TESTING URMEL-3D BY MODELING A FERRITE-TUNED RF CAVITY*

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Summary

We have tested the rf cavity codes collectively known as URMEL-3D by studying the tuning of the fundamental mode of the Advanced Hadron Facility (AHF) booster cavity. Because of computer costs and turnaround time, we limited ourselves to problem sizes between 30 000 and 35 000 mesh points, which meant we had to use a simplified model of the coupling capacitor. Because we did not know *a priori* how to model this capacitor, we used its shape as a parameter to be varied. We generated three different models for the cavity, varying the details of the coupling capacitor, and plotted the variation of the fundamental frequency as a function of the permeability of the ferrite. The three resulting curves had similar shapes, and one of them fit the experimental data.

Not only is this the first time the codes have been used on such a complicated geometry, it is also the first time the codes have been used with such high permeabilities (μ) and permittivities (ϵ). The results obtained with such a relatively coarse mesh indicate that the codes are working well and that they should be useful in the design of rf cavities.

URMEL-3D

URMEL-3D is the subset of the MAFIA (MAxwell's Equations solved by the Finite Integration Algorithm) codes that calculates the resonant frequencies of rf cavities. MAFIA is the name given to a set of codes[1] intended for use in the computer-aided design of three-dimensional magnets, rf structures, and structures in which wake-field effects are important. The codes are currently being developed by a collaboration between Los Alamos National Laboratory, Thomas Weiland and his group at DESY, and Bernhard Steffen at KFA-Jülich.

AHF Booster Cavity

The AHF booster cavity[2] shown in Fig. 1 is cylindrically symmetric except for the coupling capacitor and the power tetrode. The cavity is basically a quarter-wave resonator tuned by the ferrite ring and the solenoidal coils shown at the left side of the drawing. Changing the magnetic field also changes the permeability of the ferrite and, hence, the effective inductance and resonant frequency of the cavity.

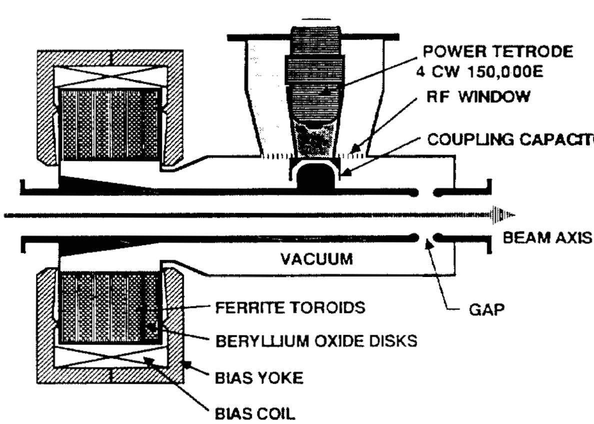

Fig. 1. Cross section of AHF booster cavity.

Computer Models

Cross sections of the three computer models used are shown in Figs. 2(a), (b), and (c). Computer-generated three-dimensional plots of these models are shown in Figs. 3(a), (b), and (c). We can see that the coupling capacitance increases from the model labeled Capacitor 1 to the one labeled Capacitor 3. The rf windows in Figs. 2(a) and (b) have $\epsilon = 10$, $\mu = 1$. The ferrite in each model has $\epsilon = 13.724$, the average value for the ferrite plus beryllium oxide spacers of the actual cavity, and an average μ ranging from 1 to 2.4.

Comparison with Experiment

Figure 4 shows the variation of the fundamental frequency as a function of μ for each of the three models. Figure 5 compares the model labeled Capacitor 2 with experimental data. In fact, the fundamental frequency was not measured as a function of μ; it was measured as a function of bias current (see Table I).

