DESIGN STUDY OF A COMPACT DEFLECTING CAVITY AT IHEP*

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Abstract

For the XFEL project proposed by the Institute of High Energy Physics (IHEP), a sophisticated beam spreader is required to separate a single beam into multiple beams. One of the deflecting cavities used in the spreader has been investigated and optimized. It is a 325MHz, compact RF-dipole superconducting cavity, with the transverse R/Q of 2907Ω, geometrical factor G of 88.5 Ω, and the pressure sensitivity df/dp of -1.7 Hz/mbar. At the nominal deflecting voltage of 7MV, the peak electric field Epeak is 41 MV/m and peak magnetic field Bpeak is 48.6 mT. This paper presents the optimal design of the cavity and its fabrication scheme.

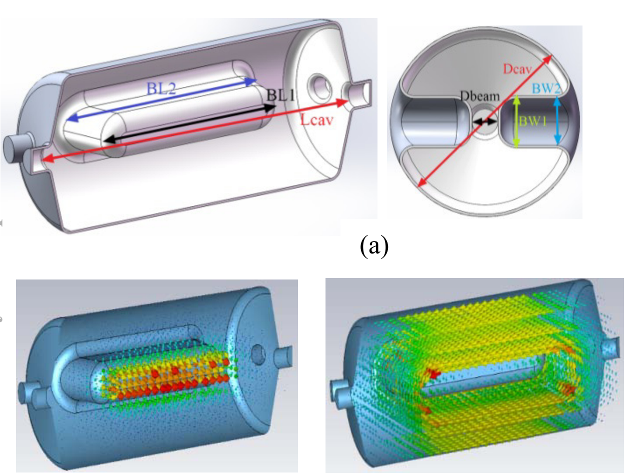
INTRODUCTION

Recently, IHEP proposed a hard x-ray XFEL facility based on a 7 GeV superconducting linac [1-2]. To make more effective use of the high quality and expensive electron beam, a beam spreader is preliminary designed. And, the R&D of the key component of the spreader, which is a 325MHz superconducting deflector, has been promoted.

EM DESIGN OF THE CAVITY

Several types of deflecting and crabbing structures have been developed and applied in accelerator facilities, such as the disk-loaded structures operating at room temperature, the squashed-elliptical superconducting cavities, the parallel-bar and rf-dipole cavities [3-4]. Among them, the rf-dipole type was selected for our cavity because of its compact structure and high-performance.

The electromagnetic (EM) design of the cavity, including the multipacting effect and the high order modes (HOM) was carried out mainly using the codes CST MWS and CST PS.



(a)

(b) (C)

Figure 1: Geometrical parameters (a), electrical filed (b) and magnetic field (c) of the deflecting cavity.

Since the dimensions of the loading bar are most critical to the RF properties of the cavity, much effort was made to the optimization of the loading bar, and its longitudinal section is chosen to be trapezoid-shaped so as to improve the transverse R/Q of the cavity. Shown in Fig. 1 and Table 1 are the final optimized results.

Table 1: Geometrical and RF Parameters of the Cavity

Parameters	Symbol	Value
Cavity length [iris to iris]	Lcav	685.3mm
Bar top length	BL1	370mm
Bar top width	BW1	80mm
Bar bottom length	BL2	423mm
Bar bottom width	BW2	80mm
Cavity diameter	Dcav	141.3mm
Beam aperture	Dbeam	40mm
Deflecting voltage	Vt	7MV
Frequency of fund. mode	f0	325MHz
Half wavelength of pi mode	$\lambda/2$	461.2mm
Frequency of nearest HOM		515.6MHz
Peak electric field	Ep	41MV/m
Peak magnetic field	Bp	48.6mT
Transverse R/Q	(R/Q)t	2907Ω
Geometrical factor	G	88.6Ω

MECHANICAL DESIGN

In addition to the geometrical parameters listed in Table 1, the cavity is made of bulk Niobium and the thickness of the cavity wall is 4 mm. The material of the stiffener is Nb-Ti alloy. The main properties of these two materials are shown in Table 2.

Table 2: Mechanical Properties of Nb and Ti-45Nb

Parameters	Nb	Ti-45Nb
Young's modulus [Pa]	1.03e11	6.21e10
Poisson's ratio	0.38	0.34
Density [g/cc]	8560	5700
Yield strength[MPa] at 295K	70.26	475.8
Ultimate strength[MPa] at 293K	184.7	544.7

The code COMSOL was adopted to analyse the mechanical properties of the bare cavity and the design of the stiffener, which is used to strengthen the cavity mechanically. To reduce the simulation time, a model with three symmetry planes was used and only one eighth of the cavity was needed to be simulated. The code ANSYS

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WORKBENCH was also used to cross check the simulation result by COMSOL.

