BROADBAND HIGHER-ORDER MODE (HOM) DAMPER FOR SSC LEB FERRITE-TUNED CAVITY*†

L. Walling, G. Hulsey, and T. Grimm
Superconducting Supercollider Laboratory
MS-4010, 2550 Beckleymeade Ave. Dallas, TX 75237

Abstract

This paper reports results of using High-Frequency Structure Simulator (HFSS) to design a Smythe-type broadband longitudinal HOM damper for the SSCL low energy booster (LEB) ferrite-tuned cavity. The damper is designed to have a shunt impedance varying from less than 1 kohm between 100-200 MHz to about 3 kohm at 1 GHz. Above 1 GHz, the ferrite should effectively damp all HOM.

I. INTRODUCTION

The LEB cavity[1] is a ferrite-tuned λ/4 coaxial cavity that tunes from 47.5 to 59.8 MHz in about 20 ms and requires 127 kV on the gap at the peak voltage in the cycle. R. Baartman of TRIUMF did a coupled bunch mode beam instability analysis[2] for the LEB. According to his analysis, the allowable longitudinal shunt impedance of the cavity HOM's as a function of frequency is shown in Fig. 1. Also shown is the calculated achieved shunt impedance.

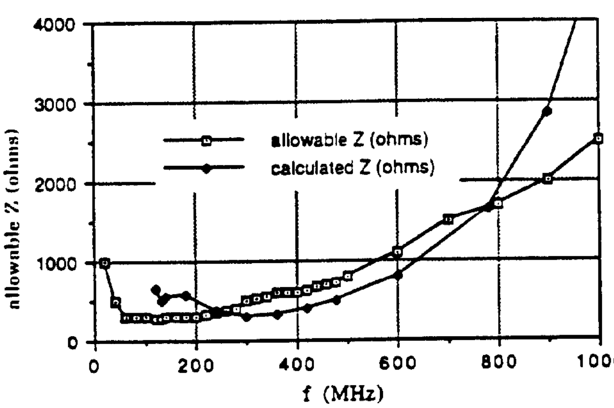

Fig. 1. Narrow Band Impedance in the SSC LEB.

For fixed-frequency machines, HOM dampers can be designed to address individual modes. Since the LEB has a large frequency swing, it is more convenient to build a broadband damper. A Smythe-type[3] broadband damper has been designed using two-element high-pass filters between the damping cavity and four discrete water-cooled loads. A cross-section of the gap end of the cavity with HOM damper is shown in Fig. 2. The filter/loads are distributed around the circumference of the damping cavity in such a pattern as to damp transverse as well as longitudinal modes (Fig. 3).

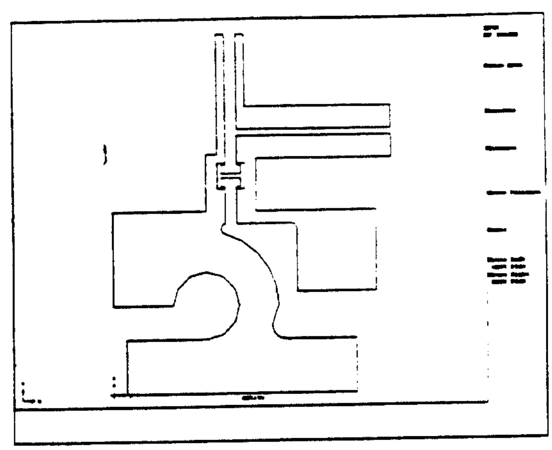

Fig. 2. Cross-section of Final LEB HOM Damper.

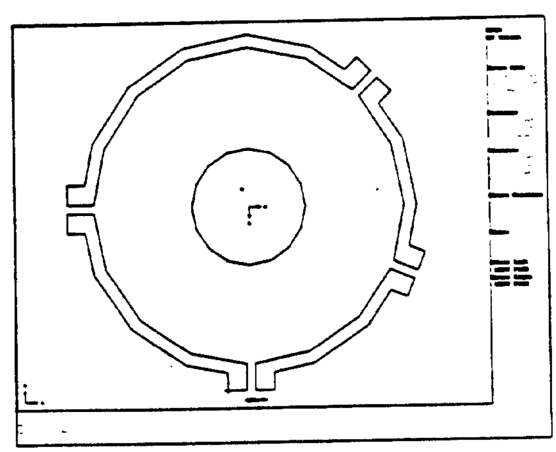

Fig. 3. Axial Arrangement of Filters and Loads on HOM Damper.

