The Interaction of a Beam with a Beam Line Higher-Order Mode Absorber*

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"'Round and 'round and 'round and 'round."
N. Cherry

I. INTRODUCTION

Plans for CESR-B, the proposed upgrade of the CESR e^+e^- storage ring to a B-factory [1], call for beam currents of $\sim$ 1 A. Studies indicate that the beams will be unstable unless the higher-order modes (HOMs) in the superconducting cavities are strongly damped; $Q \leq 100$ is required for the dangerous modes [2]. The cavity is designed to enable all HOMs to propagate into the beam pipe, where a layer of microwave-absorbing ferrite is to provide the damping. The load geometry is shown in Figure 1. RF measurements with a full-size mock-up of the cavity and loads made of two types of ferrite, TT2-111-series and Ferrite-50,[1] indicate that this scheme provides the required damping [3]. The HOM loads can also interact directly with the beam. Preliminary predictions for the effect of loads made of TT2-111V[2] ferrite on beam stability in CESR-B are given in this paper.

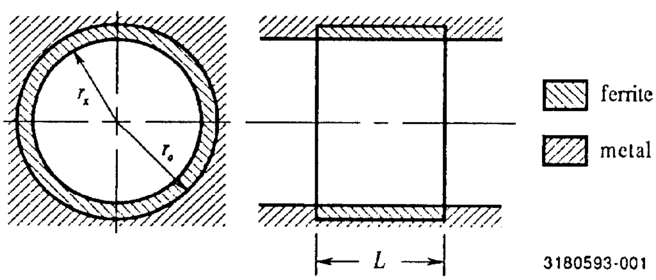

Figure 1. Load geometry. For a full-size load, $L = 150$ mm, $r_x = 118.4$ mm, and $r_o = 121.6$ mm.

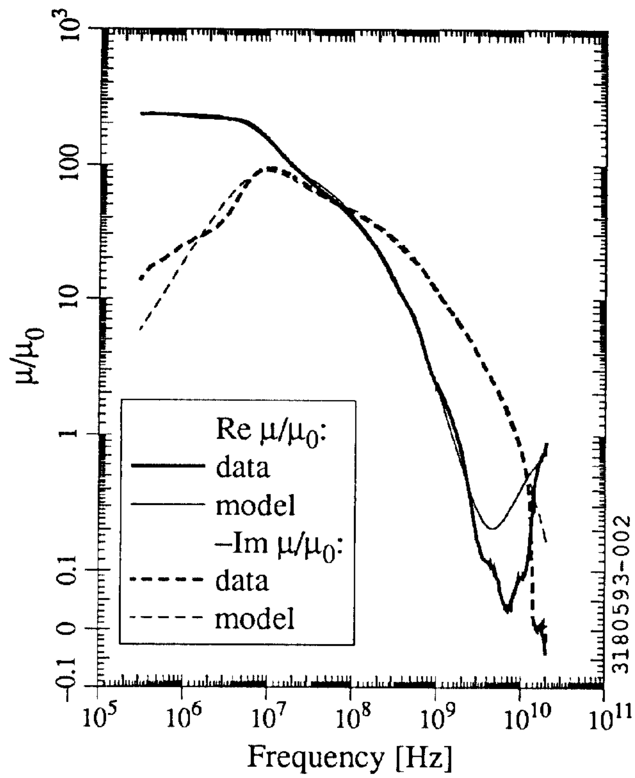

Figure 2. Measured and fitted values of the real and imaginary (times -1) parts of μ for TT2-111V.

II. COUPLING IMPEDANCE PREDICTIONS

The beam coupling impedance of a load was predicted using (i) AMOS, a program which calculates wake fields in the presence of absorbing materials [4], and (ii) analytic formulae for the coupling impedance of a conducting pipe with a material layer. The formulae were derived using an approach previously applied to multi-layer pipes [5, 6]; a detailed explanation of the technique and its application to the resistive wall can be found in [7]. In the analytic calculation, the beam pipe is assumed to be homogeneous in the axial direction, so that end effects are neglected.

Prediction of the impedance requires knowledge of the microwave properties (complex permeability μ and permittivity ϵ) of the absorbing material. The properties of TT2-111V and some other absorbing materials were measured using the coaxial transmission line technique [8]. Measured values of μ are shown in Figure 2. The 6-pole "relaxation" model fit used in AMOS is also shown. The measured ϵ/ϵ_0 has a real part of about 14 and an imaginary part corresponding to a DC conductivity of about 0.0023 $(\Omega\text{m})^{-1}$; these are the values that were input to AMOS.

