Proceedings of the Linear Accelerator Conference 1990, Albuquerque, New Mexico, USA

COMPUTER SIMULATIONS OF NEW DIELECTRIC ACCELERATOR DEVICES*

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Abstract Recently, dielectric wakefield accelerator structures have been successfully demonstrated at the Argonne Advanced Accelerator Test Facility. This paper describes computer simulations of these experiments, including schemes for damping transverse deflecting forces in these devices. These simulations were performed using the MAFIA and ARRAKIS codes. MAFIA is a set of electromagnetic solvers in three dimensions widely used for designing accelerator components. The ARRAKIS codes are time-domain electromagnetic solvers which have been recently developed and implemented on massively parallel computers such as the Connection Machine.

Introduction

Time-domain finite-difference (TDFD) codes have been useful tools for calculating wakefield effects, and have been extensively validated for structures involving metal and vacuum only [1]. Experiments performed recently at the Argonne Advanced Accelerator Test Facility (AATF) [2] to measure longitudinal and transverse wakefields induced by electron beams in dielectric structures offer an unique opportunity for validating these TDFD codes for applications that include dielectric materials.

In this paper, we report computer simulations of AATF experiments and related dielectric schemes using the MAFIA codes [3] and the ARRAKIS codes [4]. The MAFIA codes are a standard set of general purpose electromagnetic solvers in three dimensions widely used for designing accelerator components. The TDFD code in the MAFIA group is called T3. Although the geometries involved in the AATF experiments at this time have been mostly axisymmetric, T3 will allow us to extend our simulations to 3D dielectric device geometries in the future.

The ARRAKIS codes differ from the MAFIA package in having been designed specifically for problems involving dielectric devices. Although presently restricted to 2D problems, thus requiring each azimuthal mode to be computed individually, these codes permit some flexibility in specifying dielectric properties and boundary conditions. Rapid computational turnaround with large meshes is achieved through the implementation of the ARRAKIS codes on parallel computers, with the ARCHON subset (used for the simulations reported in this paper) developed for the Connection Machine. Recent work on ARRAKIS has emphasized studies of transverse wake suppression mechanisms and noncollinear drive-witness beam transformer geometries.

*Work supported by the US Department of Energy, Offices of High Energy and Nuclear Physics, including Contract W-31-109-ENG-38.

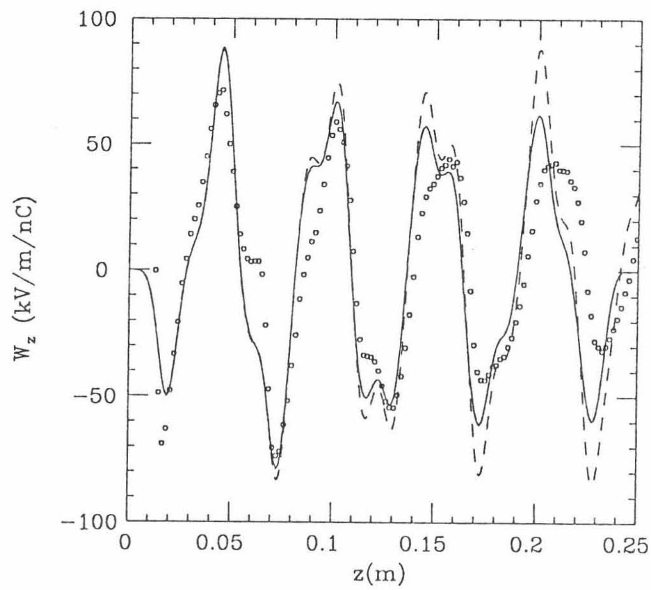

Figure 1: AATF measurement (o) of the longitudinal monopole wake with MAFIA (solid curve) and ARCHON (dashed curve) calculations.

Dielectric Device Simulations

Longitudinal (monopole) and transverse (dipole) wakes were computed for one of the AATF dielectric waveguide experiments [5]. The device geometry used here consisted of a dielectric tube of inner radius 1.27 cm, outer radius 2.22 cm, dielectric constant $\epsilon = 2.6$, and rms drive bunch length $\sigma_z = 3.0$ mm. The computed and measured wakes are shown in figures 1 and 2. Note that the ARCHON and T3 longitudinal wakes have each been convolved with a Gaussian ($\sigma_z = 3.0$ mm) to reflect the smearing of the measured wake by the finite length witness beam. No attempt was made to adjust the computed transverse wakes. The accuracy of the measurements is roughly ±5 kV/m/nC for the monopole wake and ±0.4 kV/m/nC/mm for the dipole wake.

The numerical and experimental results demonstrate reasonably good agreement over a long distance (24 cm) behind the drive bunch. The computed wakes reproduce well the overall shape of the measurement, with some discrepancies in detail on the amplitudes of the maxima and minima, and in the wavelength of the dipole wake.

