MECHANICAL STUDY OF FIRST SUPERCONDUCTING HALF-WAVE RESONATOR FOR INJECTOR II OF CADS PROJECT*

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Abstract

Within the framework of the China Accelerator Driven Sub-critical System (CADS) project, institute of modern physics (IMP) has proposed a 162.5MHz half-wave resonator (HWR) Superconducting cavity for low energy section (β=0.09) of high power proton linear accelerators. For the geometrical design of superconducting cavities structure mechanical simulations are essential to predict mechanical eigenmodes and the deformation of the cavity walls due to bath pressure effects and the cavity cool-down. Additionally, tuning analysis has been investigated to control the frequency against microphonics and Lorentz force detuning. Therefore, several RF, static structure, thermal and modal analyses with three-dimensional code Traditional ANSYS have been performed [1]. In this paper, we will present some results about mechanical analysis of the first superconducting HWR cavity in order to further optimization in the near future.

INTRODUCTION

The cavity geometry has been optimized to reach the design frequency 162.5MHz and β=0.09 and also we want to minimize value of peak electrical and magnetic field on the cavity surface relative to the accelerating electrical field on the cavity axes (Bpk/Eacc and Epk/Eacc) [2]. So the fabrication technology and resonator structural properties including cooling down, vacuum, etching and so on, also should be taken into account at the beginning of design. SC HWR cavities are highly sensitive to mechanical deformations due to the small loaded bandwidth of some SCRF applications. So accordingly for HWR the stability of the cavity structure against any external distortions is the primer design goal. In order to improve df/dP for a low Beta HWR cavity, the typical approach is to add some stiffening ribs on the cavity, but it will not be discussed in this paper. Here, we will investigate this type of structure and then we will improve it in the future. Primarily structural analysis was completed to determine the locations of the model that were beyond yield strength.

Since CADS accelerator will work in CW regime, the main goal of our cavity structural design is a minimization of the resonant frequency dependence on the external pressure fluctuations. The general basics of the cavity structural design are to avoid using the plane surfaces as illustrated in Figure 1. Besides, four access ports at each cavity (two at the bottom, two at the top) guarantee draining off of the chemical etching and easy access to the inner surfaces during the high pressure water rinsing (HPR).

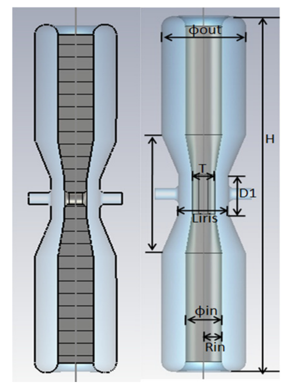

Figure 1: The cross section of HWR cavity with the main geometric parameters: Liris-iris to iris length, T-inner conductor thickness, D1-cavity diameter.

Table 1: Some Properties of HWR Cavity

Para.	Frequency	β	Diamater	Uacc	Epeak	Bpeak
Value	162.5	0.093	40	0.78	25	50
Unit	MHz	---	mm	MV	MV/m	mT

STRUCTURAL ANALYSIS

Injector II of CADS is composed by an ECR ion source, LEBT, RFQ and superconducting accelerating section. And in superconducting accelerating section, there are two cryomodules and each cryomodule is composed of 8 superconducting Half-Wave-resonator cavities and 9 superconducting solenoids. The proton beam will be accelerated from 2.1 MeV to 10MeV. Before structure analysis the geometry of HWR cavity was taken from a sat. model that was generated in software CST Microwave Studio and represented one cavity structure. The ANSYS RF results were compared to CST and to HFSS models of the same cavity for final verification. And the difference among these code result is only about 0.065%.

During mechanical analysis of HWR cavity, the variation of RF Eigen frequency was calculated, including pressure sensitivity, Lorentz force detuning, tuning sensitivity and resonant vibration and etc.. The

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relationship between changes in RF frequency and mechanical deformations is given by the Slater Perturbation Theorem as the following equation 1, where E_0 and H_0 are the unperturbed electric and magnetic fields respectively, U_0 is the stored energy, f0 is the original cavity frequency, and Δf is the frequency shift:

$$\frac{\Delta f}{f_0} = \frac{\int_{\Delta v} (\mu_0 |\bar{H}_0(\vec{x})|^2 - \varepsilon_0 |\bar{E}_0(\vec{x})|^2) d^3x}{4 \cdot U_0} \qquad (1)$$

PRESSURE SENSITIVITY

A sequential coupled field analysis RF-Structural-RF is used to predict the frequency shift due to cavity deformations under external pressure using codes ANSYS. As the cavity stiffening environment is hard to determine when cavity design, it is necessary to provide this research under two cavity beam port boundary conditions: fully fixed and completely free. The same meshed model was used for all types of simulations and that is very important as we can evaluate the frequency shift at the same scale.

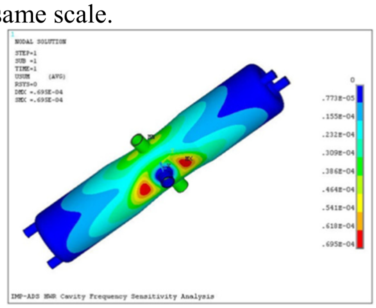

Figure 2: Structural analyses results of HWR with beam pipes fixed (cavity deformation).

