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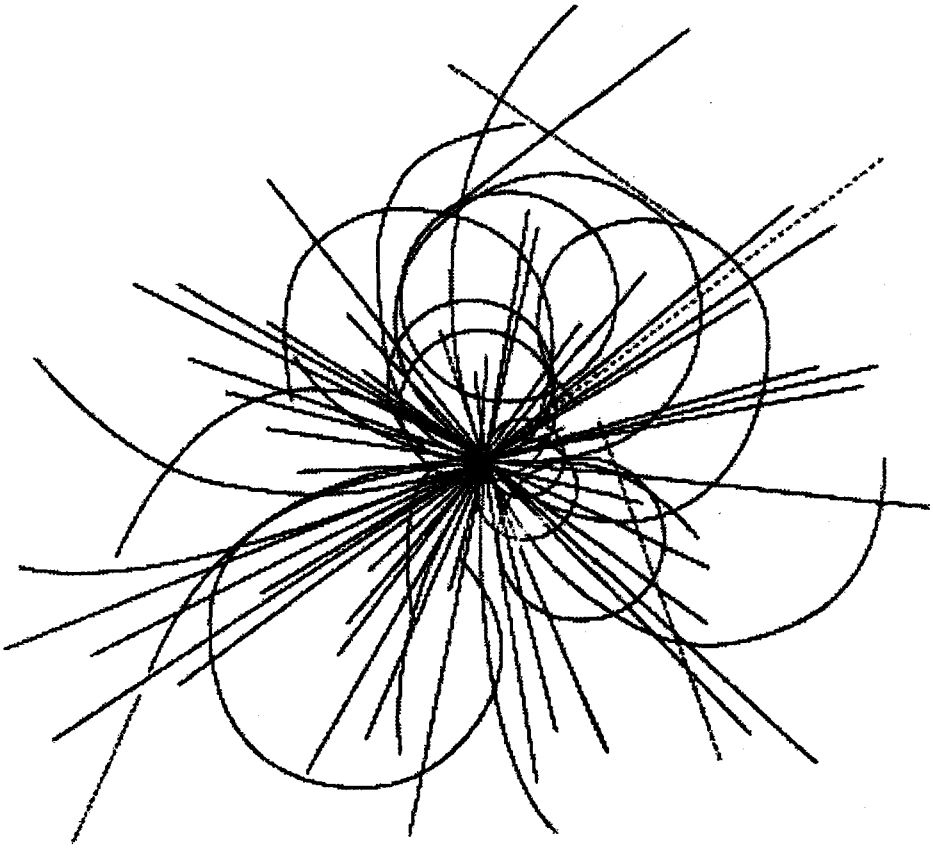

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Structural and Thermal Analysis of a Solid-Cooled, Low Energy Booster, Radio-Frequency-Cavity Tuner at the Superconducting Super Collider*

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STRUCTURAL AND THERMAL ANALYSIS OF A SOLID-COOLED, LOW ENERGY BOOSTER, RADIO-FREQUENCY-CAVITY TUNER AT THE SUPERCONDUCTING SUPER COLLIDER

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ABSTRACT

A three-dimensional heat conduction and structural model was developed to analyze and optimize the design of a solid-cooled low energy booster (LEB) radio-frequency (RF) cavity tuner concept. Consideration was given to three cooling options: (i) using beryllium oxide (BeO) disks, (ii) using aluminum nitride (AlN) disks and (iii) using neither BeO nor AlN disks. The results indicate that solid cooling is feasible from thermal and structural viewpoints if a minimum of two BeO disks or four AlN disks are used.

INTRODUCTION

The RF cavity tuner (modeled) consisted of five ferrite disks encased in a copper housing (Figure 1-a). The perpendicular biasing of the ferrites used for tuning the LEB RF cavity results in heat generation in the ferrites, housing and in the BeO (or AlN). A cooling system is needed to remove this heat[1,2] and ensure that the peak ferrite temperature and stress is maintained at safe levels. Therefore, a model was developed to analyze solid-cooling of the tuner. In this concept, the heat generated in the ferrites will be transferred by conduction to an external water jacket either directly through the ferrites (option iii above) or by using annular BeO (or AlN) disks glued between the ferrites (options i and ii). The BeO (or AlN) facilitates heat conduction from the ferrites. Details of this work are documented elsewhere.[2]

ANALYSIS

The temperature and stress distributions were assumed to be steady and three-dimensional. The thermo-structural properties were assumed to vary with temperature. The problem was solved using ANSYS.[3] Due to symmetry, only 1/32 of the tuner was modeled. Thus, the model spans 22.5 degrees in the tangential direction and includes 2 1/2 ferrites (with a symmetry plane passing through the innermost ferrite). Figure 1-b illustrates the computational domain that includes the ferrites, the epoxy, the BeO (or AlN) disks, the housing side walls and the ribs. Cooling water at 35°C flows through the water jacket.

