325 MHz CW ROOM TEMPERATURE HIGH POWER BUNCHING CAVITY FOR THE CHINA ADS MEBT1

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Abstract

Two room temperature high power bunching cavities are required to be located in the ADS MEBT1 section. Double re–entrant nose cone geometry has been adopted as the type of the bunching cavity for its simplicity, higher shunt impedance and lower risk of multipacting. SUPERFISH is used to optimize the internal dimensions of the bunching cavity, then the RF–thermal–structural–RF coupled analysis were carried out in ANSYS to obtain the preliminary mechanical design, the layout of the cooling channels is optimized to suppress the frequency shift as much as possible. The cavity was specially designed to have the capability to withstand the 1 atm air pressure effect. In addition, the main dimensions of the coupler and tuner are also estimated.

INTRODUCTION

The ADS pilot project based on the proton linac is being developed at IHEP, Beijing, China [1]. In order to realize the matching in both transversal and longitudinal phase spaces, one Medium Energy Transport Line (MEBT1) is needed in the front end injector—injector–I [2], while bunching cavity is one of the key components. Two 325 MHz bunching cavities with a relatively large aperture of 34 mm and an effective voltage of 120 kV are required. In order to obtain high shunt impedance and low risk of multipacting, the nose–cone geometry shown in Fig. 1 has been selected as the cavity shape.

The China ADS accelerator will operate at the CW mode (100% duty factor), SUPERFISH was used to optimize the internal geometric dimensions of the cavity. The RF–thermal–structural–RF coupled analysis has been done in ANSYS to finalize the layout of the cooling channels, so that the Von Mises stress induced by the high RF heating load can be fairly lower than the yield strength of the cavity material. To suppress the frequency shift caused by the air pressure, the cavity was designed to have double walls consisting of an inner copper wall and an outer stainless steel wall. HFSS and CST Microwave Studio have been used to match the power coupler and estimate the tuner tuning range.

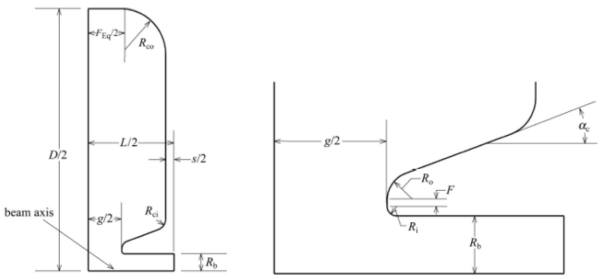

Figure 1: Cavity with nose–cone geometry.

CAVITY INNTERNAL SHAPE OPTIMIZATION

The cavity internal geometric dimensions determine its RF characteristics, such as the shunt impedance *R*, the transit–time factor *T*, the Kilpatrick factor and so on. Cavity with higher *R* and *T* has lower RF heat load, and then the cooling design can be simplified to the largest extent. With the fixed effective cavity voltage, lower Kilpatrick factor will greatly reduce the possibility of electrical discharge (sparking). Fig. 2 shows the relationship between the effective impedance *RTT*, the Kilpatrick factor and the main cavity internal dimensions.

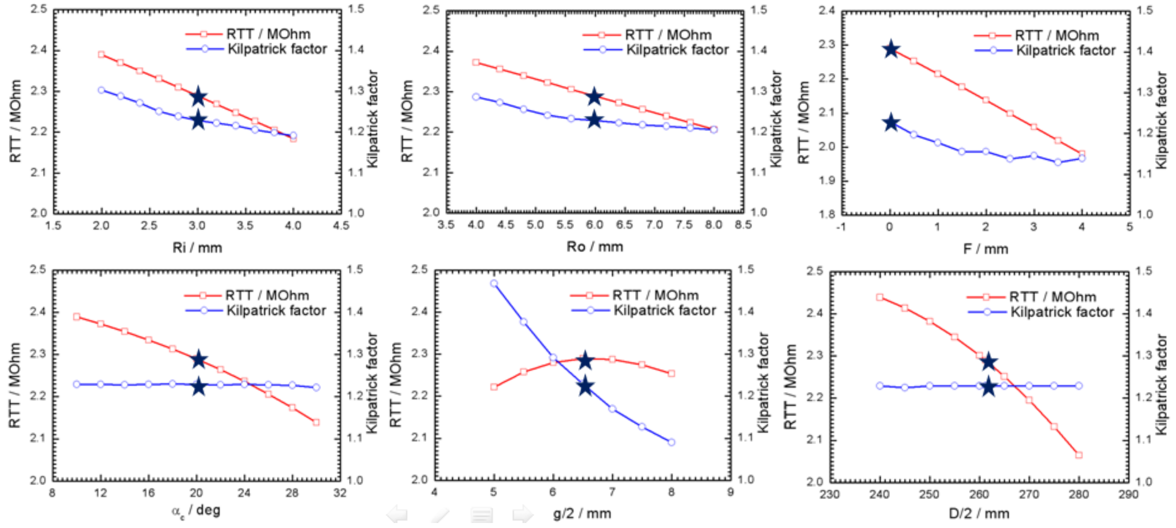

Figure 2: Relationship between the effective shunt impedance *RTT*, the Kilpatrick factor and *Ri*, *Ro*, *F*, α_c, *g*/2, *D*/2.