Predictions for the monopole longitudinal impedance $Z_0^{\parallel}$ are shown in Figure 3. There is a significant difference between the AMOS and analytic predictions above 1 GHz, possibly due to the fact that the analytic calculation neglects end effects. The "broad-band" longitudinal and transverse impedances are shown in Figure 4. More information on the impedance predictions and on additional

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[1] TT2-111-series ferrite and Ferrite-50 are products of Trans-Tech, Inc.
[2] We use "TT2-111V" to refer to a variety of TT2-111R ferrite with enhanced DC conductivity.

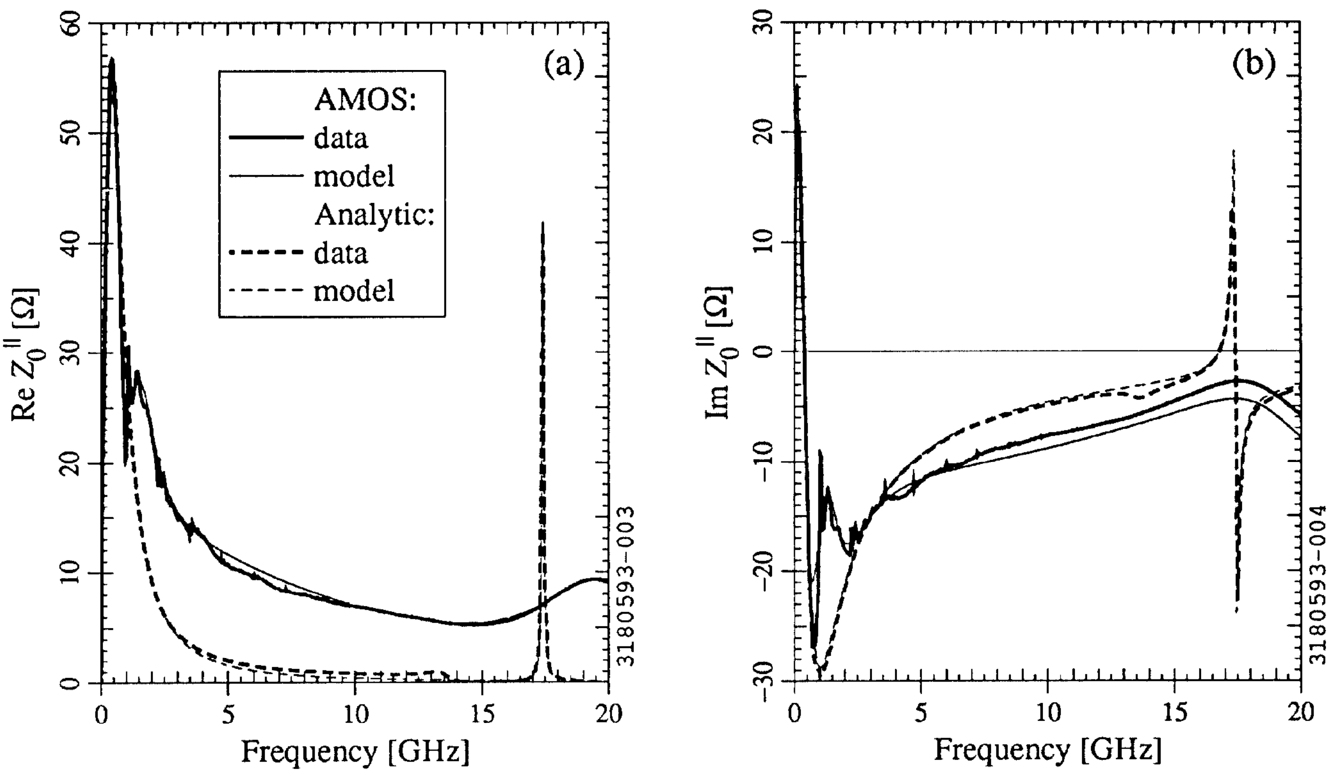

Figure 3. Predicted (a) real part and (b) imaginary part of the longitudinal monopole coupling impedance for a full-size TT2-111V load, along with model values used for ZAP. The complex conjugates of the AMOS values are shown.

