DESIGN OF A MEDIUM BETA HALF-WAVE SC PROTOTYPE CAVITY AT IMP*

A.D. Wu#, S.H. Zhang, W.M. Yue, Y.M. Li, T.C. Jiang, F.F. Wang, S.X. Zhang, L.J. Wen, R.X. Wang, C. Zhang, Y. He, H.W. Zhao,
Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, Gansu 730000, China

Abstract

A superconducting half-wave resonator has been designed with frequency of 325 MHz and beta of 0.51. The geometry parameters and the three shapes of inner conductors (racetrack, ring-shape and elliptical-shape) were studied in details to decrease the peak electromagnetic fields to obtain higher accelerating gradients and minimize the dissipated power on the RF walls. To suppress the operation frequency shift caused by the helium pressure fluctuations and maximize the tuner ranges, the frequency shifts and mechanical characters were simulated in the electric and magnetic areas separately. At the end, the helium vessel was also designed to keep stability as possible. The fabrication and test of the prototype will be complete at the beginning of 2016.

INTRODUCTION

Low beta superconducting Half-wave resonators have developed for Chinese Accelerator Driven Sub-critical System (C-ADS) at Institute of Modern Physics [1]. The production development of the 162.5 MHz half-wave resonators (squeezed) with the optimal beta of 0.101 have achieved great success and revealed excellent performance on the High Current Proton Superconducting Linac for C-ADS Injector II [2, 3]. Because of its simple structure, easy to fabrication and surface preparation, it attracts people to research the application on the medium beta section for the high power and continuous wave mode linear accelerators for the ADS [4].

RF DESIGN

The main task of RF design aims at reducing the normalized magnetic field and dissipated RF power. The RF property simulations were complete by the CST Microwave Studio Software [5].

An elliptical inner conductor was proposed to optimize the distribution of surface field, the Epeak/Eacc of 4.03 and Bpeak/Eacc of 7.08 mT/MV/m were achieved, where Eacc is accelerator gradient defined by the voltage gain over the efficient length of βλ.

EM Characters

The geometry of half wave transmission lines resonator, with TEM class structure, consists of the inner conductor and out conductor. The electric field concentrates on the center of inner conductor near the beam pipe, and magnetic field encircles around the inner conductor of two short dome areas, as illustrated in Figure 1.

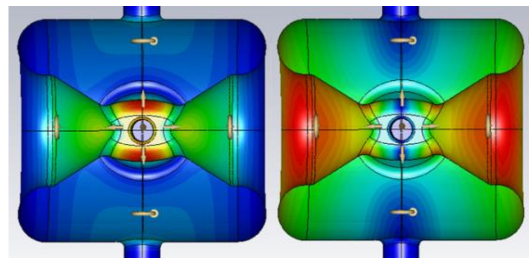

Figure 1: The surface electromagnetic field distribution of elliptical shaped center inner conductor HWR, the left for electric field and the right for magnetic field. The field strength decrease as the color changes from red to green to blue.

The RF property mainly depends on the shape of inner conductor and geometry parameters. In order to identify a proper shape which can obtain uniform distributed fields and higher shunt impedances effectively, three types of inner conductors, named after the cross profiles of inner center conductors as ring shaped (RS), race track (RT) and elliptical shaped (ES), were taken into optimizations, as shown in Figure 2. Additionally, the cavity aperture radius is 25 mm for the beam dynamic consideration.

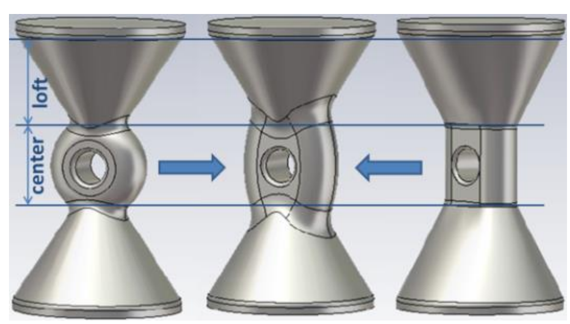

Figure 2: Three types of inner conductor, ring shaped (left), elliptical shaped (medium) and race track (right).