Stress and Deformation of the Bare Cavity

Shown in Fig.2 and Fig. 3 are the stress and deformation distribution of the bare cavity at cryogenic temperature under the external pressure of 1 bar, with two beam ports fixed. The helium pressure sensitivity df/dp is -360Hz/mbar. We may see that the maximum stress on the cavity is about 50MPa (52MPa got by ANSYS and 49.9MPa by COMSOL), less than the yield strength of Nb, yet the pressure sensitivity is very large. So, the stiffener is absolutely needed for the cavity.

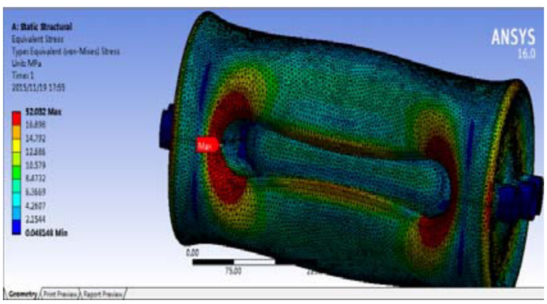

Figure 2: Stress of the bare cavity, got by ANSYS.

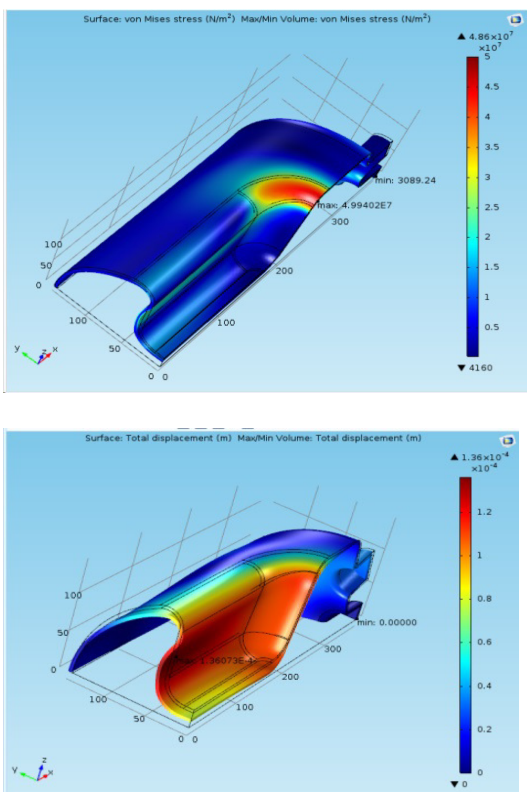

Figure 3: Stress (up) and deformation (down) distribution of the bare cavity, got by COMSOL.

Stiffener Design

In order to control the deformation rate and reduce the pressure sensitivity of the cavity, a set of stiffeners were designed. For this deflecting cavity, the idea of the stiffener is to prevent the loading bars of the cavity from moving closer and the bar width from becoming wider. Several types of the stiffeners were investigated and an optimized design was got, illustrated in Fig. 4.

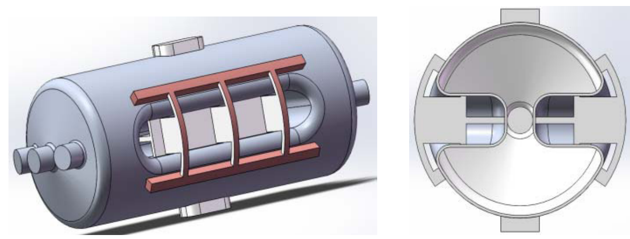

Figure 4: Schematic diagram of the cavity with stiffeners.

After strengthened with the stiffeners, the maximum stress of the cavity is improved to less than 40MPa and located on the stiffener; the largest deformation is decreased to 0.05mm, while the pressure sensitivity is improved to -1.7Hz/mbar from the original -360Hz/mbar.

Lorentz Force Detuning

The Lorentz force detuning is an effect where the cavity is deformed by the radiation pressure. The magnetic field applies pressure and deforms the surface outward, while deformation due to electric field is inward, as shown in Fig. 5.

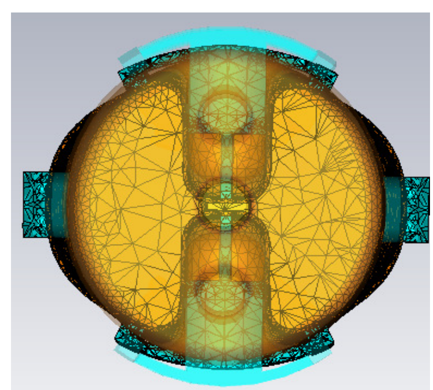

Figure 5: Cavity deformation due to Lorentz force.

Simulated by CST Multiphysics, the Lorentz coefficients of the cavity with and without the stiffener are -424.4Hz/MV^2 and -198.7Hz/MV^2 respectively.

Microphonic Effect

Superconducting cavities, with their narrow bandwidth are usually prone to microphonic effects, so does this deflecting cavity, and ANSYS was used to predict the microphonic cavities.