RESULTS

Quantitative Sensitivity Results (Table 1)

When neither AlN nor BeO were used (rows 1, 4, 7 and 10), the peak stress in the ferrite resulted in a safety factor of less than 2 (compared to its tensile strength of 39 MPa). Further, the same cases also indicated the highest temperatures in the ferrites and the epoxy.

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Cases using AlN (rows 2, 5, 8, 11, 13 and 15) indicated factors of safety well in excess of 2 in the ferrites and between 1 and 3 in the AlN (compared to its flexural strength of 46 MPa). Further, the peak temperature in the ferrite and epoxy were less than 70°C which is safe compared to the maximum operating temperature of epoxy of 150°C and the curie temperature of ferrite of 200°C. When using BeO (rows 3, 6, 9, 12, 14 and 16), the safety factors were always greater than 2 in the ferrites and about 15 in the BeO (compared to its yield point under tension of 151 MPa). For the same cases the peak temperatures in the ferrite and epoxy were always less than 65°C.

Note, there is an uncertainty in the curie temperature and the tensile strength of ferrite. There is also an uncertainty in the thermal and structural properties of the low conductivity epoxy. Therefore, safety factors for stress (based on tensile strength) greater than 3 may be desirable. Also, note that a higher thermal conductivity of epoxy lowers the peak temperatures and stresses (Table 1). A thicker layer of epoxy lowers the stresses but raises the temperatures slightly. Using four or six BeO (or AlN) disks lowers both the peak stresses and the temperatures (rows 13–16).

Note, for all the cases shown in Table 1, the peak temperature and Von-Mises stress in the copper as well as the maximum shear stress in the epoxy were small compared to their corresponding thermal and structural limiting values. In addition, recent experiments indicate that steady state is reached within 30 minutes of the startup of the tuner and so transient results are not of interest since steady state represents the worst case condition.

Qualitative Results

To obtain a physical feel for the phenomena, the qualitative results for the case when two BeO disks are employed (Table 1, row 3) are shown in Figures 1 (b–d). For each of these figures, the scale on the right gives the magnitudes. The isotherms in the tuner (ferrites, BeO, housing walls, ribs etc.) show that the peak temperatures (symbol I) are located at the inner radius of the ferrite midway between the housing and the BeO as shown in Figure 1-b. The lowest temperatures (symbol A) are present on the copper.

The principal stresses in the ferrites given in Figure 1-c indicate that the peak value is located at the inside radius, near the junction of the ferrite and copper housing side wall. This may explain why a thicker layer of epoxy reduces the peak stresses (Table 1). Figure 1-d shows that the shear stresses in the epoxy are small compared to its lap shear strength of 7 MPa.

SUMMARY

A three-dimensional, structural and thermal model was developed to evaluate a solid-cooled LEB RF cavity tuner. The results were found to be sensitive to: the use of BeO or AlN or neither of them, the number of BeO (or AlN), the thermal conductivity and the thickness of the epoxy. The use of BeO gave the lowest peak temperature and stress in the ferrite.

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2. R. Ranganathan, "LEB RF cavity tuner solid cooling," AMC-2210005, SSC Laboratory, (1993).
3. ANSYS Engineering Analysis System, Revision 4.4, Swanson Analysis Systems, Inc., Houston, Pennsylvania, (1989).

NOMENCLATURE AND UNITS

k_g	thermal conductivity of epoxy, W/ (mC)
S_a	peak AlN stress (MPa)
S_b	peak BeO stress (MPa)
S_f	peak ferrite stress (MPa)
T_a	peak AlN temperature (°C)
T_b	peak BeO temperature (°C)
T_e	peak epoxy temperature (°C)
T_f	peak ferrite temperature (°C)
x_g	thickness of the epoxy between the ferrites and BeO (or AlN), microns

