COMPUTER SIMULATIONS OF A WIDE-BANDWIDTH FERRITE-LOADED HIGH-POWER WAVEGUIDE TERMINATION*

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ABSTRACT

We describe our experience of using MacNeal-Schwendler's finite element code EMAS® [1] to design a 10 kW ferrite-loaded rectangular waveguide termination [2]. We require a VSWR of <2:1 over a bandwidth of 700 MHz to 3 GHz. We present results in the frequency domain for several distributions of ferrite tiles in the waveguide.

I. INTRODUCTION

High power, broad-bandwidth waveguide loads are required to terminate higher-order-mode(HOM)-damping waveguides on the PEP-II B factory RF cavities [3]. We use MacNeal-Schwendler Corporation's (MSC) 3D finite element code, EMAS® to calculate the return loss and power distribution for several configurations of flat ferrite tiles against the walls of a rectangular waveguide. MSC's XL®, version 3B, is used for pre- and post processing. Ferrite was chosen for its ability to absorb electromagnetic energy. EMAS® was chosen for its ability to model lossy ferrite. The goal is to distribute the power over the tiles to minimize hot spots that might cause outgassing or breakage. We believe that a power loss density of 20 watts/cm^2 or less is sufficient but attempt to achieve 10 watts/cm^2 or less.

Bandwidth	700 MHz - 3 GHz
Waveguide f_c	600 MHz
VSWR	2:1
Power	10 kWatts
Dimensions (mm)	25H x 250W x 500L
Bakeable	150° C
Ultra High Vacuum Compatible	

TABLE 1: Specifications

II. MODEL

A. Geometry, Elements and Material

Our model is one meter long with the ferrite distributed in the last 500 mm. Figure 1 shows the waveguide geometry with a vertical symmetry plane that

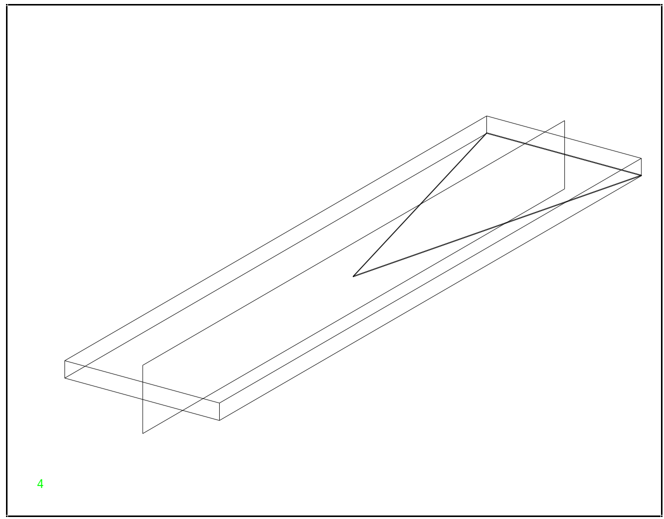

Figure 1: Waveguide model showing the symmetry plane and a 1-mm thick triangular ferrite wedge.

halves the model size and the number of elements and grid points. This and the appropriate boundary conditions reduce the problem size, hard disk storage requirements and computation time. Space constraints in the storage ring tunnel require the actual load's length to be less than 500 mm. The model is longer to separate the ferrite from any anomalous fields near the excitation plane at the open end of the waveguide.

All waveguide walls are considered ideal (i.e., lossless). We ran simulations for several ferrite thicknesses, but in practice found substantial cost savings with a commercially available ferrite that is 25 mm x 25 mm x 4 mm. We typically use two linear *(hexa* or *tetra)* elements across the ferrite thickness such that a 4 mm thick material has two 2-mm thick elements. We also examined thicknesses of 1, 2, 3 and 6 mm. There is a single layer of (vacuum) elements the same size above the ferrite. The remaining volume to the opposite wall is equally divided into (typically) four layers. To maintain thinner elements across the waveguide cross-section would increase the number of elements and problem size beyond our hard disk capacity without increasing accuracy.

The ferrite's frequency-dependent complex permeability μ^*_r , and permittivity ε^*_r [4], are used and are assumed to be isotropic (though EMAS® allows anisotropic properties).

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B. Excitation

The loads, while broadband, are excited at distinct frequencies and power levels. The power in each mode depends on the current and bunch configuration in the storage ring; we used the typical values shown in table 2, based on measured cavity mode spectra for modes below the beam pipe cut-off frequency.