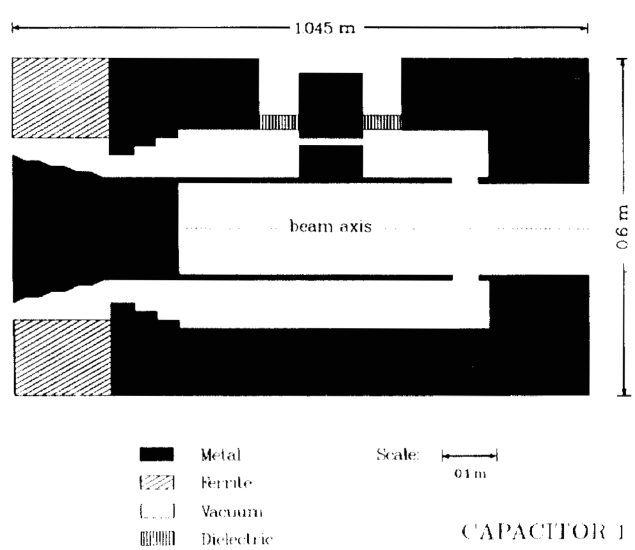

Fig. 2(a). Cross section of Capacitor 1, one of the three computer models of the AHF cavity. The radius of the input capacitor is 0.057 m. The dielectric rf window has $\epsilon = 10$ and $\mu = 1$; the ferrite has $\epsilon = 13.724$ and μ ranging from 1 to 2.4. The cross section is taken along the symmetry plane and is drawn to scale.

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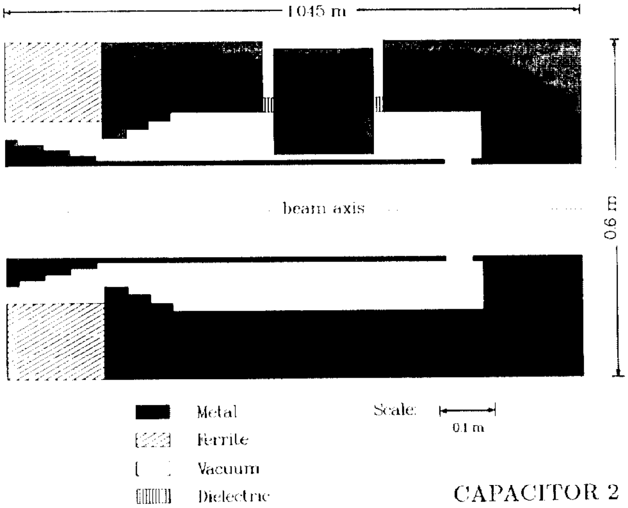

Fig. 2(b). Cross section of Capacitor 2, one of the three computer models of the AHF cavity. The radius of the input capacitor is 0.090 m. The dielectric rf window has $\epsilon = 10$ and $\mu = 1$; the ferrite has $\epsilon = 13.724$ and μ ranging from 1 to 2.4. The cross section is taken along the symmetry plane and is drawn to scale.

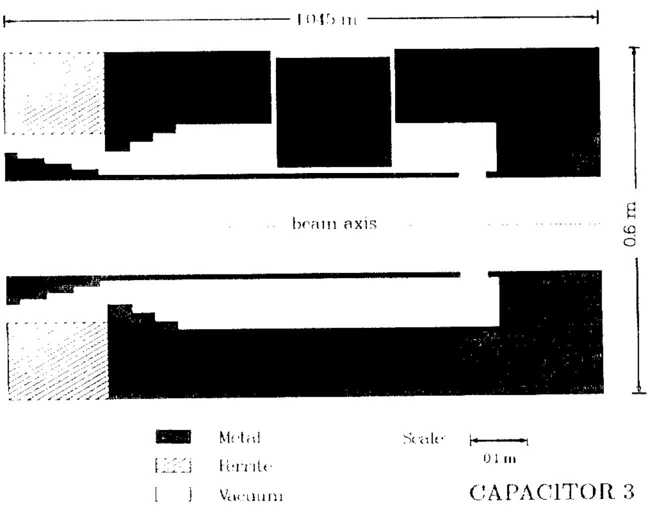

Fig. 2(c). Cross section of Capacitor 3, one of the three computer models of the AHF cavity. The radius of the input capacitor is 0.098 m. The ferrite has $\epsilon = 13.724$ and μ ranging from 1 to 2.4. The cross section is taken along the symmetry plane and is drawn to scale.