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Certain compromise has been made by considering both the RF performance and the mechanical simplicity; the dimensions marked with pentacle were finally selected. Table 1 shows the main specifications of the cavity; Fig. 3 shows the 3D cavity model and the power loss distribution on its inner wall surface.

Table 1: Main specifications of the bunching cavity

Parameter	**Value**	**Unit**
Frequency	325	MHz
Particle energy	3.2128	MeV
Effective voltage	120	kV
Q	27159	
Effective shunt impedance *RTT*	2.26	MOhm
Power dissipation (SUPERFISH)	6.3	kW
Peak electric field	21.9	MV/m
RTT/Q	84.3	Ohm
Inner cavity diameter	522.5	mm
Bore diameter	34	mm
Gap	13	mm
Cavity length (wall–to–wall)	170	mm
Tuner tuning range	740	kHz
Kilpatrick factor	1.23	

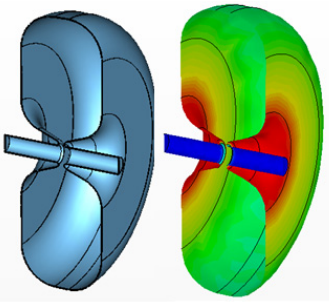

Figure 3: The 3D cavity model and the power loss distribution on the inner cavity wall surface.

RF–THERMAL–STRUCTURAL–RF COUPLED ANALYSIS

The average power dissipation of the two bunching cavities will be ~6.3 kW obtained by SUPERFISH, but real power is generally 1.2–1.4 times of that, here a compromised factor of 1.3 is used in the RF–thermal–structural–RF analysis by ANSYS.

Figure 4 shows the preliminary mechanical design of the cavity. The main body is made of OFE free copper with two separate parts, which will be welded together along the circumference of the 45 mm thick cavity side walls. Due to the internal vacuum, the two end walls was designed to have double plates—25 mm thick inner copper plate and 10 mm outer stainless steel stiffening plate, which are used to suppress the cavity deformation (i.e. frequency shift) induced by the 1 atm air pressure effect. The copper and stainless steel plates are welded together completely before finish machining. Moreover, to reduce the frequency shift caused by the RF heating, 10 rectangular cooling channels (10 mm × 10 mm) with 3 m/s water flowing velocity were applied, of which 8 for the two nose cones/end plates and 2 for the side walls.

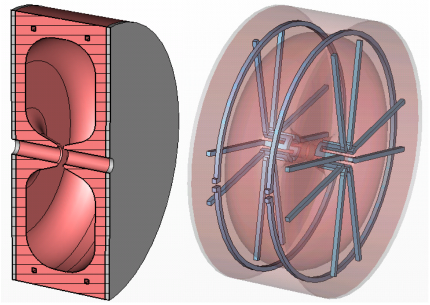

Figure 4: Preliminary mechanical design.

Figure 5 shows the temperature distribution in the cavity body with 20 °C cooling water. The maximum temperature rise is located at the nose cone region, which is 33.5 °C and 12.7 °C higher than the minimum temperature of 20.8 °C. Correspondingly, the cavity body deformation is shown in Fig. 6. Part of the cavity end wall has the largest deformation of 16.3 μm, while the nose cone separation is only reduced by 3.25×2=6.5 μm (~20 kHz frequency decrease [3]). The cavity frequency shift due to the overall deformation is –57 kHz.

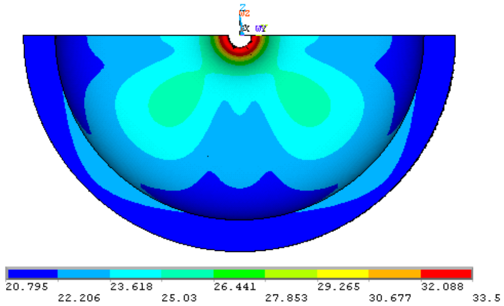

Figure 5: Temperature distribution in the cavity body for 20 °C cooling water.

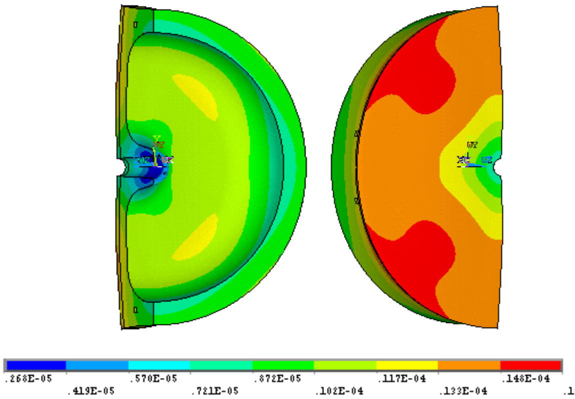

Figure 6: Deformation distribution in the cavity body for 20 °C cooling water.

Figure 7 shows the von Mises stress distribution for 20 °C cooling water. It can be seen that the maximum Von Mises stresses are both fairly lower than the yield strengths of the stainless steel (>260 MPa) and copper materials (~33 MPa).