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II. DESIGN TECHNIQUE

Smythe showed that his damper could be modeled as a circuit element that is in shunt with the gap of the cavity. The circuit representing the cavity and damper is shown in Fig. 4. Then r_{sh}, the shunting resistance of the damper, is

$$r_{sh} = 1/\mathrm{Re}\{1/z_d\} \quad (1)$$

The damper impedance, z_d, can be approximated by solving the circuit,

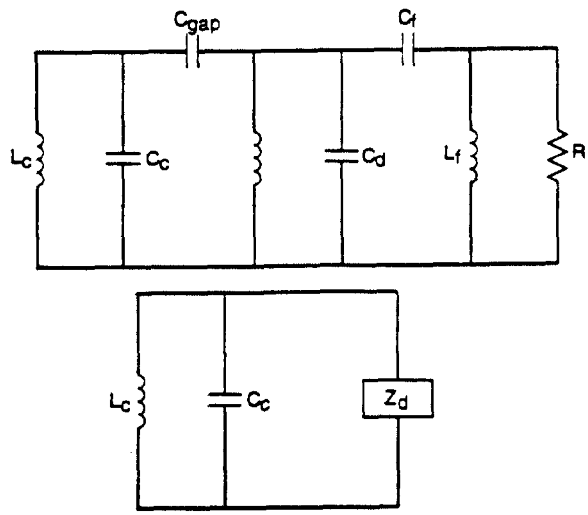

Fig. 4. Circuit for LEB HOM Damper with High-Pass Filters between Smythe Cavity and Loads.

where L_c and C_c are the cavity inductance and capacitance, L_d and C_d represent the damper cavity and L_f and C_f the filter parameters.

Originally, we intended to design a simple Smythe damper. However the 3λ/4 mode occurs at a frequency much lower than three times the fundamental due to the heavy capacitive loading of the cavity. This is aggravated by the large coupling to the damping cavity which is required to damp the low-frequency modes so strongly. After determining the amount of coupling that would be required, we determined that it would be impossible to find a design that would yield the required damping over the band while leaving the accelerating mode with a large enough shunt impedance so as not to overdrive the power amplifier (and burn up the 5 kW damping resistors). This could be determined easily using the lumped circuit model. Therefore we decided to try adding a high-pass filter between the damper and the load. The lumped circuit model for the damper plus filter could be used to estimate the required coupling capacitance to the damping cavity and roughly estimate the circuit parameters. Because the required coupling capacitance turned out to be very large (about 12 pF), the current paths from the gap to the point at which the filter/load is shunted across the Smythe capacitor became long, which reduces the damping of the HOMs. This results in a damping cavity that is not well-represented by any type of circuit approach.

HFSS, with its s-parameter format and finite-element mapping of the rounded surfaces, was the ideal tool for such a design. The main problem was to find an approach that would be fast and efficient, since modelling the entire damper including filter results in a large problem that takes hours to run. Therefore the design was done in three stages which combined the use of numerical results from HFSS and lumped element analysis in the first two stages to speed up the design process.

Step 1. Pseudo-2d HFSS analysis (Fig. 5). We modeled an angular wedge of 2 slices of about 5-10 degrees each (we have found that one thin slice of elements does not yield an accurate solution.) The load is represented by a thin disk of resistive material which represents the four loads in parallel. This is a one-port problem with the port located at a cross section of the cavity just far enough away from the gap such that the fields are approximately transverse. The reflection coefficient is calculated by HFSS and written out to a file. This file was read using a small FORTRAN code which transformed S11 from the port to the gap, then calculated r_{sh}. This was useful to develop a cavity that had approximately the desired r_{sh} over the band, although the fundamental mode shunt impedance was too low.

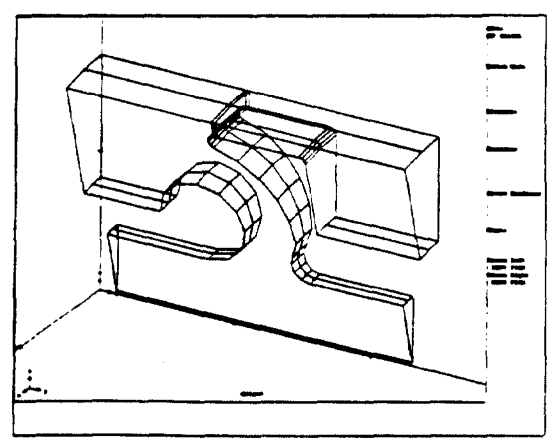

Fig. 5. HFSS Model Using a Disk of Resistive Material to Represent the Loads.