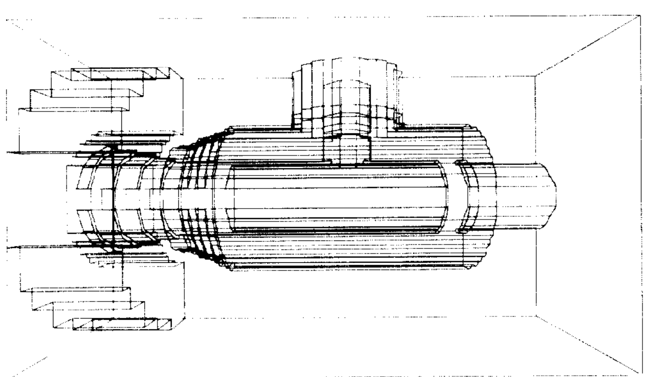

Fig. 3(a). Three-dimensional plot of Capacitor 1. Only one-half of the cavity is generated.

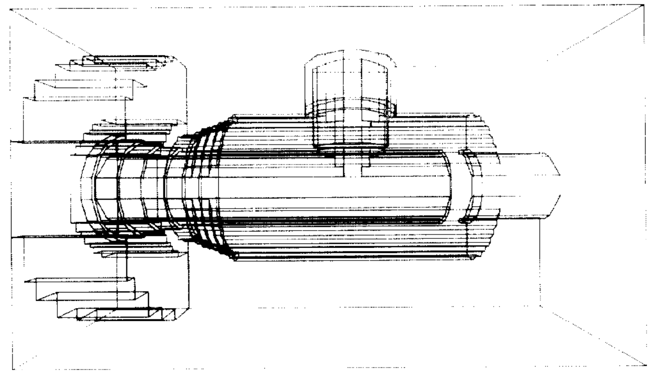

Fig. 3(b). Three-dimensional plot of Capacitor 2. Only one-half of the cavity is generated.

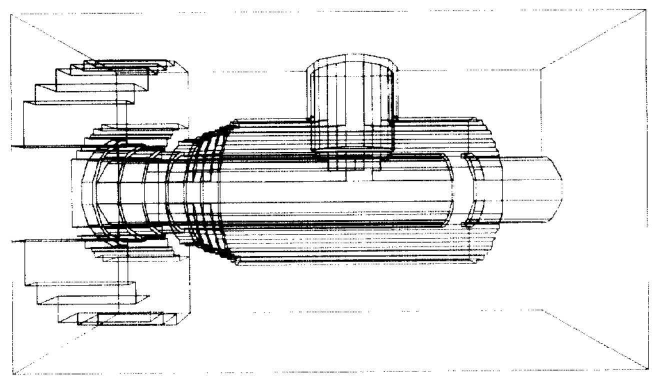

Fig. 3(c). Three-dimensional plot of Capacitor 3. Only one-half of the cavity is generated.

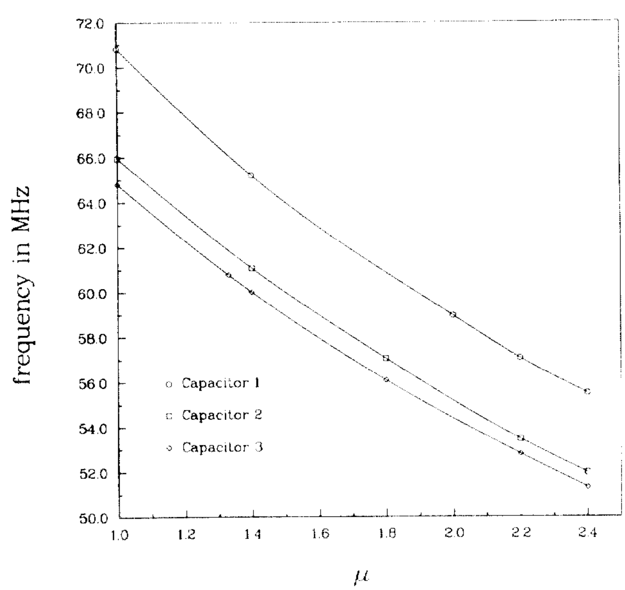

Fig. 4. Plot of computed frequency vs average permeability of the ferrite region for the three computer models of the AHF cavity. Smooth curves have been drawn through the computed points, indicated by the different plotting symbols.