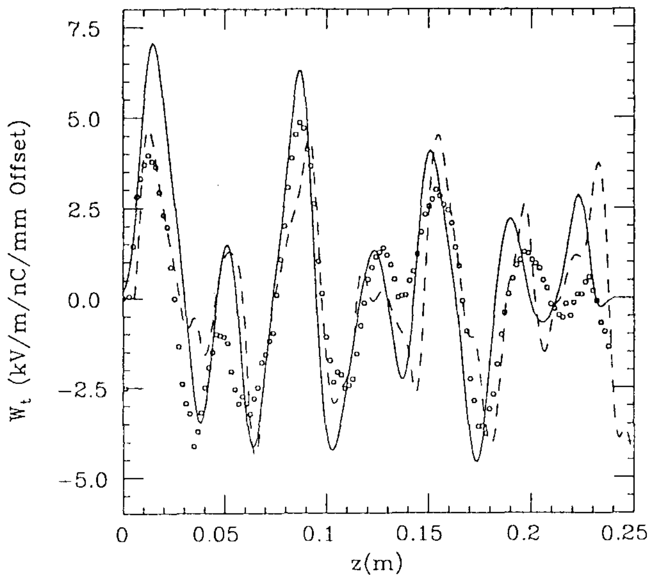

Figure 2: AATF measurement (o) of the transverse dipole wake with MAFIA (solid curve) and ARCHON (dashed curve) calculations.

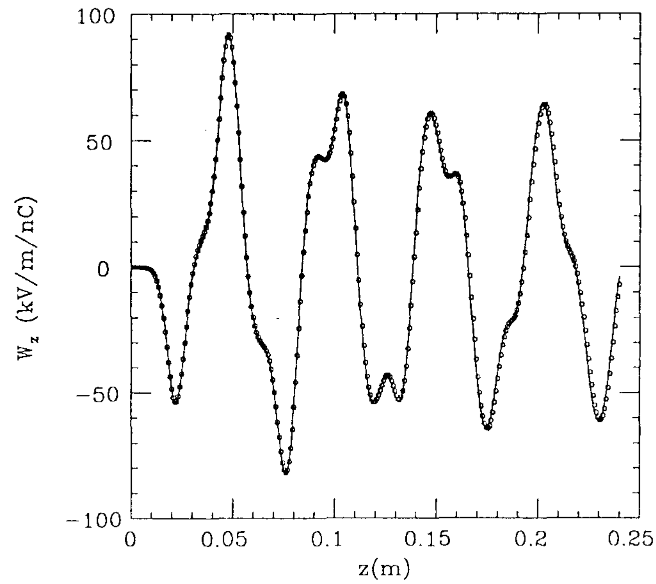

Figure 3: Comparison of longitudinal wakes in a dielectric structure with (o) and without (line curves) longitudinal cuts to interrupt azimuthal current flow in the outer boundary. (T3 simulation)

Another set of simulations were performed for dielectric structures with the thickness of the dielectric small compared to the radius of the structure. In this limit the longitudinal and transverse wakes have been shown analytically [6] to reduce respectively to a cosine and a sine function with the same wavelength. This asymptotic behavior has been reproduced in the MAFIA and ARCHON simulations. The amplitudes and wavelengths of these sinusoidal functions calculated using the two codes are compared with the analytic values in Table 1 for structures of inner radius 12.7 mm, $\epsilon = 2.25$, $\sigma_z = 4$ mm, and dielectric thicknesses of 1.6 and 2.4 mm.

For the most part, the codes are in good agreement with theory, with the largest discrepancies occuring in the transverse wake amplitudes. The origin of this disagreement is not understood and is currently being investigated.

The suppression of deflecting wakes is of some importance if dielectric wakefield structures are to be of use in high energy accelerators. A technique for effecting this [2] proceeds from the observation that while the accelerating modes in dielectric devices are pure TM_{0n}, the deflecting modes are all hybrids (HEM_{mn}). Interrupting the azimuthal current flow in the outer conducting jacket, either by introducing cuts or replacing it altogether by a longitudinal wire layer, should therefore not affect the monopole components of the wake but should allow the dipole and higher parasitic modes to leak through for damping by an external layer of lossy material.

T3 simulations were performed to show that longitudinal cuts at the outer metallic wall of a dielectric structure will modify the dipole but not the monopole wake. The geometry used was the same as for the calculation in figures 1-2, but with two longitudinal cuts in the outer jacket, taken in the plane normal to the plane of displacement of the drive beam. Both cuts were 2mm in height, and the beam length used was $\sigma_z = 4$ mm. Closure was provided by assuming a second cylindrical conducting shell at a radius of 3 cm.

Figures 3-4 show the computed wakes for this device with and without the longitudinal cuts. Differences between the monopole wakes are negligible, while the shape of the transverse wake is greatly distorted in the cut geometry.