Effect of Inner Conductors

The effects of quadrupole asymmetry on the variously of inner conductor are analyzed for the low energy coaxial resonators, especially the compassion between the racetrack and ring shaped inner centre conductors [6, 7]. Beside the advantages of better acceleration field symmetry as the results of symmetrical geometry along with the beam axial line, the center conductor with ring shaped can also provide higher R/Q and lower

*Work supported by the Important Directional Program of the Chinese Academy of Sciences (Y115210YQO), 973 Project (Y437030KJO).
#antonwoo@impcas.ac.cn

ISBN 978-3-95450-178-6

Bpeak/Eacc. Along with the cavity length axial direction, because of the loft transition from a circle section in the center conductor to the round base of inner conductor, the ring structure can produce a more uniform magnetic fields distribution. However, the surface of ring shaped center has a more sharped variation than the race track, so it is easy for race track center conductor structure to get low normalized surface electric field. Under our expectation of lower normalized electromagnetic fields and higher R/Q, an elliptical shaped center conductor was proposed, which combined the advantages of both race track and ring shaped structures. The ring shaped center conductor can be deemed as a special case of elliptical shaped, where the semi major axis along with the cavity length is equal to the semi minor axis which vertical to the beam line. Therefore, there is not much difference on the RF properties, besides the normalized electric field, between the elliptical shaped and ring shaped center conductors.

Results and Comparison

Due to taking advantage of race track and ring shaped center conductors, the elliptical shaped can obtain the lower normalized surface fields and higher R/Q, as shown in Table 1. With the same magnetic areas structures, the Epeak/Eacc of the ring shaped (RS) is about 18% higher than the else. The R/Q of the race track is about 10% lower than other else, and also with lower Epeak/Eacc. Therefore, we chose the elliptical shaped center conductor as the final RF structure to further study and fabrication.

Table 1: RF Simulation Results for Different Conductors

Parameters	ES	RS	RT	Unit
E_{peak}/E_{acc}	4.04	4.78	3.93	void
B_{peak}/E_{acc}	7.07	7.04	7.49	mT /MV /m
R/Q	261	262	238	Ω
G	120	120	120	Ω

MECHANICAL ANALYSIS AND STUDY

The purpose of mechanical design is concentrated on the keeping static structure safety and minimizing the frequency sensitivity caused by the helium pressure variations for continue-wave facility. These parts of works are completed with using of ANSYS [8].

Analysis Approach

The common approach to meet the requirement of structure safety and the stability of frequency, is to make the cavity more rigid by adding the stiffer ribs at the out of cavity walls. It is easy to decrease the equivalent stress to a certain degree if the strength of ribs is enough. However, the volume deformation cannot be avoided completely, and it will be not feasible for frequency tuning if the cavity is too rigid. The sufficient method is to adjust the contribution of frequency shift for a compensation, which the positive from high magnetic fields and the negative from high electric fields [9]. The opposite domains have been divided, as shown in Figure 3.

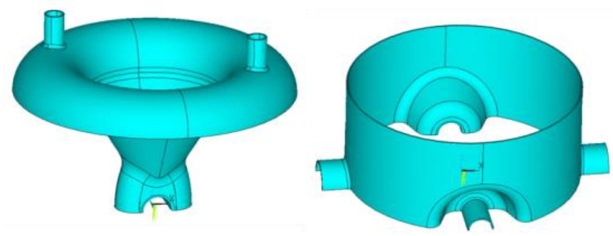

Figure 3: The naked cavity half model for frequency sensitivity was broken into magnetic (left) and electric (right) domains.

The boundary condition of the beam pipes, which connected with the tuning system, has a great influence for the frequency sensitivity. Under the two extreme conditions, for the beam pipes fixed and free, the parameters of df/dp were predicted for high electric and high magnetic areas, as illustrated on the Table 2. When the pipes fixed, the total sensitivity can accurately meet with compensation effect from two areas. For the really operation condition, the tuner is more likely to push the beam pipes than pull them. Thus, the pipe fixed condition was chosen as our optimized target.

Table 2: Prediction of Frequency Sensitivity for the Divided Areas of the Naked Cavity

Boundary	E_areas	M_areas	*df /dp*
Pipe fixed	0 bar	1 bar	+20.7 Hz/mbar
	1 bar	0 bar	-15.1 Hz/mbar
	1 bar	1 bar	+05.6 Hz/mbar
Pipe free	0 bar	1 bar	+20.7 Hz/mbar
	1 bar	0 bar	-48.2 Hz/mbar
	1 bar	1 bar	-36.9 Hz/mbar

Mechanical Design

To meet the request of pressure safety and the frequency stability, the C-shaped ribs, two daisy slabs and the helium vessel are designed, as depicted in Figure 4.

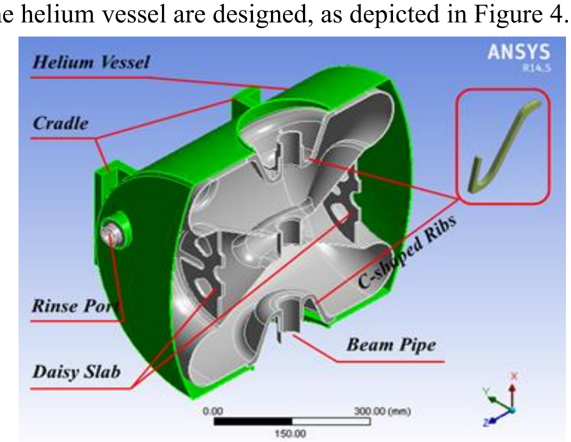

Figure 4: Schematic diagrams of HWR051 with the ribs and helium vessel in ANSYS.

