

MECHANICAL DESIGN OF A 650 MHZ SUPERCONDUCTING RF CAVITY FOR CEPC*

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Abstract

A 650 MHz superconducting RF cavities have been proposed by IHEP for the Circular Electron-Positron Collider (CEPC). The major components are a 2-cell elliptical cavity, end groups, stiffness and helium vessel, which have been optimized to meet the design requirement. The minimization of the Lorentz force detuning and the sensitivity of resonance frequency to Helium pressure variations was the main goal of the optimization. Also detailed stress analysis, tuning and microphonics performance of dresses cavity will be presented in this paper.

INTRODUCTION

As the Higgs boson has been discovered in 2012, some proposals are being raised building a Higgs factory for further fine measurement of the new particle. Circular Electron-Positron Collider (CEPC) has been launched by IHEP to study of a 50-100 km ring collider [1], and now is under extensive design. The CEPC baseline accelerator [2] is a fully partial double ring configuration with a circumference of 100 km and the RF system for Higgs, W and Z operation [3] in each beam line of electron and positron as shown in Fig. 1. The layout and parameters of SRF system [4] are chosen to meet the minimum luminosity requirement for each operating energy, and with possible higher luminosity.

For CEPC collider, 650 MHz 2-cell superconducting RF cavities shared between the two collider rings has been proposed to operate in CW mode at 2 K. The main RF parameters of the 650 MHz 2-cell cavity [5] are listed in Table 1. There are 56 cryomodules in the main ring, and each of the 10 m-long collider cryomodule contains six 650 MHz cavities [2], as shown in Fig. 2. So the number of 650 MHz 2-cell cavities needed in the main ring is 336.

Table 1: Parameters of 650 MHz 2-cell Cavity

Parameters	value
R/Q	212.7 Ω
G	284.1 Ω
E_p/E_{acc}	2.38
B_p/E_{acc}	4.17 mT/(MV/m)
length	1060 mm
equator diameter	410 mm

This paper reports the mechanical design and optimization of the 650MHz 2-cell elliptical cavity. The pressure sensitivity, cavity rigidity, Lorentz force detuning (LFD), stress

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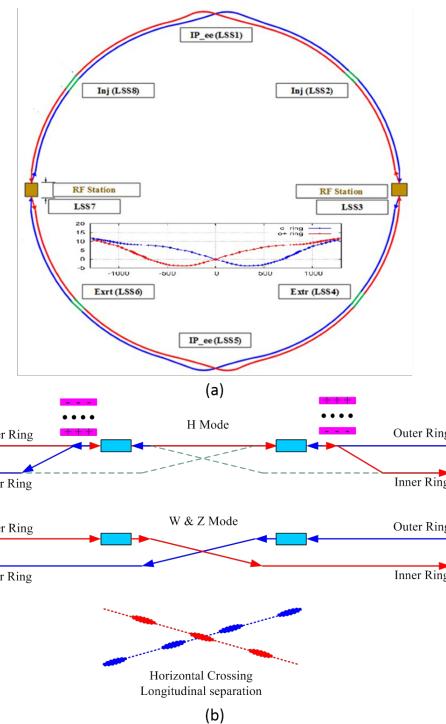


Figure 1: The CEPC baseline design (a) and one section of RF station layout (b).

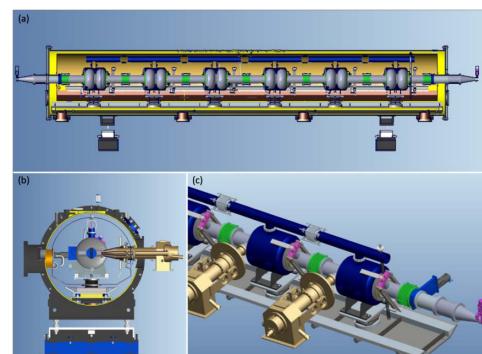


Figure 2: The layout of 650MHz 2-cell cavities in cryomodules.

analysis and Microphonics have been studied to improve the mechanical stability.