ARCHON was used to model an experiment performed at the AATF which used a dielectric device in which the outer jacket was replaced by a longitudinal wire layer. The inner and outer radii of the dielectric tube were 1.27 and 1.905 cm respectively, and $\epsilon = 2.6$. Beam parameters were $\sigma_z = 3.5$ mm, charge/pulse= 4 nC, and offset= 6 mm. The device was enclosed in a solid conducting tube 2.54 cm in radius.

The longitudinal wire boundary was treated in ARCHON by assuming E_ϕ is continuous across it and neglecting any effects of the finite wire dimensions. The simulation (figure 5) is in qualitative agreement with the AATF data.

Conclusions

The MAFIA and ARRAKIS codes were used to model wakefields in dielectric loaded accelerator struc-

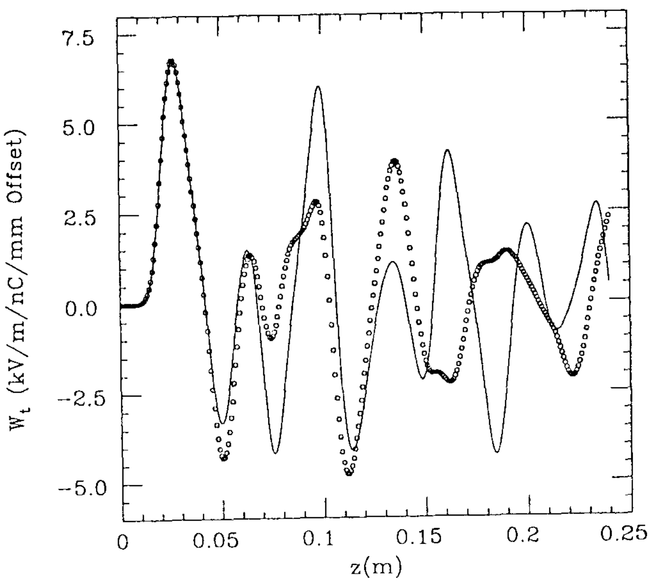

Figure 4: Transverse wakes for the same devices as figure 3. Note the distortion of the wake introduced by the longitudinal cuts.

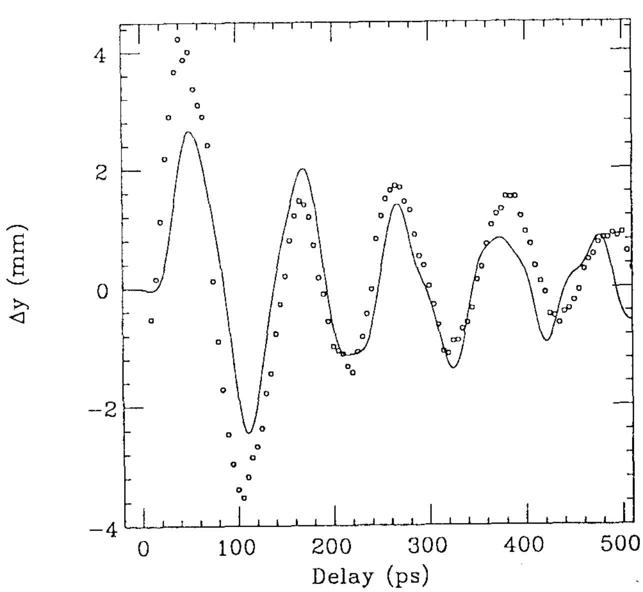

Figure 5: AATF data (o) and ARCHON simulation (solid curve) of the dielectric structure with longitudinal wire boundary described in the text. Witness beam transverse deflection is plotted as a function of relative driver-witness delay.

tures. With some exceptions reasonable agreement with measurements at the Argonne Advanced Accelerator Test Facility and with theory were obtained. The simulations also demonstrated that transverse wakes in dielectric devices may be controlled by interrupting the azimuthal current in the outer wall, without affecting the monopole wake.

Acknowledgements

MAFIA calculations were performed at the National Energy Research Supercomputer Center at The Lawrence Livermore National Laboratory. Connection Machine time for the ARCHON runs was provided by the ANL Mathematics and Computer Science Division's Advanced Computing Research Facility.

References

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Table 1. Comparison of MAFIA, ARCHON, and analytic results for the thin dielectric limit.

W_l (10^{13} eV/m/C) and λ_l (mm) are the amplitude and wavelength of the longitudinal wake; W_t (10^{15} eV/m^2/C) and λ_t (mm) are the amplitude and wavelength of the transverse wake.

	MAFIA	ARCHON	analytic
(1.6 mm dielectric)			
W_l	4.87	5.61	5.20
λ_l	16.2	17.5	15.4
W_t	2.27	1.56	1.40
λ_t	17.2	16.8	15.4
(2.4 mm dielectric)			
W_l	7.73	7.79	8.66
λ_l	20.4	20.5	18.3
W_t	4.46	2.30	3.12
λ_t	21.7	21.8	18.2