**Final Report:
Calculation of Longitudinal and Transverse
Impedances of Ferrite-50 Beampipe Insert
for Cornell B-Factory**

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Final Report: Calculation of Longitudinal and Transverse Impedances of Ferrite-50 Beampipe Insert for Cornell B-Factory*

December 16, 1991

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Problem Description

As outlined in M. Tigner's letter to D. Prosnitz (dated 5/16/91 - see Appendix A), our task was to calculate the longitudinal monopole ($m = 0$) and the transverse dipole ($m = 1$) impedances of a simple structure consisting of a beampipe with a recessed ferrite (Ferrite-50) ring, as shown in Fig. 1. In support of this goal we also undertook to compute the impedance of a small scale model (Fig. 2) for which impedance measurements had been made by Linda Walling, now of SSCL.

Approach

To carry out the required calculations we used the AMOS wakefield code [1,2], together with a recently developed physics package that models dispersive media in the time domain. AMOS is a finite-difference, time-domain (FDTD) code similar to TBCI [3] (but with materials), and a discussion of the technique used to simulate the dispersive ferrite may be found in a recent paper by Luebbers, et al. [4]. The magnetic response function, $\tilde{\chi}_m$, of the ferrite was modeled as a relaxation process of the form

$$\tilde{\chi}_m(t) = \sum_l \alpha_l e^{-\beta_l t} \sinh(\gamma_l t), \quad (1)$$

which yields a magnetic susceptibility of the form

$$\chi_m(\omega) = \sum_l \frac{\alpha_l}{2} \left[\frac{1}{(\beta_l - \gamma_l) + i\omega} - \frac{1}{(\beta_l + \gamma_l) + i\omega} \right], \quad (2)$$

where α , β , and γ are real constants, and $\beta > \gamma > 0$. The parameters can be obtained by performing a pole extraction, with the resulting single-term fit to the experimentally measured values shown in Fig. 3. The parameters α , β , and γ characterize the material to AMOS, and are used as input parameters to the code. Note that we did not apply the dispersive model to the dielectric properties of the ferrite, as its implementation in AMOS was not complete when the calculations discussed in this report were made. Instead, we modeled the dielectric properties using a constant ϵ' , chosen to be representative of the measured properties in the several GHz range, and a conductivity which yields an ϵ'' that goes like $\frac{1}{\omega}$.

The AMOS code has been extensively tested in wake potential and impedance applications, including comparisons with analytic results, code-code comparisons [5], and comparisons with experimental measurements [6].

Numerical Results: Small Model

We first considered a small “scale” model of the 24 cm pipe problem. This geometry is shown in Fig. 2. Note that it is *not* a scale model of the B-Factory design problem, as the ferrite ring is too thick. Even if it was to scale, one could not extrapolate to the behavior of the full scale geometry because of the dispersive nature of the ferrite. However, it nevertheless represents the only hard data on the impedance of a structure similar to the one of interest, at least as of the publication date of this report. The measurements were taken by Walling while she was still at LANL (July, '91) using the wire technique [7]. The AMOS-calculated impedances are plotted along with the measured data in Figs. 4-7. Using the real part of the longitudinal impedance in the expression

$$k = 2 \int_{\omega=0}^{\infty} \text{Re} [Z_{||0}(\omega)] e^{-\frac{\omega^2 \sigma^2}{c^2}} d\omega, \quad (3)$$

the calculated loss factor of this structure for a $\sigma = .75\text{cm}$ Gaussian bunch is 1.96 V/pC.

The comparison shows reasonable agreement between calculation and experiment for the longitudinal impedance, $Z_{||0}$, and for $\text{Re}[Z_{r1}]$, but a large discrepancy is seen for $\text{Im}[Z_{r1}]$. The experimental result shows a large imaginary component to Z_{r1} for high frequencies which is not seen in the numerical results. This difference is not understood at present.

Because of the very small radial extent of the ferrite, as compared with the beampipe radius, AMOS was run with several different cell sizes to establish a maximum size which would yield reliable results. It was discovered that when the radial cell size was such that the number of cells radially in the ferrite was a minimum of four, further refinements did not yield significantly more accurate results (see Fig. 8). We also checked that the effects of the beampipe termination, which was a first order Mur radiation condition, were negligible by comparing runs with various pipe lengths (see Fig. 9).

Numerical Results: 24 cm Beampipe Problem

Results of the 24 cm beampipe problem shown in Fig. 1 are illustrated in Figs. 10-13. Data shown are for a resolution of 4 cells radially in the ferrite ring, which turned out to be adequate for this case as it was for the scale model. The loss factor for a $\sigma = .75\text{cm}$ Gaussian bunch is computed using Eqn. (3) to be 1.16 V/pC. No experimental data was available on this geometry as of the date of this report, and as indicated above it was not possible to use the scale model measurements to benchmark this calculation.