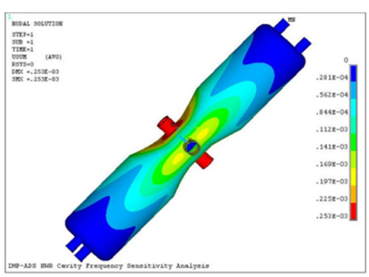

Figure 3: Structural analyses results of HWR with beam pipes free (cavity deformation).

Table 2: Pressure Sensitivity under 1 Atm

Boundary	Displacement	Stress	Δf	df/dp
fix	0.0695	5.786	17.892	23.54
free	0.252	19.066	110.773	145.6
Unit	mm	ksi	kHz	Hz/torr

From the above results we can see that the main frequency shift is caused by the beam port displacements. Although in this analysis the cavity has been simulated without helium vessel. While the helium vessel adds rigidity to the beam ports and in other words it is equivalent approximately to the fully constrained conditions. Whatever the different boundary condition, the cavity seems to be too soft so we need add some ribs on it for strength the cavity. And recently we just explore how to add these stiffening ribs.

Lorentz Force Detuning (LFD)

Since the superconducting HWR cavity will work in cw mode, so it will be static Lorentz force on the cavity walls. The pressure results in a deformation of the SC HWR cavity walls with changing the cavity volume by ΔV. And it creates the frequency shifts, which may be approximated as a perturbation using Slater's Theorem[3]. This shift is usually quantified by KL which is defined as

$$K_L = \frac{\Delta f}{(E_{acc})^2} \qquad (2)$$

The numerical coupled analysis for LFD effect has been done and also an initial simulation of the cavity under beam pipes full constrain can be showed. From this formula, we can see that the frequency shift is proportional to the accelerating gradient. With the increase of accelerating gradient, the resonant frequency also decreases. Figure 4 shows the deformation of the cavity with LFD effect .

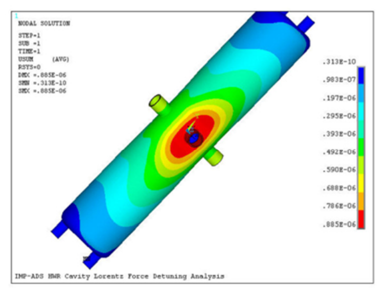

Figure 4: Deformation of the cavity wall (fix boundary condition)

From the above simulation the final fitting curve of the Δ f and E_{acc} is

$$\Delta f = -4.657 E_{acc}^2 - k \qquad (3)$$

Finally according to the equation 2, the obtained Lorentz force detuning coefficient K_L is -4.657Hz/(MV/m)^2.

Modal Analysis

Generally speaking, it is difficult to eliminate vibrations in cavities because the situation around the cavity and the helium vessel is extremely complicated. In practice the structural modal analysis need to be provided with helium vessel fixed at the supports and tuner fixed by the tuner stem. While here the results is obtained from naked HWR cavity. And then we have the lowest frequency of modal analysis is 188Hz, which is far from the dangerous frequency obviously. Certainly it is need to

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be further tested for all the accelerator with helium vessel, coupler, tuner and cryomudule etc. to verify the analysis.

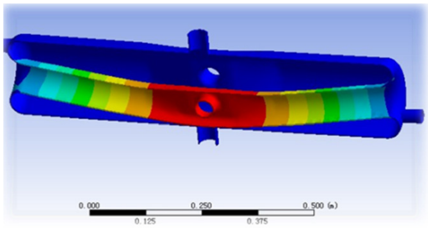

Figure 5: One of Model analyses results of HWR cavity with cleaning pipes free (cavity deformation).

Tuning Sensitivity

The role of the tuner is to ensure that the cavity resonance frequency will match the desired accelerator operating frequency. Tuners are generally made an active part of a complete RF control system which fulfills several functions. It stabilizes the frequency, amplitude, and phase variations induced by sources such as the RF drive, beam current variations, LFD, and microphonics. The usual tuning method for SC cavities is to change the length of the cells by mechanical adjustment of the overall length of the cavity. This method will not only bring in new HOM, but also not cause a big change for previous HOM[4].

The main factors that may be needed at the design of tuner are as follows:

- The tuning sensitivity of HWR cavity is 180KHz/mm;
- The spring constant of the HWR cavity is 2.2KN/mm;
- The limited space available (tuning range) is about 2mm.

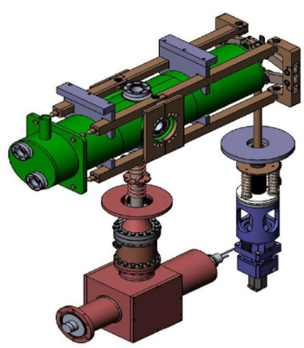

Figure 6: The IMP mechanical tuner: tuner(dark gray), helium vessel (green), and coupler (red).

Considering the fabrication tolerances for the cavity, the tuner may be able to retune the cavity over a range of 150 kHz cantered on the nominal operating frequency of 162.5 MHz.

Figure 7: Mechanical Tuner of HWR cavity test with copper HWR prototype .

CONCLUSION

We Mechanical analysis has been developed for 162.5 MHz SRF HWR cavities for the proposed CADS at IMP. The design of the tuner has been described and results of the static performance of the first copper HWR prototype have been got recently. In view of the mechanical results we find obviously that the SRF HWR cavity is much too sensitivity. So Some stiffening ribs must be added on the cavity wall. Besides, the coupled field analysis is in progress with more realistic boundary conditions ,including helium vessel.

ACKNOWLEDGMENT

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