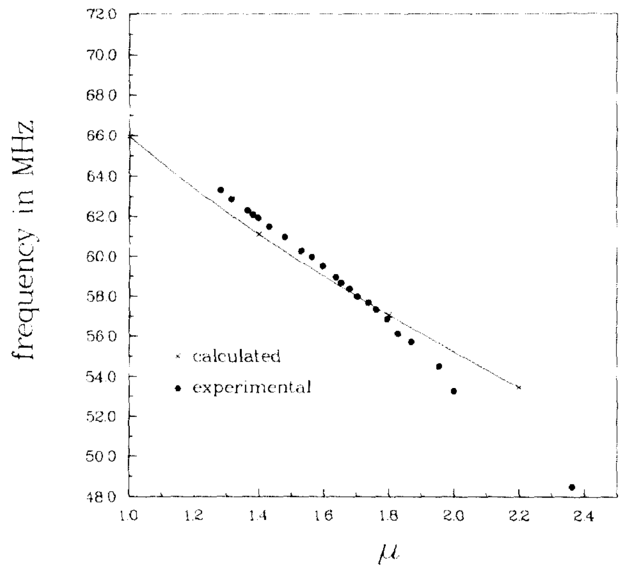

Fig. 5. Comparison of calculations (Capacitor 2) with experiment. The frequency of the fundamental mode is plotted as a function of the average permeability of the ferrite rings plus the beryllium oxide spacers.

R. Carlini* provided the following formulas to convert bias current to permeability:

$$\mu = 1 + 810/H, \tag{1}$$

$$H = (3000/427) \times I, \tag{2}$$

TABLE I

FUNDAMENTAL FREQUENCY AS A FUNCTION OF BIAS CURRENT

Bias Current (A)	Fundamental Frequency (MHz)
70	48.50
95	53.26
100	54.50
110	55.72
115	56.10
120	56.86
125	57.33
130	57.69
135	57.98
140	58.37
145	58.68
150	58.95
160	59.50
170	59.97
180	60.28
200	60.96
220	61.49
240	61.92
250	62.10
260	62.31
300	62.88
340	63.33

where I is the bias current in amperes, H is the magnetic field intensity in amperes/meter, and μ is the permeability of the ferrite rings. Equation (1) is valid only in the region above saturation, and the ferrite region of the computer model is only roughly represented, which may account for the fact that the calculated curve in Fig. 5 deviates from the experimental points for higher μ's.

Conclusions

Modeling a cavity with permeabilities greater than 1, especially with permittivities as high as 13.724, is a rigorous test for a cavity code. The consistent curves of Fig. 4 and the reasonable agreement with experimental data in Fig. 5 indicate that the URMEL-3D part of the MAFIA codes is working well. Clearly, more testing needs to be done against experimental results, but it appears that the codes are well on their way to becoming an effective design tool for rf cavities.

Acknowledgments

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References

1. T. Barts, M. J. Browman, R. Cooper, C. T. Mottershead, G. Rodenz, S. G. Wipf, R. Klatt, F. Krawczyk, W. R. Novender, C. Palm, T. Weiland, B. Steffen, "MAFIA – A Three-Dimensional Electromagnetic CAD System for Magnets, RF Structures, and Transient Wake-Field Calculations," Proc. 1986 Linac Conf., Stanford Linear Accelerator Center, Stanford, California, June 2-6, 1986, to be published.
2. "The Physics and Plan for a 45 GeV Facility That Extends the High-Intensity Capability in Nuclear and Particle Physics," Los Alamos National Laboratory report LA-10720-MS, May 1986.

* Private communication with R. Carlini, Los Alamos National Laboratory, Group MP-14.