Frequency (MHz)	Power (Watts)
714	1200
952	100
1190	200
1428	150
1666	700
1904	700
2142	400
Total Power	3450 Watts

TABLE 2: Excitation Frequencies and Power

We assume propagation in the TE_{10} mode at these frequencies and calculate the equivalent H fields at these power levels [5] as:

$$P_z = \mathrm{Re}[\frac{1}{2}\int_0^b\int_0^a (E \times H^*)dxdy]\vec{u}_z$$
$$= \frac{1}{4}E_{ox}^2 \frac{\beta_g}{\omega\mu_0}ab,$$

where a and b are the waveguide height and width and

$$H_y = \frac{E_{ox}}{Z_g}\sin(\frac{\pi y}{b})e^{-j\beta_g z},$$

where $Z_g = \dfrac{\omega\mu_0}{\beta_g}$ and $\beta_g = (\omega^2\mu_0\varepsilon_o - \dfrac{\pi^2}{b^2})$.

These H-field values are applied (using EMAS® *surface H-field* excitations) in a sinusoidal distribution across the waveguide end. Appropriate boundary conditions are applied and we use EMAS®'s *AC Analysis* solver for the general solution. Computation time is on the order of a few minutes on a SPARC 20, Model 51.

III. RESULTS

Once the model is solved we plot the electric and magnetic fields, power loss density and calculate the total power loss in the ferrite. Figure 2 shows electric field contours in volts/meter in the waveguide when the model shown in figure 1 is excited at 714 MHz and 1200 watts. Figure 3 shows power loss density in watts/m^3 in the ferrite of figure 1. The return loss is -17dB and within specifications, however, there is region of power loss >55 watts/cm^2.

The integrated power dissipated in the ferrite elements was within 10% of the excitation (input) power and deemed sufficiently accurate. The desire to reduce high power concentrations was then used to guide design of subsequent models. Some return loss calculations were compared with solutions from Hewlett-Packard's HFSS® and found to be in agreement.

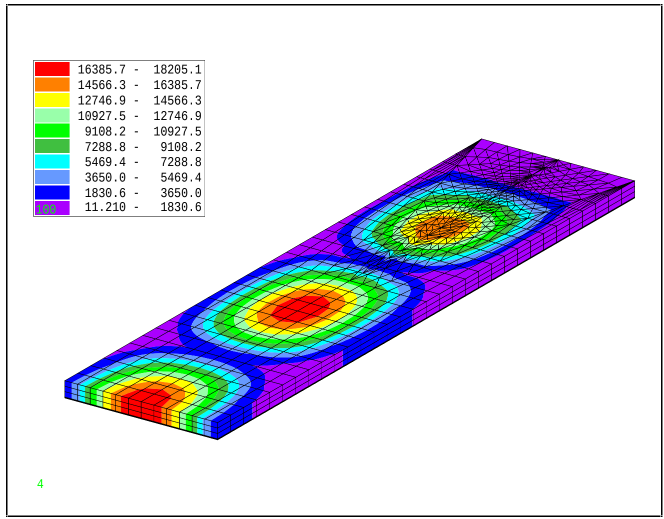

Figure 2: Electric field contours, in volts/meter. This shows E-field attenuation toward the waveguide end (upper right). Excitation is at lower left and at 714 MHz, TE_{10} mode.

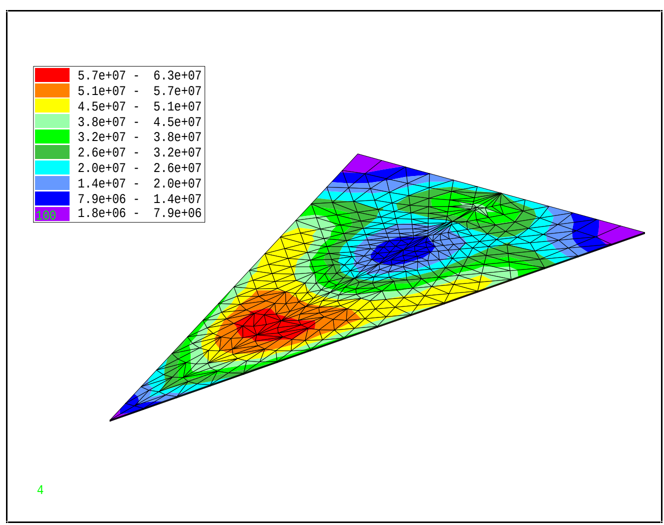

Figure 3: Power loss density in watts/m^3 in ferrite wedge of figures 1 and 2.