Conclusion

In conclusion, we found reasonable agreement with Walling's measurements on the scale model for $Z_{||0}$ and for $\text{Re}[Z_{r1}]$. However, there is a qualitative difference between experiment and calculation found for $\text{Im}[Z_{r1}]$. These results are consistent with our previous work, where comparisons involving induction modules (measured by Walling using

the same technique) showed agreement to within about 20% when 3-D geometric effects in the cells were eliminated. It should be noted, however, that these previous comparisons did not include a look at $\text{Im}[Z]$, as it was only the real part of the impedance that was relevant in estimating the severity of the beam breakup instability.

Additional experiments are warranted to help understand this discrepancy, and to put error bars on the measured results. It would also be useful to carry out additional calculations in which the dielectric dispersion in the ferrite was included. This capability is now installed in AMOS, and could be applied in another series of calculations on the small scale model and/or to the full inserts-plus-cavity configuration as it will exist in the accelerator.

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Appendix A

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May 16, 1991

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Dear Don,

This is a follow-up to our conversation at the PAC meeting to describe an EM impedance problem for AMOS. It is one of great practical importance for us.

Wanted are the beam impedances $Z_{||}$ and $Z_{\perp}$ for a circular cylinder of Ferrite 50 (TransTech), ID 24 cm, OD 24.5 cm and 15 cm length. The ferrite is embedded in a copper tube of the same ID and 25 cm OD and essentially infinite length, as indicated below. We would appreciate having a result in a few months.

We have measured ϵ' , ϵ'' , μ' , μ'' from 0.5 to several GHz. The results are enclosed. The dc values of μ_r and ρ are 150 and 25 ohm cm, respectively. It would seem reasonable to employ a quadratic interpolation. $\epsilon_r(\text{dc})$ is unknown to us at present. The value of about 20 at 500 MHz could be used until we produce a better one.

By way of verification we intend to make wire measurements which find Z by means of a network analyser. Should the calculation show it to be large enough, we will also measure the Z 's by putting a sample length into CESR and measure the beam transfer function for a 1.5 cm bunch.

All details of the verification will be available to you.

Sincerely,

Mauzy
Mauzy Tigner

encl.

cc: H. Padamsee
D. Moffat

- (1) 24 cm diameter beampipe with Ferrite-50 insert. Insert has a 2.5 mm radial thickness and is 15 cm in axial length.

- (2) Small "scale" model measured by L. Walling. Beampipe diameter is 4.13 cm in diameter, and the Ferrite-50 insert has a 3.2 mm radial thickness and is 3.49 cm in axial length.

- (3) Electric and magnetic properties of Ferrite-50. Measured data was taken at Cornell. We model the material using a dispersive model for the magnetic properties of the ferrite, a constant permittivity (real part), and a constant electric conductivity. One term was used in the expansion of the magnetic impulse response (Eqn. 1), with parameters $\alpha = 1.41 \times 10^{11}$, $\beta - \gamma = 1.09 \times 10^9$, and $\beta + \gamma = 7.92 \times 10^{10}$.

- (4) Comparison of calculated and measured values of the real part of the longitudinal monopole impedance for the small model shown in Fig. 2.

- (5) Comparison of calculated and measured values of the imaginary part of the longitudinal monopole impedance for the small scale model shown in Fig. 2. Measured values have been multiplied by -1 to correct for difference in sign convention.

- (6) Comparison of calculated and measured values of the real part of the transverse dipole impedance for the small scale model shown in Fig. 2.

- (7) Comparison of calculated and measured values of the imaginary part of the transverse dipole impedance for the small scale model shown in Fig. 2. Measured values have been multiplied by -1 to correct for difference in sign convention.

- (8) Calculated values of the real part of the longitudinal $m = 0$ impedance for various FDTD cell sizes. Numbers indicate the number of cells radially in the ferrite ring, which has an axial thickness of 3.2 mm.

- (9) Calculated values of the real part of the longitudinal $m = 0$ impedance for various pipe lengths.

- (10) Calculated value of real part of longitudinal monopole impedance for 24 cm diameter beampipe problem shown in Fig. 1.

- (11) Calculated value of imaginary part of longitudinal monopole impedance for 24 cm diameter beampipe problem shown in Fig. 1.

- (12) Calculated value of imaginary part of transverse dipole impedance for 24 cm diameter beampipe problem shown in Fig. 1.

- (13) Calculated value of real part of transverse dipole impedance for 24 cm diameter beampipe problem shown in Fig. 1.

- (14) Comparison of measured values of $\text{Re}[Z_{||0}]$ reported by Walling with values calculated for modified small model. Geometry is as described in Fig. 2, except that the beampipe radius and ferrite insert radial thickness have been reduced by a factor of two.

- (15) Comparison of measured values of $\text{Im}[Z_{||0}]$ reported by Walling with values calculated for modified small model. Geometry is as described in Fig. 2, except that the beampipe radius and ferrite insert radial thickness have been reduced by a factor of two. Measured values have been multiplied by -1 to correct for difference in sign convention.