PRELIMINARY DESIGN OF 325 MHZ HALF-WAVE RESONATOR*

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Abstract

The Half-Wave Resonator (HWR) has been widely used in proton and heavy ion accelerators, for it has particular advantages of accelerating low energy charged particles. Preliminary design of a 325 MHz β=0.12 superconducting HWR cavity has been proposed at Institute of High Energy Physics (IHEP). The basic geometric parameters choices of the cavity are based upon theoretical model and numerical calculation, and then the RF performances are optimized by extensive electromagnetic simulations. In this paper, the detailed mechanical analysis, frequency control, and the considerations for fabrication of the 325 MHz HWR cavity are also presented.

INTRODUCTION

The HWR, which works in meter wave band, has particular advantages of accelerating low energy charged particles, and it has been wildly used in proton and heavy ion accelerators. The HWR cavity is compact in structure and has the virtues of high performance, low cost and easy to access. Preliminary design of a 325 MHz HWR cavity is proposed in IHEP. The main requirements are listed in Table1.

Table 1: Main Requirements of the Cavity

Requirements	Description
Particle type	Proton
Frequency	325 MHz
β	0.12
Operating mode	CW
Operating Accelerating Voltage at β=0.12	0.5～0.7 MV/cavity
Beam current	10 mA

The main goal of excellent performance design is convenient to practicality, and the detailed process including electromagnetic (EM) design, mechanical analysis, and fabrication of the cavity is presented in this paper.

DESIGN

For the type of cavity, a large number of international design, develop, and experiences have been accumulated and provide us a great many of inspiration [1], especially the design from Half-Wave Resonator Cryomodule for Project X of Fermilab [2][3].

Considering the high average current, the aperture of the cavity is chosen as 35mm. The centre section is spherical, which may simplify the electron beam welding (EBW) of the ports as all the interfaces are circular. The top and bottom of the cavity has a rounded end, which is preferable if multipacting is a concern. Conical inner conductor helps to raise the shunt impedance, and the centre conductor is flattened to a racetrack shape near the iris. The geometric parameters of 325 MHz HWR are shown in Fig.1.

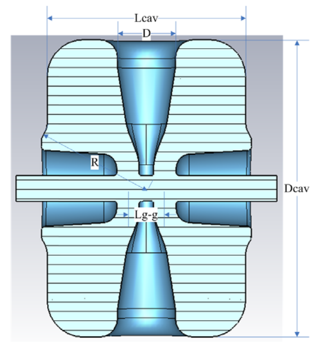

Figure 1: The cross section of the cavity with the main geometric parameters: L_{cav}=274 mm; D= 80 mm; D_{cav}=405.6 mm; R=160 mm; $L_{g\text{-}g}$= β λ/2=55 mm.

Electromagnetic Design

There are four RF parameters should be highly concerned during the design period: E_{peak}/E_{acc}, H_{peak}/E_{acc}, R/Q, and G. Perfect parameters need the lower E_{peak}/E_{acc}, H_{peak}/E_{acc}, and higher R/Q, G. In order to get a set of better RF properties, several geometric parameters of the 325 MHz HWR cavity were typically optimized, such as the L_{cav}, R, D_{cav} and so on. For example, one of the parameter sweep results is shown in Fig.2. From the Fig.2, the range is from 36 mm to 54 mm, E_{peak}/E_{acc}, R/Q, and G decrease greatly, while H_{peak}/E_{acc} increases. Comparing four aspects of factors, 46 mm is adopted for the inner radius of the nose cone for a trade-off.

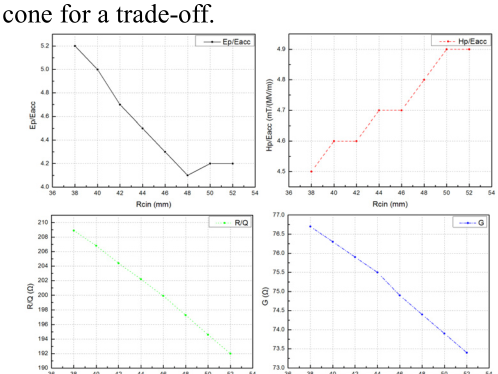

Figure 2: The sweep results of inner radius of nose cone.

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As a preliminary optimization result, electromagnetic field distributions are shown in Fig.3, and RF parameters of the cavity are listed in Table 2.

