STUDY ON FREQUENCY CHANGE BY 3D RECONSTRUCTION OF DEFORMED CAVITIES OF LINAC COLLINEAR LOAD*

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Abstract

Collinear load, consisted of several coaxial cavities, is a substitute for traditional waveguide-type load to absorb the remnant power of the LINAC and makes the accelerating structure compact and small-size. The power loss on the cavities of collinear load brings thermal deformation which affects their resonant frequency deeply. In this paper, a new approach of 3D reconstruction of the thermal deformed cavities is utilized to evaluate the accurate influence on frequency change caused by non-uniform deformation and water cooling strategies of collinear absorbing load are studied. Then the thermal behavior of a six-cavity collinear load, which is coated with Kanthal alloy and FeSiAl alloy and used on a 2856MHz, 2π/3 mode respectively, is researched. The results show that the collinear load with Kanthal alloy can only absorb up to 10kW, while with FeSiAl alloy it can dissipate 15kW when the water flow controlled within 3.0kg/s for energy saving.

INTRODUCTION

The remnant power dissipated in collinear load causes temperature raise and non-uniform thermal deformation, in turn occuring resonant frequency change, which is usually required to be controlled within ±150kHz. It is generally considered that the resonant frequency of the s-band(2856MHz) disk-loaded cavity changes 50kHz when temperature rises 1°C uniformly[1]. In recent years, as the rapid development of computer technology, the relations between the deformation and the frequency change are studied by numerical method [2,3,4]. However, in these researches, the deformation is treated linearly to get the frequency changes of the cavities.

In this paper, a technology of 3D reconstruction of deformed cavity is introduced to study the accuracy influence on the cavities' frequency changes caused by non-uniform deformation [5]. Based on this technology, the thermal performance and cooling strategies of six-cavity collinear absorbing load coated with Kanthal alloy (resistance-type absorbing material) and FeSiAl alloy (magnetic hysteresis absorbing material) are studied.

3D RECONSTRUCTION

3D reconstruction of the deformed cavities is to create a "bridge" between heat-solid analysis in FEM software I-DEAS and electromagnetic field analysis in CST Microwave studio (MWS abbreviately) and realized heat-solid- electromagnetic coupling simulation. The flow chart of 3D reconstruction of the cavities is shown in Figure 1. First the FEM model is renewed by adding the nodal displacements to the coordinates of the corresponding nodes. Then the boundary nodal data of the cavities is extracted and sorted. According to the data, section curves of the inner surfaces of the cavities are obtained and the inner surfaces are constructed by interpolation surface skinning technology. Finally the deformed solid model enclosed by the inner surfaces is created and directly saved as IGES files which can be imported into CST Microwave Studio. It is a reconstruction based on original deformed mesh of FEM model, so the error in the process can be controlled.

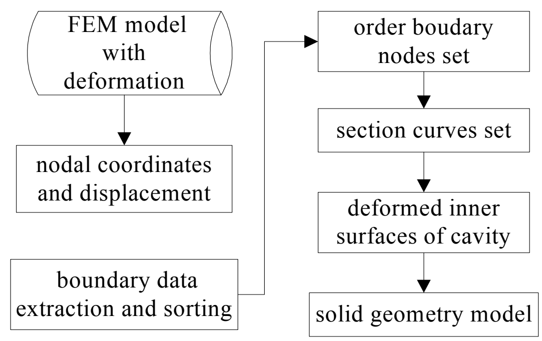
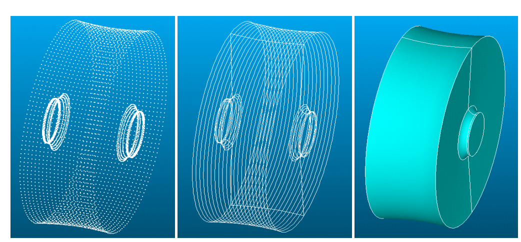


Figure 1: Flow chart of 3D reconstruction.

Figure 2 is the 3D reconstruction process of inner vacuum volume in disk-loaded cavity. The reconstruction error will be minished as the increment of the node density of section curves. Simulation result shows that the frequency change caused by the geometric model error is less than 15kHz when one section curve is interpolated by 144 nodes.



(a) nodes (b)section curves (c)deformed cavity

Figure 2: 3D reconstruction of inner vacuum volume.

COOLING STRUCTURE OF COLLINEAR LOAD

In order to control the frequency change, cooling system is necessary. The collinear load is connected to the end of accelerating tube by hydrogen welding directly. So a simplest cooling structure is to extend the cooling

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system of the accelerating tube to cover and cool off the collinear load. A simulation is done when water flux is 3.0kg/s, inlet water temperature is 28.6°C, copper loss is 9.19kW and remnant power is 10.15kW. The axial temperature distribution of the tube with collinear load is shown in Fig.3. However, too high temperature of the collinear load will lead to unbearable thermal deformation and resonant frequency changes.