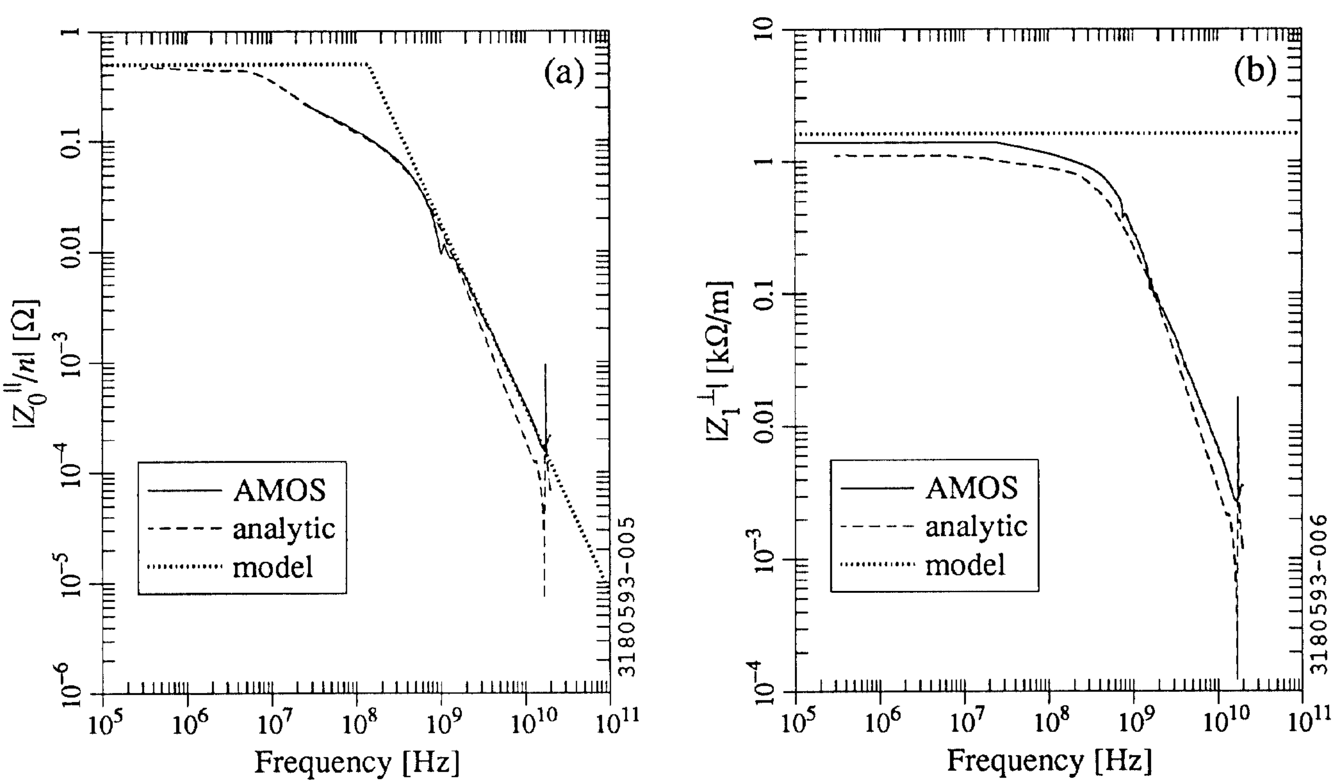

Figure 4. Predicted (a) $|Z_0^{\parallel}/n|$ and (b) $|Z_1^{\perp}|$ for a full-size TT2-111V load, along with model values used for ZAP.

wire measurements may be found elsewhere [9, 10].

III. BEAM STABILITY PREDICTIONS

The ZAP program [11] was used to predict the effect of the ferrite loads' coupling impedance on CESR-B beams. Relevant machine parameters are given in Table 1.

Table 1. Selected CESR-B Machine Parameters.