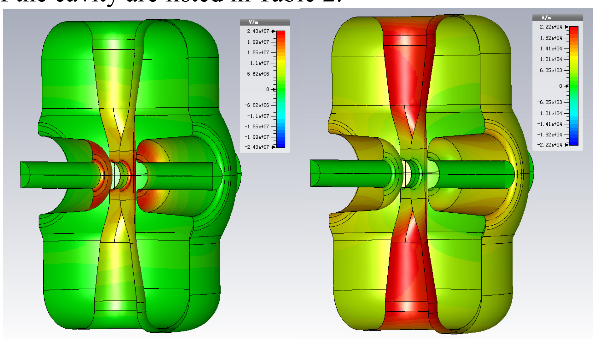

Figure 3: Electric field distribution (left) and magnetic field distribution (right) of the cavity.

Table 2: RF Parameters of the Cavity

RF parameters	Result
E_{peak}/E_{acc}	4.2
H_{peak}/E_{acc}	4.8 mT/(MV/m)
R/Q	198.8 Ω
G	73 Ω

In the EM design and optimization, tetrahedral mesh type and the symmetry of the boundary condition are used, which significantly reduce the simulation time. Additionally, the RF parameters' convergence by tetrahedral mesh type is also studied, which is shown in Fig.4. We can see that 1000K of the mesh cells is enough.

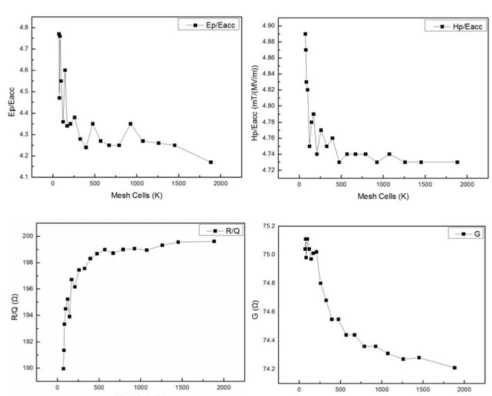

Figure 4: RF parameters' convergence of mesh cells.

The multipacting analysis is done using Track3P module developed by SLAC [4]. Typical SEY (Secondary Emission Yield) curve for niobium of 300° bake out is shown in Fig.5. From the Fig.5, we can see that the multipacting rang of kinetic energy is about from 70 eV to 1600 eV. The resonant energy of every resonant particle left on every scanned accelerating gradient and the resonant particles locations are shown in Fig.6. From the Fig.6, we can see that multipacting may happen at 2.9 MV/m, 4.3 MV/m, and 8.8 MV/m. As the position of resonant particles on 8.8 MV/m located in the couplers, it may be introduced by the setting of the module. Therefore, when the accelerating gradient is higher than 4.5MV/m, there will be no multipacting happened.

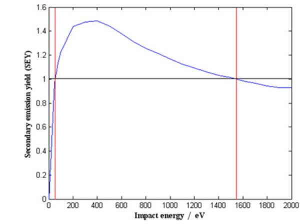

Figure 5: SEY curve for Niobium of 300℃ bake out.

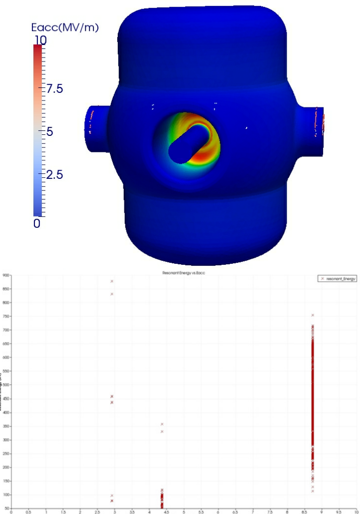

Figure 6: Multipacting location (upper) and multipacting resonant energy VS. E_{acc} (bottom) results from Track3P.

Mechanical Analysis

The mechanical properties of the cavity without ribs have been simulated using CAD software (SolidWorks) and ANSYS code. Material is assumed to be 3.0 mm. The results are shown in Fig.7 and Table 3.