The problem with achieving an even distribution of power in this configuration is that the ferrite is such a good absorber. With any thickness greater than 1 mm, the power never penetrates sufficiently along the load to average under 10 watts/cm^2.

Better results were achieved with strips as shown in Figure 4. The power loss density exceeds 25 watts /cm^2 in a relatively small region, figure 5. Return loss is -17dB. It should be noted that the total surface area in this configuration is about 520 cm^2. Therefore, with 10 kwatts input power distributed evenly over the ferrite, the power loss density is about 20 watts/cm^2.

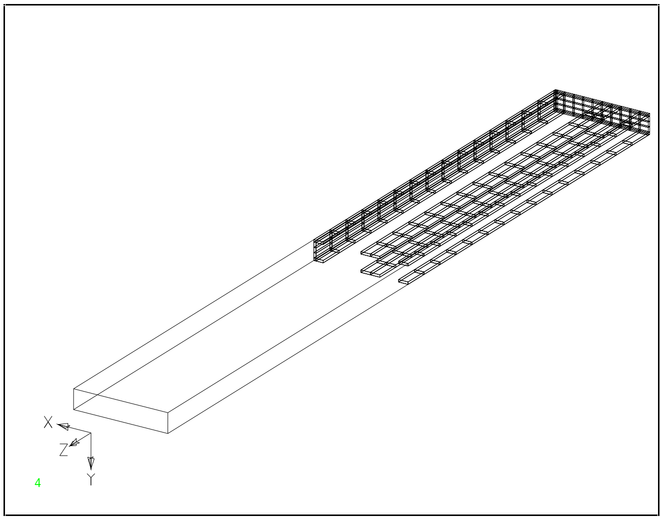

Figure 4: 3 mm thick ferrite strips 1/2" and 1" wide. The symmetry permits modeling half the termination.

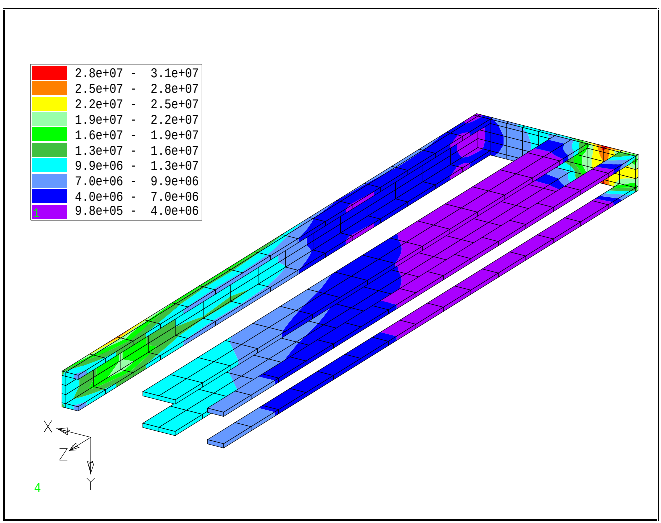

Figure 5: Power loss density exceeds 20 watts/cm^2 in a relatively small area. Return loss = -17dB.

IV. COMMENTS ON EMAS®/XL

The benefits and difficulties of computer modeling are well known. The codes tend to have steep and long learning curves and to demand lots of computing resources and time to model and generate meshes. MSC has developed this and similar software for over 30 years and the code's capabilities and complexities reflect this. We scarcely scratched the surface of EMAS® or XL® capabilities; e.g., in addition to the EMAS® *AC Analysis* module we used, there are at least 15 other solvers and many attributes we didn't need (or perhaps didn't know we needed). Though it was difficult in the beginning, once we became sufficiently adept with XL® and EMAS® it was easy to generate a variety of geometries in our admittedly very simple models.

MSC has now integrated an advanced solid modeling technology known as the ConceptStation® with EMAS® (and other MSC FEA codes). The ConceptStation® is a solid modeler that offers an intuitive interface with pre- and post processing and a host of other capabilities. Thus the steep learning curve and the difficulties with generating models and meshes have been addressed.

V. CONCLUSIONS

Though we have not yet achieved our design goal the simulations lend considerable insight to our problem. A lossy dielectric and ferrite combination is to be used in the PEP-II cavity HOM loads [2].

VI. ACKNOWLEDGMENTS

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