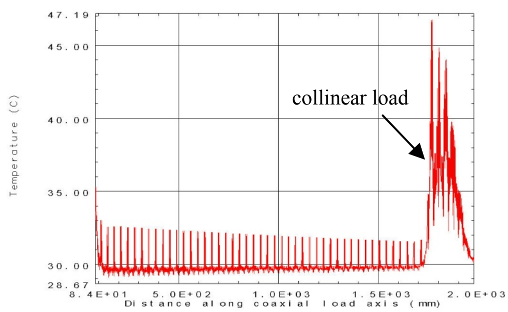

Figure 3: Axial temperature of accelerating tube with one-way cooling structure.

Furthermore, a two-way cooling structure is applied to accelerating tube with collinear load separately, as shown in Fig. 4, and a symmetrical double helix jacket-type cooling structure is used to enhance the forced convection heat transfer between water and the collinear load.

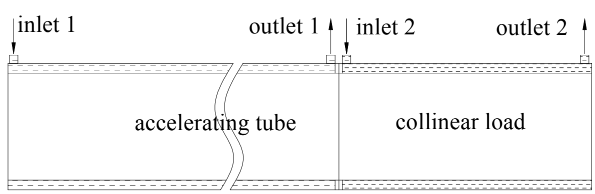

Figure 4: two-way cooling structure.

COLLINEAR LOAD WITH KANTHAL ALLOY COATINGS

Kanthal alloy(Fe, 20%~30% Cr, 5% Al,and trace of Mn) is first used as the absorbing material in collinear load. The physical property of coating film of Kanthal alloy is measured by experiments as shown in table 1. The skin depth of Kanthal coatings is about 61.9 μm in s-band(2856MHz).

Table 1: Physical properties of Kanthal alloy coating

Item	Value
ρ (kg/m^3)	7100
α (1/K)	1.35×10^{-5}
λ (W/m/K)	7.1
σ (S/m)	8978
μ (H/m)	2.58
q (Pa • L/s/cm^2)	$<1\times10^{-10}$

Simulation in MWS shows that the highest attenuation constant of cavity is only 4.95db when the thickness of coating is 100 μm and fully coated the inner wall of the cavity. While the one-way attenuation is 15db, the last cavity can only dissipate about 7% of the remnant power. A power loss allocative decision with 21.02db attenuation of collinear load is 2.119kW, 2.010kW, 1.999kW, 1.810kW, 1.385kW and 0.545kW when the remnant power P_{re} is 10kW.

Thermal-structure coupling analysis is done by I-DEAS with inlet cooling water of 23°C at a different flow rate. Fig. 5 shows the thermal deformation when water flow is 3.0kg/s. It is obvious non-uniform. The biggest and smallest radial displacement is 2.11 μm and -4.38 μm. The axial displacement is between0.61 μm and 5.15 μm. The last cavity shrinks to the spigot shaft because of its low power loss.

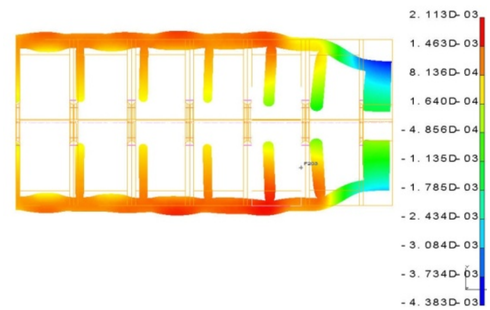

Figure 5: Thermal deformation of collinear load with Kanthal coatings.

Figure 6 shows the frequency changes of the cavities under different remnant power and water flow. The frequency changes of the cavities are from -95kHz to 74kHz with remnant power 10kW and water flow 3.0kg/s. However, when the remnant power is 15kW, the frequency changes outran ±150kHz even though the water flow is 4.0kg/s.

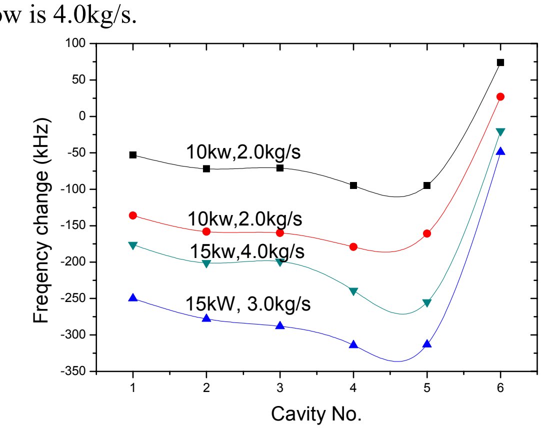

Figure 6: Frequency change of collinear load with Kanthal coatings.

COLLINEAR LOAD WITH FESIAL ALLOY COATINGS

FeSiAl alloy(85%Fe-9.6%Si-5.4%Al),also named sendust alloy, is an multi-type microwave absorbing material mainly by magnetic hysteresis effect. The microwave energy is dissipated in the volumes of FeSiAl alloy coatings nearly uniformly. Therefore the attenuation constant of the cavities can be enlarged by adding the thickness of coatings.