THE MODEL

The mechanical model includes the cavity, stiffness, end-groups and liquid helium (LHe) vessel, and the material of them are niobium with RRR300, niobium, Ti-45Nb alloy and titanium respectively, as shown in Fig. 3. The maximum allowable stress (S) at room temperature of Niobium,

Ti-45Nb alloy and titanium are 47 MPa, 156 MPa and 98 MPa.

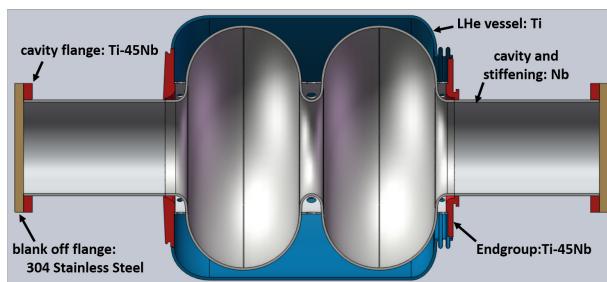


Figure 3: The model of 650 MHz 2-cell cavity.

Compared to 3 mm, the cavity wall thickness was chosen to be 4 mm. Because the helium pressure sensitivity will be reduced by about 30%, from -295 Hz/mbar to -185 Hz/mbar. Meanwhile, the LFD coefficient decreased from $-8.2 \text{ Hz}/(\text{MV}/\text{m})^2$ to $-7.4 \text{ Hz}/(\text{MV}/\text{m})^2$. A stiffening rings were added to the cavity to minimize the LFD, and the thickness of stiffness is 3 mm. The helium vessel was constructed using 5 mm thick titanium sheets and 0.4 mm thick titanium bellows.

The mechanical design of the 650 MHz 2-cell cavity was optimized using SolidWorks [6] and ANSYS [7].

STIFFNESS POSITION OPTIMIZATION

In one ring option, the cavity stiffness only depend on the position of the ring R. We change the R from 102 mm to 110 mm and calculated the stress under 2 load conditions of the cavity, evacuated and under helium pressure. In these simulations we keep left beam port flange fixed.

The results of 650 MHz 2-cell cavity under evacuation is shown in Fig. 4. The peak von Mises stress is located at the bellows, and the maximum deformation is at the iris. The deformation and stress vary linearly with the increase of R. When R is larger than 106 mm, the stress meets the safety requirement.

Under 2 bar LHe pressure, the results are shown in Fig. 5. The areas applied load is the outside of the cavity shell and the inside of the LHe vessel. The deformation and stress decrease in a fluctuation way with the increase of R.

According to the optimization results, the radius of stiffening ring position is adopted to be 108 mm, which can improve the strength of the cavity and avoid the cavity over stiffening.

PRESSURE SENSITIVITY

The cavity operates at 2 K in the liquid helium bath. The cavity frequency dependence on changes in external pressure is called pressure sensitivity (df/dp). The boundary condition is left beam port fixed, and the calculated df/dp is $-68.7 \text{ Hz}/\text{mbar}$. Our previous experience indicates a helium pressure fluctuation of about 2 mbar. This results in a frequency shift of 137.4 Hz which should be considered

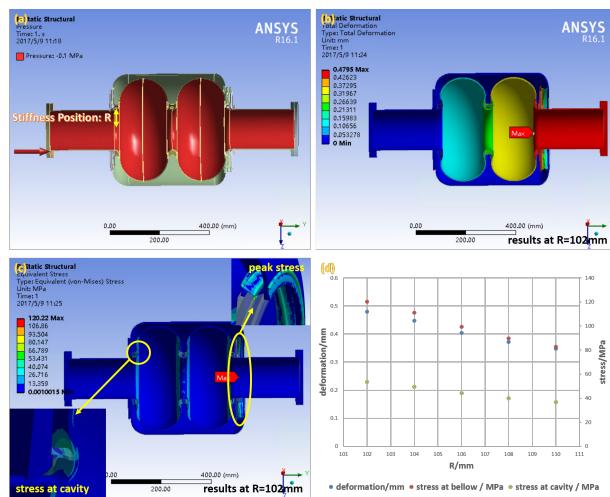


Figure 4: The results of 650 MHz 2-cell cavity under evacuation.