Parameter	Low-Energy Ring	High-Energy Ring
Ring circumference	764.84 m	
Beam energy	3.5 GeV	8 GeV
Beam current	1.98 A	0.87 A
Particles per bunch	$1.92 \cdot 10^{11}$	$0.84 \cdot 10^{11}$
Longitudinal bunch size	1 cm	
Total RF voltage	11.64 MV	33.82 MV
RF Frequency	500 MHz	
Momentum compaction	0.011	0.0084
Momentum spread	$6.44 \cdot 10^{-4}$	$8.30 \cdot 10^{-4}$
Horizontal betatron tune	11.56	12.56
Vertical betatron tune	8.63	
Horizontal tune spread	$2 \cdot 10^{-4}$	
Chromaticity	1	
Number of HOM loads	5	14

Single-bunch thresholds were predicted from the calculated broad-band impedances. A constant $|Z_1^\perp|$ and a SPEAR-like $|Z_0^\parallel/n|$ was assumed (see Figure 4). SPEAR scaling was used to obtain the effective $|Z_0^\parallel/n|$. The results are given in Table 2. ZAP predicts no bunch lengthening due to potential well distortion.

Growth rates for longitudinal and transverse coupled-bunch instabilities were predicted with ZAP, after fitting $Z_0^\parallel$ and $Z_1^\perp$ to a multi-mode resonator model. Because the AMOS and analytic impedances are somewhat different, they were fitted separately. The model impedances used for $Z_0^\parallel$ are shown in Figure 3. There was a significant disagreement between the predictions from the two possible formalisms (Wang and Zotter) in some cases. The worst-case results are given in Table 3. The $a = 1$ mode has the fastest growth time in all cases. As can be seen, all modes are predicted to be stable in the presence of radiation damping.

Table 2. Predicted single bunch thresholds.

Instability type	Threshold particles/bunch	
	Low-Energy Ring	High-Energy Ring
Transverse fast blow-up or mode coupling	$1.9 \cdot 10^{13}$	$1.5 \cdot 10^{13}$
Microwave / turbulent bunch lengthening	$7.9 \cdot 10^{12}$	$7.5 \cdot 10^{12}$

Table 3. Predicted worst-case growth times for coupled-bunch instabilities. CESR-B radiation damping times are also given for comparison.

Instability type	Fastest growth time	
	Low-Energy Ring	High-Energy Ring
Longitudinal	44 s	106 s
Transverse	4 s	6 s
Type of damping	**Radiation damping time**	
	Low-Energy Ring	High-Energy Ring
Longitudinal	12 ms	4.2 ms
Transverse	25 ms	8.5 ms

The loss factor was calculated from the predicted $Z_0^\parallel$. In the worst case (the AMOS prediction for the low-energy ring), the direct power transfer from the beam to the load is 11.5 KW per load, which corresponds to an average power dissipation of 0.102 W/mm^2.

IV. CONCLUDING REMARKS

The ZAP results indicate that the single-bunch instability thresholds from the loads are at least a factor of 40 above the design beam current for CESR-B and the coupled-bunch growth times due to the loads are at least a factor of 100 longer than the radiation damping times. We plan to design a scaled load with appropriately magnified effects and test our understanding of its interaction with a beam in the existing CESR storage ring.

V. REFERENCES

[1] M. Tigner, *Conference Record of the 1991 IEEE Particle Accelerator Conference*, p. 132-134.

[2] H. Padamsee *et al.*, ibid., p. 786-788.

[3] V. Veshcherevich *et al.*, *Proceedings of B Factories: The State of the Art in Accelerators, Detectors, and Physics*, SLAC-400/CONF-9204126, p. 177-180.

[4] J. DeFord *et al.*, *Proceedings of the 1989 IEEE Particle Accelerator Conference*, p. 1181-1183.

[5] B. Zotter, *Particle Accelerators* **1**, 311 (1970).

[6] A. Piwinski, *IEEE Trans. Nucl. Sci.* **NS-24**, 1364 (1977).

[7] A. Chao, in AIP Conf. Proc. no. 105, M. Month, Ed., (AIP, New York, 1983), p. 353-523.

[8] W. Hartung *et al.*, "Measurements of the Microwave Properties of Some Absorbing Materials," presented at the Microwave-Absorbing Materials for Accelerators Workshop, CEBAF, 22-24 February 1993.

[9] W. Hartung *et al.*, "Assessment of the Coupling Impedance of Beam Line Higher-Order Mode Loads," ibid.

[10] J. DeFord *et al.*, these proceedings.

[11] M. Zisman, *Particle Accelerators* **23**, 289 (1988).