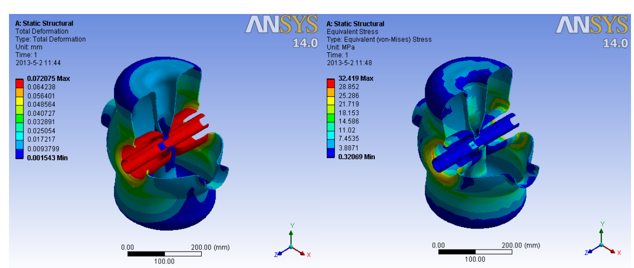

Figure 7: Simulation of deformation (left) and stress (right) for the cavity at 2 bar, and all the port are free.

Table 3: Mechanical Parameters of the Cavity

Mechanical parameters	Result
df/dp	0.13 KHz/Torr
Frequency sensitivity for tuning	1375 KHz/mm
Deformation sensitivity for tuning	0.13 mm/KN
Peak deformation under 1 bar with pipe free	0.04 mm

As shown in Fig. 7, the peak stress, 33 MPa, less than 55 MPa which is the maximum allowable stress. So the bare cavity as presented can tolerate 2 bar in room temperature and meets the maximum working pressure (MAWP) conditions [5]. In the Table 3, the pressure sensitivity (df/dp) is checked, and the geometry structure stability of the cavity is excellent.

The calculation of the mechanical resonance modes is performed by fixed the end of both beam tubes. The frequencies of the lowest six modes are listed in Table 4. All the frequencies of these modes are higher than the power frequency. The third mode seems not to be dangerous, for this mode does not cause a frequency shift. But the others are longitudinal and deleterious. Stiff ribs should be considered to reduce the influence of microphonics.

Table 4: Mechanical Resonance Modes of the Cavity

Mode	Frequency/Hz
1	92.76
2	114.43
3	142.1
4	156.9
5	190.4
6	238.4

Frequency Control

In order to get accurate frequency in the 4.2 K environment, the changes of frequency should be studied, and the results are shown in Table 5. So the frequency of the cavity after fabrication is 323.76 MHz.

Table 5: Frequency Changes of the Cavity

Description	Change	Frequency
4.2K, vacuum (1bar), operating frequency	0 KHz	325.0135 MHz
300K, vacuum (1bar)	-465 KHz	324.5503 MHz
300K, atmospheric pressure, neglect ε_r	+99.1 KHz	324.6494 MHz
300K, atmospheric pressure, +200 μm	-886 KHz	323.7634 MHz

FABRICATION

After careful electromagnetic and mechanical analysis, the whole cavity structure is determined. The fabrication starts with the machining of 22 individual parts, which is shown in Fig.8. The shell of this cavity is integral made by spinning forming, which may decrease the number of welds and reduces the risk taking by the welds.

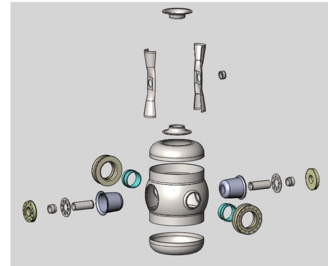

Figure 8: The exploded view of the cavity.

The fabrication sequence is shown in Fig.9. For the EBW, most of the welds are circle, which may greatly reduce the difficulty during the cavity's fabrication.

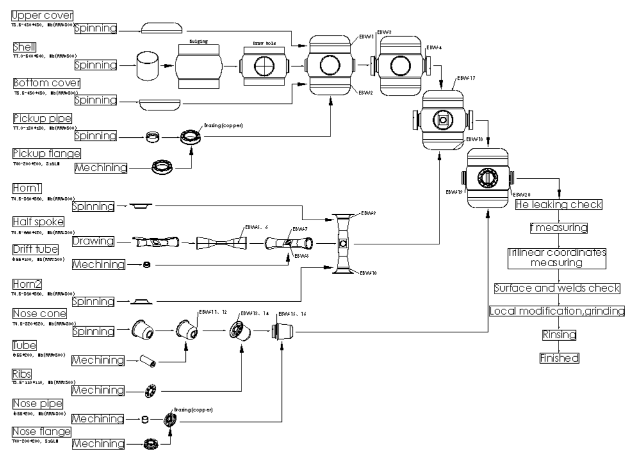

Figure 9: The fabrication sequence of the cavity.

CONCLUSION

The cavity structure has been designed carefully from the view of electromagnetic and mechanical optimization. According to the simulation results, the HWR cavity has a good performance which can satisfy design requirement well. In the future, the fabrication, post-processing and testing are the focus of our work.

ACKNOWLEDGMENT

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