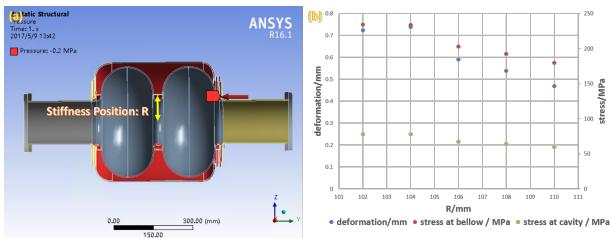


Figure 5: The results of 650 MHz 2-cell cavity under 2 bar LHe pressure.

during tuner design. Increasing the radius of the bellow can further reduce the helium pressure sensitivity.

The peak deformations and the peak von Mises stress of the cavity are shown in Fig. 6. The results vary linearly with the pressure changes. We consider the maximum pressure of the liquid helium of 2 bar. The peak stress is 44.5 MPa, which is under the allowable limits. The peak deformation and stress of the cavity under 2 bar of pressure are shown in Fig. 7.

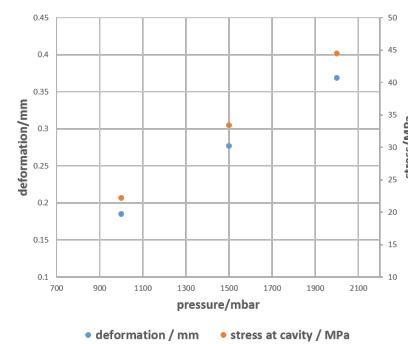


Figure 6: The peak deformation and stress of the cavity under different pressures.

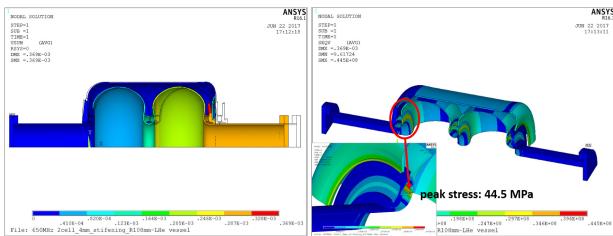


Figure 7: The peak deformation and stress of the cavity under 2 bar LHe pressures.

TUNING

The tuning force is applied on the right endgroup, and the left port is fixed, as shown in Fig. 8. Calculated tuning sensitivity is 310 kHz/mm, and stiffness is 16 kN/mm. The peak deformation and peak von Mises stress under 3 kN are shown in Fig. 9. The max tuning force is about 7.8 kN (the stress will reach allowable limits), and the tuning range is about 151.8 kHz. The tuning range will increase appropriately when the cavity is cool down to 4.2 K or 2 K.

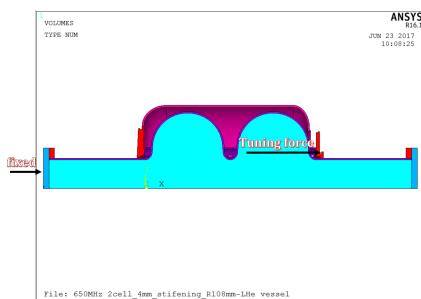


Figure 8: The load and boundary conditions of tuning.

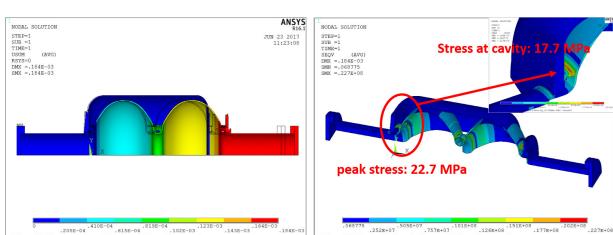


Figure 9: The peak deformation and peak von Mises stress under 3 kN.

LORENTZ FORCE DETUNING

The Lorentz force detuning is simulated with the left port fixed condition. The calculated results is shown in Fig. 10, and the LFD coefficient is $-4.16 \text{ Hz}/(\text{MV/m})^2$. The peak deformation of the 650 MHz 2-cell cavity is the high electric field region, which is shown in Fig. 11. A possible solution to further reduce the LFD is adding the second stiffening ring or change the position of the stiffening ring of the cavity.