The C-shaped ribs were attached at the out of beam pipes and the caps, in which the peak stress occurs, to keep the pressure safety. Generally, the more rigid of the beam caps, the more static structure safety the cavity is. However, it will be hard to move the beam pipes to obtain the wide range of frequency tuning. The C-shaped ribs can help to relief the equivalent stress and meet the requirement of tuning, as depicted in the Table 3.

Table 3: Mechanical Parameters and Frequency Sensitivity from Higher Electric Areas with the C-shaped Ribs

Peak stress /MPa	1.0atm	1.5atm	2.0atm	*df/dp* Hz/mbar
Pipe fixed	46.1	65.8	87.8	-7.2
Pipe free	53.5	80.3	107	-48.8

The absolute values of df/dp from the electric areas will decrease from -15.1 to -7.2 Hz/mbar at the condition of pipe fixed, but it is about -48.5 Hz/mbar with no difference for the pipes free condition. The tuning sensitivity is 185 KHz/mm (total displacement) when the displacements take place on the beam pipes. The cavity stiffness is 4.9 KN/mm (total displacement) with ribs attached when the tuning force load on beam pipes. It is easy to get the tuning range of 160 KHz with the tuner force of 4.5 KN applied on pipes.

Above the separated analysis, the absolute value of df/dp contributes from high magnetic areas will be three times of the electric areas when the C-shaped ribs attached. The daisy slabs with thickness of 6 mm were designed on the external wall of inner conductor, where the high magnetic field around, can reduce the df/dp form 20.7 to 16.8 Hz/mbar with efficiency of 22%. Then, the vaulted helium vessel was optimized using titanium. Instilled on the rinsing pipes, it can furtherly decrease the df/dp to 12.8 Hz/mbar. Therefore, the total frequency sensitivity can minimalize to 5.6 Hz/mbar for the request of operation condition.

Frequency Prediction

In order to achieve the resonator frequency for the operating conditions, the frequency control are taken into consideration by predicting the frequency shift that will come up due to serval major operation during fabrication and preparation, such as chemical treatment, cooling down and so on, as depicted in the Table 4. Before the electron beam welding of two end domes, the edges can be trimmed to adjust the frequency at 324.96 MHz.

Table 4: Predictions of Frequency Shift

Operation	**Shift**
BCP (~150μm)	-101 KHz
Cooling down (~300 to 4.2 k)	181 KHz
Vacuum (~1 atm)	-32 KHz
Air (ε_r~1.00059)	96 KHz
Tuner engaged (pre-push)	-100 KHz
Trimming edges (total length)	539 KHz/mm

CONCLUSION

The design study of the medium beta superconducting half wave resonator has been described including the RF optimization and mechanical study. An elliptical shaped center inner conductor is proposed, which can help to get better RF properties to meet requirement of higher accelerating gradient. Meanwhile, the mechanical analysis and design reveals that the HWR051 can operate with safety and stability at 4.2 K system. Two prototypes are under fabrication, and the vertical test will be conducted in the beginning of 2016.

REFERENCES

[1] Weiming Yue, Yuan He et al., “Development of the Superconducting Half-Wave Resonator for Injector II in C-ADS”, THP016, Proceedings of SRF2013, Paris, France. (2013)

[2] Internal Research Progress and Experimental Report: http://www.impcas.ac.cn/xwzx/kyjz/201411/t20141128_4264499.html

[3] Internal Research Progress and Experimental Report: http://www.impcas.ac.cn/xwzx/kyjz/201506/t20150609_4371265.html

[4] B. Mastapha et al., “A Compact Linac Design for An Accelerator Driven System”, MOPP003, Proceedings of Linac 2014, Geneva, Switzerland. (2014).

[5] CST: http:// www.cst.com

[6] B. Mustapha, P.N Ostroumov and Z.A Conway, “A Ring-Shaped Center Conductor Geometry for a Half-Wave Resonator”, WEPPC037, Proceedings of IPAC 2012, New Orleans, Louisiana, USA. (2012)

[7] YANG Zi-Qin, LU Xiang-Yang, Yang LIU, LUO Xing et al., Chinese Physics C, 107001 (2014).

[8] ANSYS: http:// www.ansys.com

[9] J. C. Slater, Microwave Electronics, Reviews of Modern Physics, Vol. 18 No. 4, pgs. 482-483, Massachusetts Institute of Technology, 1946.

ISBN 978-3-95450-178-6