics solver ANSYS-APDL [2]. In the simulation, niobium sheet of 3 mm thickness was firstly used, with the mechanical properties of Young modulus of 105000 N/mm2, Poisson ratio of 0.38 （see Fig. 1）.

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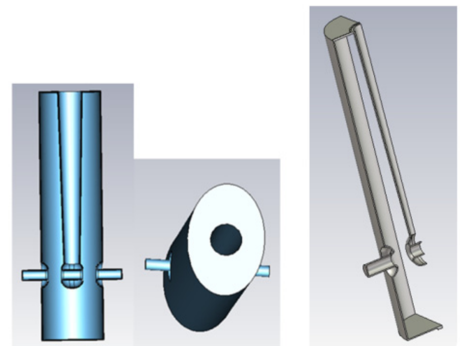

Figure 1: Mechanical model of the elliptical cylinder outer conductor QWR for the structural analysis.

Etching Effects

Surface processing is very important in order to achieve good performance of the superconducting cavity. Either the BCP or the EP is to etch proper thickness of the inner surface, which will change the frequency. According to Slater's perturbation theory, a small deformation in the cavity boundary will lead to a frequency shift.

Using the ANSYS-APDL code, the change in the frequency because of the etching can be calculated. Firstly, you have to get the electro-magnetic field distribution, and then the frequency change caused by the cavity wall's deformation can be obtained. The simulation results show that 1 μm etching thickness will lead to 27Hz increase in the frequency.

Lorentz Force Detuning

The Lorentz force on the cavity surface results from the interaction of the surface electromagnetic fields with the induced surface currents, which will exert pressure to the cavity wall, and the resulting cavity shape deformation ΔV will cause the change in the resonant frequency. The frequency shift caused by Lorentz force is often quantified by K_L which is defined as: $K_L=\Delta f/(E_{acc})^2$.

If the cavity works at the continuous wave mode, then the frequency change will be invariant, it is the static Lorentz force detuning; otherwise, when the cavity works at the pulsed wave mode, the dynamic Lorentz force detuning will be caused. In this paper, only the static situation was considered and 2.5 MV accelerating voltage was to be scaled for the naked cavity whose

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beam port is fixed. The simulation result gives the K_L with the value of -0.34 Hz/(MV/m)2 (see Fig. 2).

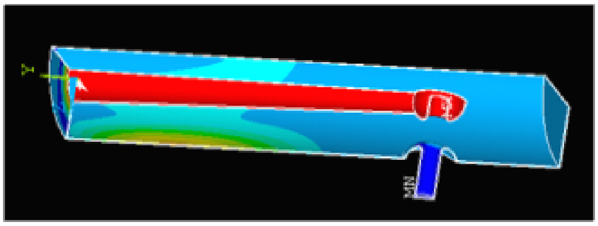

Figure 2: Deformation of the elliptical cylinder outer conductor QWR caused by Lorentz force.

Mechanical Vibration Modes

Mechanical wave in the environment can be transmitted to the cavity by various mediums, and the cavity can resonate mechanically at certain frequencies. Firstly, the naked cavity was simulated for its three lowest modes and results are shown as following, with the vibration frequency of 11 Hz, 13 Hz and 20 Hz, respectively (see Fig. 3).

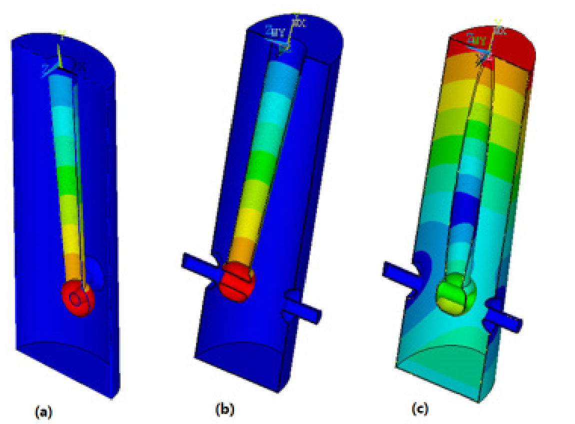

Figure 3: The lowest three vibration modes for the new-shaped naked QWR cavity.

Secondly, stiffening elements were added. A stiffening ring was added on the shorting plate and fixed in the simulation, and in order to reflect more accurately the influence of the tuner, the tuner button was fixed too (see Fig. 4-up). Different radius rings were tested to find out the strengthening effect (see Fig. 4-down). Obviously, the smallest radius ring with 60 mm can increase the mechanical frequency the highest. The vibration mode for the 60 mm stiffened-ring QWR is illustrated in Fig. 5.