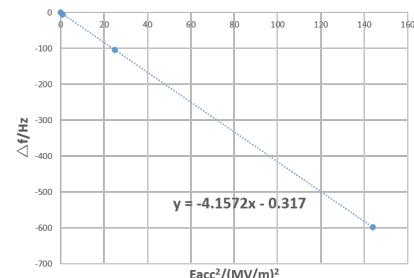


Figure 10: The LFD coefficient result of 650 MHz cavity.

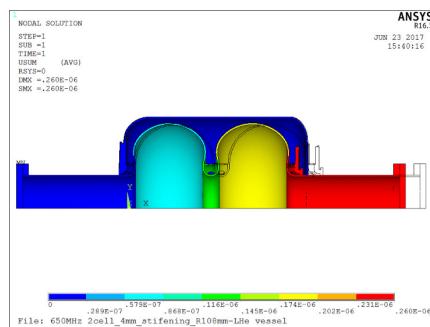


Figure 11: The peak deformation due to Lorentz force at 5 MV/m.

MICROPHONICS

The microphonics is studied with the boundary conditions, left port is fixed and part of the right endgroup is added cylindrical support. The boundary conditions are shown in Fig. 12. The first six resonant modes are summarized in Table 2, and the corresponding deformation results are summarized in Fig. 13. All mode's frequencies are above 200 Hz.

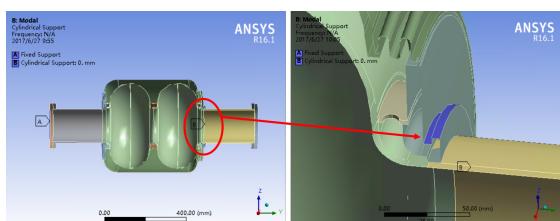


Figure 12: The boundary conditions of the calculations.

CONCLUSION

In this paper, the mechanical design and analysis of the dressed 650 MHz 2-cell cavity are described systematically. The thickness of the cavity wall and the position of the stiffening ring are optimized to minimize the Lorentz force detuning, $\Delta f/\Delta p$ and the peak stress. The tuning sensitivity also has been calculated, and a proper tuning range was obtained. The first six resonant modes are all above 200 Hz. In the next step, we can try to increase the radius of the bellow and add a second stiffening ring to further reduce the $\Delta f/\Delta p$ and the LFD.

Table 2: The First Six Resonant Modes of the 650 MHz Cavity

Mode	Frequency Hz	Vibration type
1	221.59	the cavity swings back and forth along X axis
2	254.71	the cavity swings back and forth along Z axis
3	274.07	the LHe vessel swings back and forth along Y axis
4	291.06	the right tube of cavity swings back and forth along X axis
5	364.91	the right tube of cavity swings back and forth along Z axis
6	392.21	the two cell rotates back and forth around the X axis

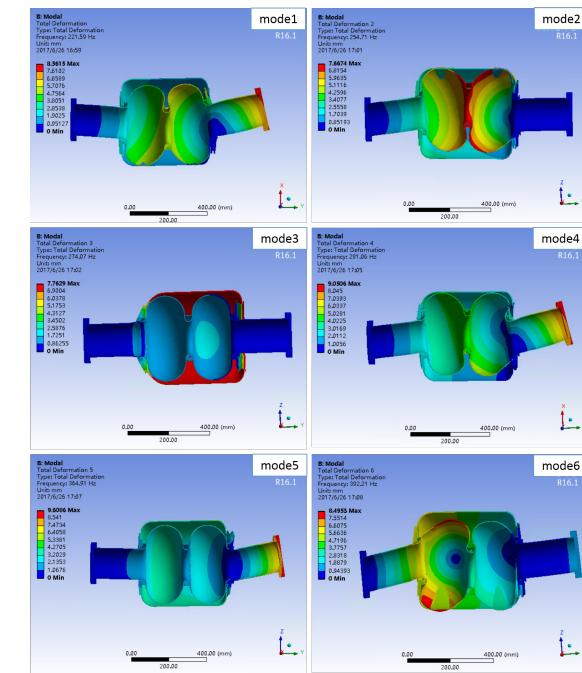


Figure 13: The first six resonant modes of the cavity.

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