The frequencies of the first 6 eigenmodes for the cavity with stiffeners are116.5 Hz, 188.6 Hz, 191.3 Hz, 214.1 Hz, 270.1Hz, and 283.9Hz respectively. The first two

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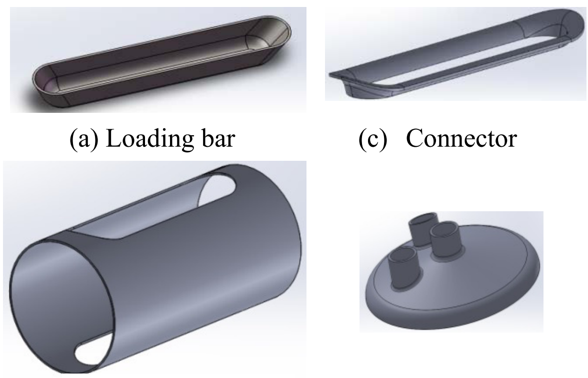
resonances are transverse, while the third one is longitudinal.

Since the frequencies of the atmosphere noise are usually less than 200Hz, the first 3 modes are more harmful and needed to be taken into account.

FABRICATION SCHEME

Fabrication Scheme

The bare cavity may be divided into the following parts: (a) two loading bars, (b) one centre shell, (c) two connectors of loading bars and shell, (d) two end walls with tubes, shown in Fig. 6.



(a) Loading bar (c) Connector (b) Centre shell (d) End wall

Figure 6: Main fabrication parts of the bare cavity.

The centre shell will be formed by rolling, while the other parts formed by stamping and Electron Beam Welding (EBW). The fundamental fabrication procedure is illustrated in Fig. 7.

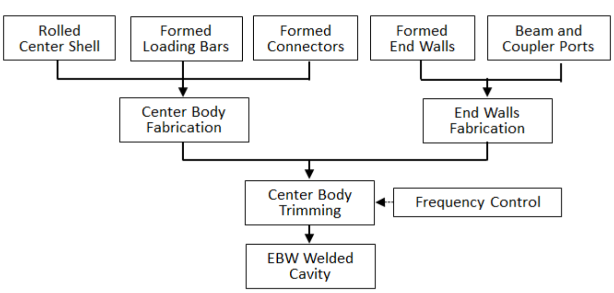


Figure 7: Fabrication procedure of the bare cavity.

Frequency Control

The target working frequency of the cavity is 325MHz at 2K. Since there are many factors to influence the frequency of the cavity, as shown in Table 3, the target frequency just after the fabrication should be predicted in advance.

The frequency of the cavity will be finally adjusted by trimming the center body, which is a traditional method to control the frequency of the SC cavities.

For this deflecting cavity, the sensitivity of the frequency to the center body is -30kHz/mm, and a margin of 30mm will be reserved at beginning.

Table 3: Frequency of the Cavity at Different Stage

Cavity status	f0 (MHz)
Evacuated and at 2K	325.000
Evacuated and at room temperature (RT)	324.535
In air, at RT and after BCP	324.440
After fabrication, in air and at RT	324.067

Impacts of Fabrication Errors

The fabrication errors are difficult to be avoided and their impacts to the RF properties of the cavity should be analysed. By simulation with CST MS, it was found that the dimension errors had slight impacts to the RF properties of the cavity, except the frequency. So the dimension errors are generally required to be less than 0.02 mm, which are not difficult to be got.

Yet, the impact of the levelness of the loading bars is remarkable. For example, the levelness error of 1 degree will decrease the R/Q of the cavity by a factor of about 8.5%, therefore the levelness of the bars should be controlled carefully in the fabrication.

CONCLUSION

A 325 MHz rf-dipole cavity with loading bars whose longitudinal section is trapezoid-shaped has been designed. The codes CST MS and CST PS are used to optimize the RF parameters, while the ANSYS WORKBENCH and COMSOL are adopted to design the stiffeners and analyse the mechanical properties. Simulation results show that the optimal cavity may meet the requirements of the spreader for IHEP-XFEL project. The fabrication scheme of the cavity has been determined and the fabrication of the prototype cavity is underway.

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REFERENCES

[1] Chen Senyu, Wang Shuhong, and Zhu Xiongwei, Towards one machine, two purposes: using a common SC linac for XFEL and ERL simultaneously [J]. Chinese Physics C, 2010, 34(1):112-114.

[2] JiaoYi, Zhai Jiyuan, Lu Huihua, Wang Jiuqing, Primary scheme of superconducting linac-driven XFEL in China [J]. High Power Laser and Particle Beams, Vol. 27, No. 5: 055101-1~4, in Chinese.

[3] T. Abe, K. Akai, M. Akemoto et al., Compensation of the Crossing Angle with Crab Cavities at KEKB [C]. Proc. of PAC2007, Albuquerque, New Mexico, USA: 27-31.

[4] S. U. De Silva and J. R. Delayen, Superconducting RF Dipole Deflecting and Crabbing Cavities [C]. Proc. of SRF2013, Paris, France: 1176-1182.