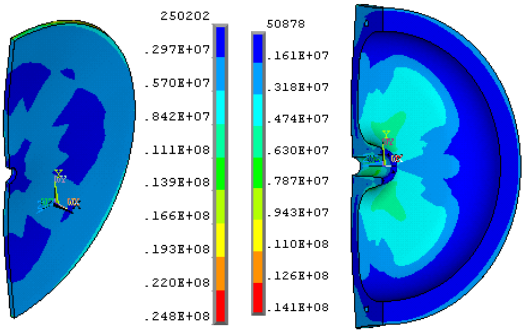

Figure 7: Von Mises stress distribution in the stainless steel plate and the cavity copper part.

If air pressure effect is also considered with the RF heating in the ANSYS coupled analysis, the cavity frequency will be further reduced because the air pressure will put an inward force on the whole cavity body.

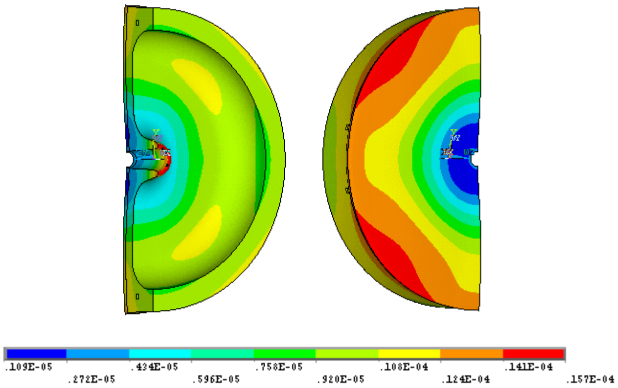

Figure 8: Deformation distribution when both RF heating and air pressure effect are considered.

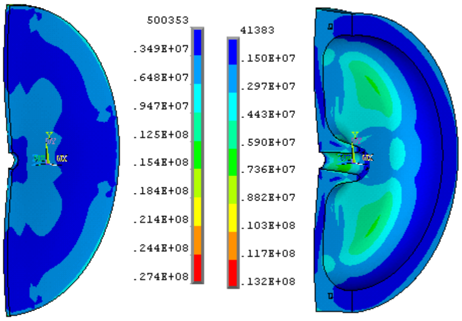

Figure 9: Von Mises stress distribution when both RF heating and air pressure effect are considered.

Fig. 8 shows the cavity deformation caused by both RF heating and air pressure, the resulted frequency shift goes up to –136.5 kHz, which can be adjusted back on resonance by the tuners. Both the nose cone tip and part of the cavity end walls have the largest deformation of 15.7 µm, and the nose cone separation decreases by 13.8×2=27.6 µm (~83 kHz frequency decrease [3]). The cavity deformation at the end wall (also the induced frequency shift) resulted from the RF heating are partially compensated (~40–45%) by the air pressure effect. The corresponding von Mises strength distribution is shown in Fig. 9. Similar to Fig. 7, the connecting edges of the copper side wall and the stainless steel plate have the largest von Mises strengths, which have no big change when air pressure effect is also included in the ANSYS analysis.

TUNER AND COUPLER

Two water cooled tuners will be adopted to tune the cavity frequency back on resonance for CW full power operation (~6.3×1.3=8.2 kW). Each tuner will be remote controlled by a step motor. A total tuning range of 2×370=740 kHz can be obtained by a slug diameter of 50 mm and a maximum penetration of 40 mm into the cavity vacuum region.

Two kinds of power couplers shown in Fig. 10 have been investigated with similar RF characteristics. Due to the relatively bigger inner conductor diameter (~21.4 mm, ~1.5 times of that for the undercut type) at the ceramic window region, the choke type was finally chosen for easy water cooling design. Moreover, for flexible adjustment of the coupling, the coupler will be designed to have a rotatable flange welded to a stainless steel transition to the cavity copper body.

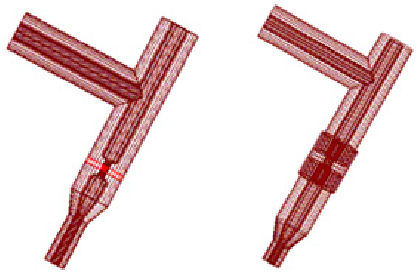

Figure 10: Two investigated power couplers (left—undercut type; right—choke type)

SUMMARY

Two CW bunching cavities with high average power up to couples of kW are needed for the ADS MEBT1 in China. The cavity was optimized to reduce the frequency shift caused by both RF heating and air pressure effects. The tuner and coupler designs were discussed.

REFERENCES

[1] H. Chen et al., "ADS Accelerator Program in China", IHEP–FNAL Workshop on Proton Accelerator, Beijing, February 15–16, 2011.

[2] H. Geng et al., "The MEBT Design for the China Accelerator Driven System", WEPS050, Proceedings of IPAC 2011, San Sebastian, Spain.

[3] G. Romanov et al., "CW Room–temperature Bunching Cavity for the Project X MEBT", WEP221, Proceedings of PAC 2011, New York, USA.