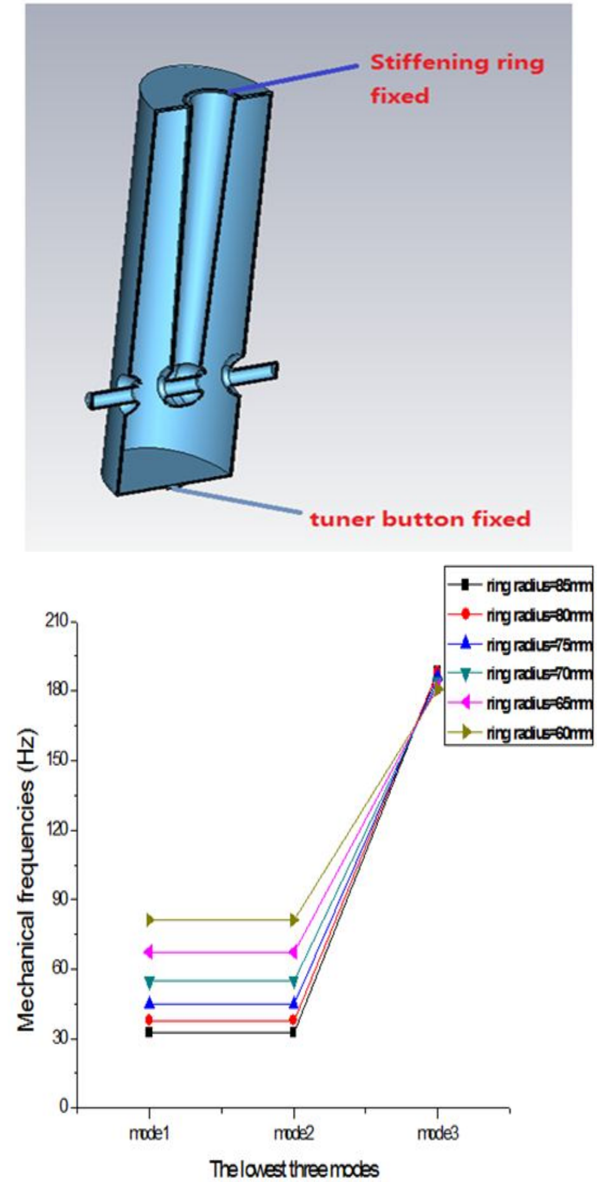

Figure 4: Stiffening ring on the short plate (up); the lowest three vibration modes frequency on the dependence of the radius of stiffening ring (down).

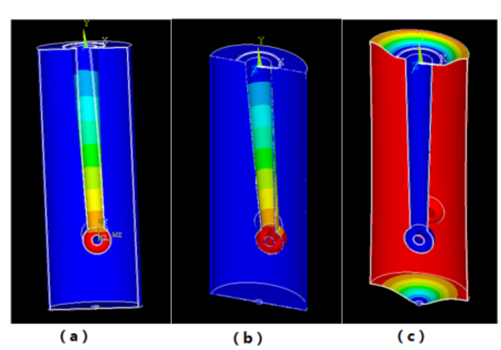

Figure 5: The lowest three vibration modes for stiffened-ring with radius 60mm QWR cavity.

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Helium Pressure Detuning

In operation, the superconducting quarter wave resonator cavity with frequency of 81.25 MHz works at 4.3K, at which temperature the liquid helium's pressure fluctuates momently. The optimization goal of the mechanical design should be to minimize the cavity's pressure sensitivity. Mechanical simulations were done to quantify the displacements and the resulting frequency vibration from a constant pressure outside the cavity wall [3].

Firstly, the model we used is the one which have the stiffening ring with radius of 60mm and found that the max displacement appeared on the outer conductor corresponding to longer axis of the elliptical cylinder (see Fig. 6).; then we added two supporting rods on the shorting plate attempting to decrease the deformation caused by squeezing on the cavity wall, but the efficacy is not so good (see Fig. 7); later, thicker material (4mm) was used for the cavity wall and the simulation results showed the max displacement was reduced more than in a factor of 2 (see Fig. 8).

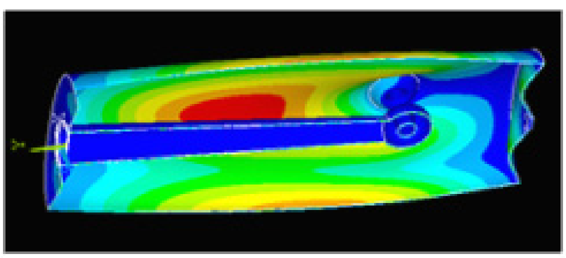

Figure 6: Deformation of ring-stiffened QWR caused by the external pressure, the frequency shift Δf due to the change in ambient pressure ΔP: df/dP~-37 Hz/mbar.

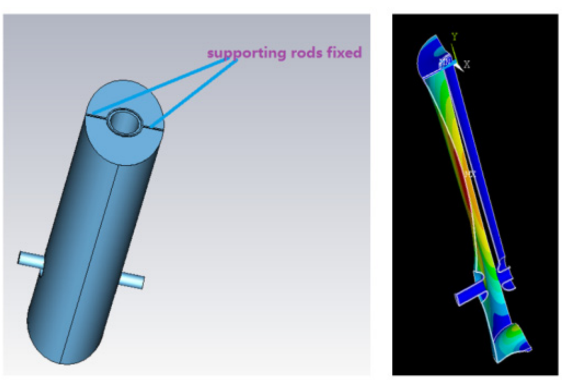

Figure7: Supporting rods on the short plate (left); deformation of ring-and-supporting-rods-stiffened QWR by external pressure: df/dP~-29 Hz/mbar.

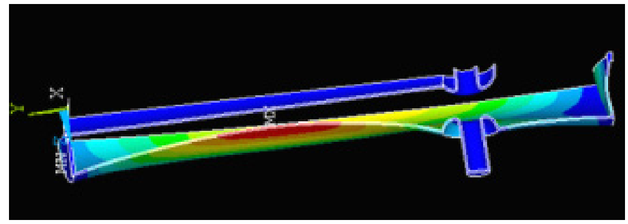

Figure 8: Deformation of ring-and-supporting-rods –stiffened-and-thickened QWR by external pressure: df/dP~-11 Hz/mbar.

CONCLUSIONS

Numerical models have been used to predict the stability of the elliptical cylinder outer conductor quarter wave resonator and relevant stiffening elements have been explored. Major flaws have been encountered in the mechanical models due to the outer conductor's elliptical cylinder shape. Better stiffening measures should be kept searching. In the next stage, the cavity with helium vessel need to be simulated and the fabrication of prototype should be carried out to verify experimentally the mechanical performance.

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