Step 2. Next, another HFSS model (Fig. 6) was built which modeled 1/8 of the axial geometry and which included a port at the position the filter/load would be placed. The full 2-port solution was obtained over the frequency range, the s-parameters stored in a file, then read into a FORTRAN code which cascaded the high-pass filter/load parameters onto port 2, then calculated r_{sh} from S11 with the new termination. The damper cavity dimensions were modeled in HFSS, then the filter quickly optimized for that geometry using the

FORTRAN code. By systematically varying the cavity dimensions and cyling through this process, the entire circuit was quickly optimized.

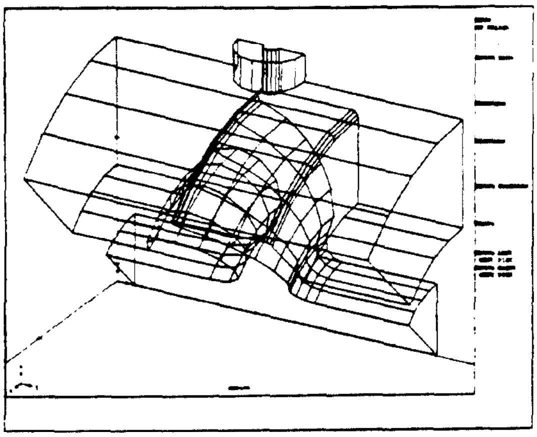

Fig. 6. HFSS Model Using 1/8 Axial Symmetry and Load Represented by Coaxial Port.

Step 3. The actual filter was added to the HFSS model (Fig. 7) to do the final checking of the design for damping, field maximums and heating. The shunt impedances of the HOMs as calculated by this HFSS model are shown in Fig. 1.

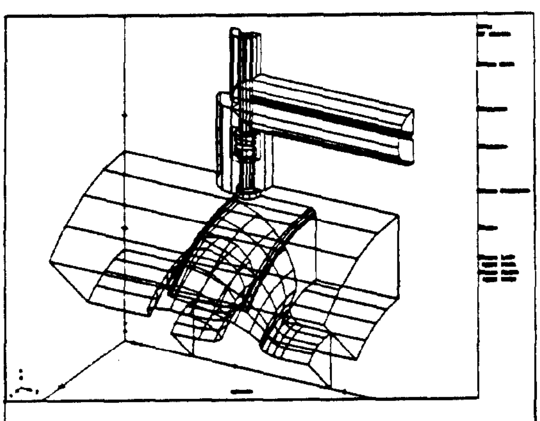

Fig. 7. HFSS Model of Entire HOM Damper.

In parallel to this effort, a hardware model of the filter using high-voltage ceramic capacitors and 5 kW water-cooled loads was built and tested at both low and high-power.

III. TRANSVERSE MODE DAMPING

We then tested the possibility of damping transverse modes by arranging the loads axially as shown in Fig. 3. A simplified model of the entire cavity with a simple Smythe damper was built using HFSS. The loads were arranged as suggested by Grimm and the cavity was excited by an off-center wire placed about 1 cm to the right and to the top of the cavity axis, looking down the axis from the gap to the tuner. This method of excitation would excite all longitudinal and transverse modes of the cavity. All materials in the cavity were artifically specified with a loss tangent that would ensure that as the cavity was swept from 300 MHz to 1 GHZ at 20 MHz intervals that any resonances would be identified. Then when resonances were found, they were identified as to longitudinal or transverse by looking at the fields near resonance. Finally, the loss tangents were reduced to zero and the frequencies were swept around the resonances. A rough analysis determined that the impedances of all transverse modes were below 100 kΩ/m. A similar analysis has not been done with the actual damper with filters, however we expect even better results because the damper has much greater coupling to the cavity than the one simulated with assymmetric loads.

IV. CONCLUSIONS

HFSS has proven to be an ideal tool for designing HOM dampers because of its s-parameter format, matched port, lossy material capabilities, and finite-element modeling technique which allows close approximation of rounded surfaces. It is very easy to model problems and make changes in models. Measurements of the cavity with damper will be performed in early spring of 1993 to verify the design.

REFERENCES

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