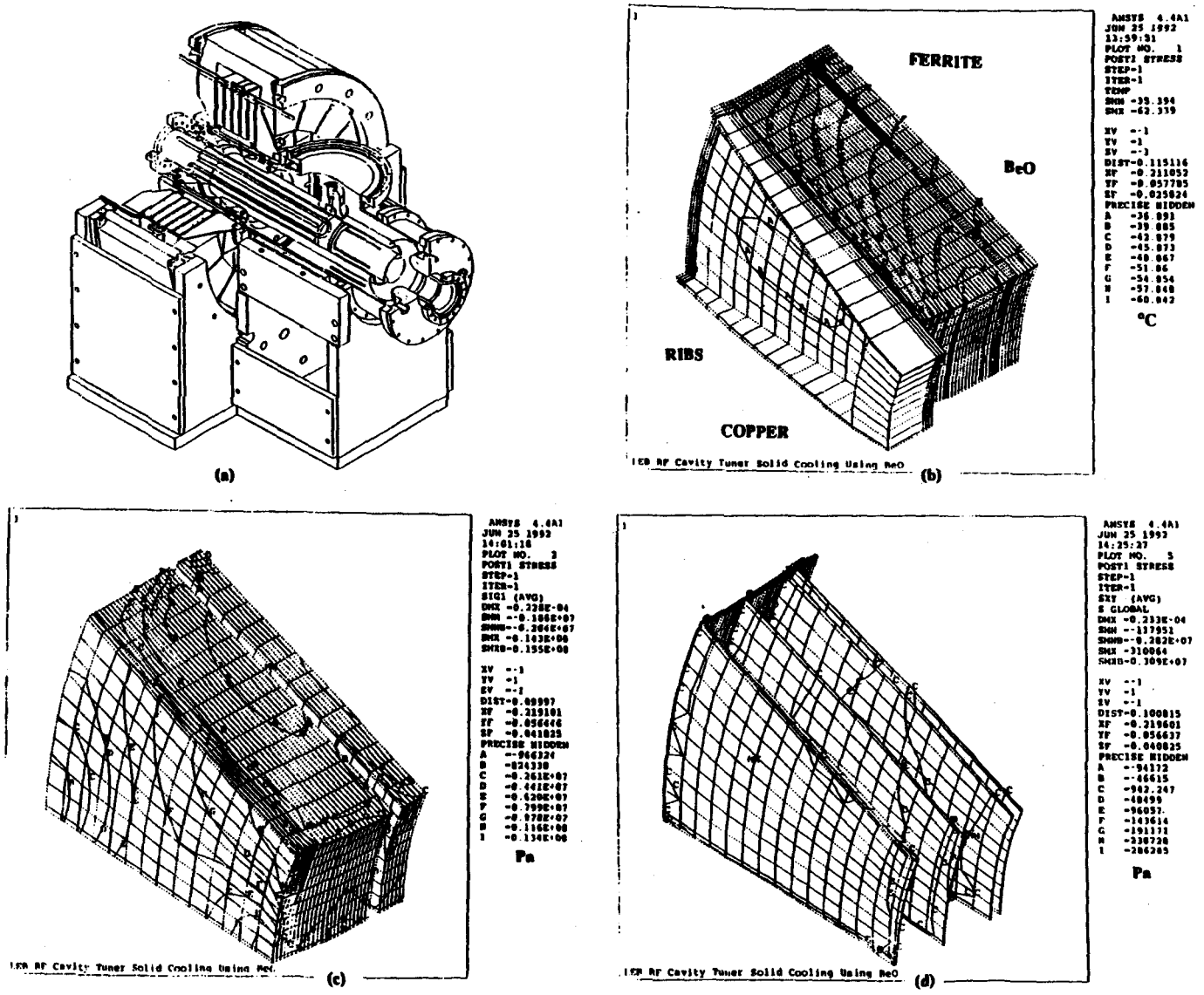

Figure 1. Qualitative results for a BeO cooled tuner.

Table 1. Sensitivity Results.

Row	no. of AlN	no. of BeO	x_s	k_s	T_a	T_b	T_f	T_o	S_a	S_b	S_f
1	-	-	50	0.8	-	-	85	83	-	-	26
2	2	0	50	0.8	63	-	66	66	32	-	15
3	-	2	50	0.8	-	59	62	61	-	8	14
4	-	-	200	0.8	-	-	85	83	-	-	21
5	2	-	200	0.8	63	-	66	66	23	-	14
6	-	2	200	0.8	-	59	63	62	-	8	13
7	-	-	50	11.6	-	-	75	74	-	-	28
8	2	-	50	11.6	56	-	58	56	24	-	28
9	-	2	50	11.6	-	51	54	52	-	6	16
10	-	-	200	11.6	-	-	75	74	-	-	23
11	2	-	200	11.6	55	-	58	55	17	-	16
12	-	2	200	11.6	-	51	54	52	-	7	14
13	4	-	50	0.8	60	-	63	60	26	-	11
14	-	4	50	0.8	-	56	59	56	-	6	10
15	6	-	50	0.8	61	-	63	61	27	-	12
16	-	6	50	0.8	-	57	59	57	-	10	9