An optimized power-loss allocation based on Dittus-Boelter correlation and Newton's law of cooling is proposed, as shown in table 2. The coatings are all sprayed on the waveguide surface.

Table 2 Power loss of collinear load with FeSiAl coatings

Cavity No.	Width of coating/mm	Thickness of coating/mm	coating loss/W	Copper loss/W
1#	8.5	0.05	1641	115
2#	10.7	0.05	1664	93
3#	13.5	0.05	1607	71
4#	19	0.05	1588	50
5#	16.2	0.1	1572	29
6#	30	0.4	1558	0

Simulation was done under a condition of 10kW remnant power and 2.0kg/s water flow. Fig. 7 shows the temperature distribution of cross-section surface of the collinear load. The six peak values of the distribution locate in the middle of coating area of the cavities. The highest temperature in the first cavity is 42°C. Fig.8 shows the thermal deformation of the cross-section. The radial displacement of the cavities is between -0.55 μm and 1.79 μm.The biggest axial displacement is 7.33 μm.

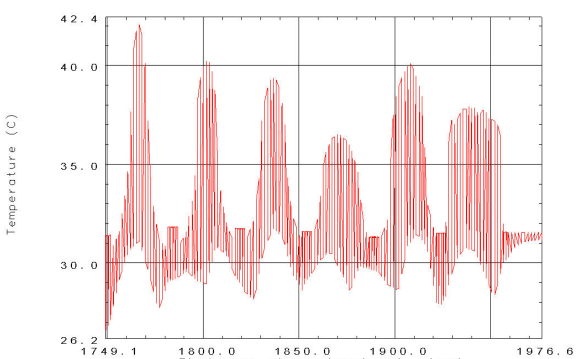

Figure 7: Temperature along the collinear load.

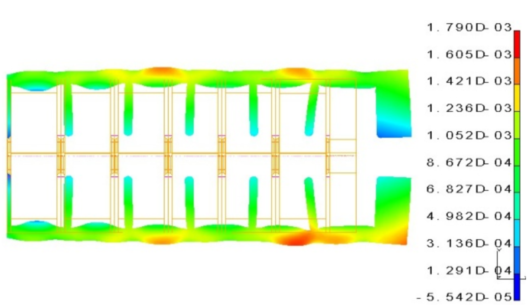

Figure 8: Thermal deformation of collinear load with FeSiAl coatings.

Figure 9 shows the frequency change of collinear load with FeSiAl coatings with different power loss and water flow. The frequency changes among six cavities are as near as dammit. It is obvious that the power loss is the most important factor on the overall frequency change of the collinear load. When the remnant power is 15kW and the water flow is 3.0kg/s, the frequency changes are within -163kHz~-127kHz.

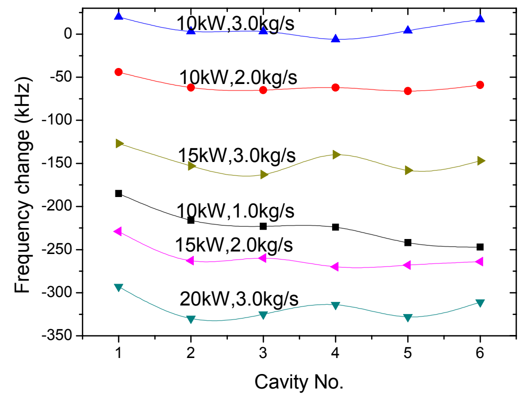

Figure 9: Frequency change of collinear load with FeSiAl coatings.

CONCLUSION

3D reconstruction method is introduced to realize the structure - electromagnetic field coupling analysis of accelerating cavities in isomerism platform. This method can accurately evaluate the influence on resonant frequency after thermal deformation and provides reliable criterion on the design of collinear load cavities and their cooling system.

Concerning the remnant power absorption capacity, FeSiAl coatings is better than Kanthal. The former can only absorb remnant power of 10kW and the latter can absorb 15kW with water flow of 3.0kg/s.

REFERENCES

[1] Neal, R B. The Stanford two-mile Accelerator[M]. New York Amsterdam: W. A. Benjamin, Inc., 1968:936-940.

[2] Peng Zhaohua, Guan Xialing. Thermal Analysis of High Current Proton RFQ Cavity[J]. Atomic Energy Science and Technology, 2005, 39(2): 160-163.

[3] Liu Huachang, Ouyang Huafu. Thermal analysis and water-cooling design of the CSNS MEBT 324 MHz buncher cavity[J]. Chinese Physics C, 2008, 32(4):280-284.

[4] Virostek S, Li D. RF, thermal and structural analysis of the 201.25 MHz muon ionization cooling cavity [C]// Proc of PAC. 2005, 4: 3560-3562.

[5] Z. Shu, L. G. Shen, M. J. Li, et al. Numerical Calculus of Resonant Frequency Change by 3D Reconstruction of Thermal Deformed Accelerator Tube[C]//Proceedings of 23rd Particle Accelerator Conference (PAC09),May 2009, Vancouver, Canada.