ADVANCED MODELING OF RF CAVITIES AND COMPONENTS FOR e+e- COLLIDERS *

Z. Li, B. McCandless, W. Mi, C.-K. Ng, M. Saparov, V. Srinivas, Y Sun, X. Zhan[1] and K. Ko
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
[1] Avant! Corporation

Abstract

The increasingly demanding design requirements of the next-generation particle accelerators have placed heavy emphasis on the accuracy and reliability of RF computer programs in order that accelerator components can be modeled and analyzed with greater confidence. Presently popular codes are inefficient in handling complex geometrical shapes, or are limited in their ability to solve large scale problems. The Numerical Modeling Group at SLAC has an ongoing effort to develop advanced numerical tools that specifically address these issues through the use of unstructured grids and multi-processing capability. This tool set consists of both time-domain (Tau) and frequency-domain (Omega) modules that calculate the standard circuit parameters of RF cavities and traveling wave structures. We will present some of the unique features (e.g. geometry from solid model, adaptive refinement, parallel processing) being included in these programs, and will show results from their use in cavity and component design for e+e- colliders such as the NLC (Next Linear Collider).

1 INTRODUCTION

Future accelerators such as the Next Linear Collider (NLC)[1] as proposed by SLAC, will need to address seriously the issues of cost, performance and reliability in their design. These considerations put increasingly demanding requirements on both the physics and engineering aspects of the machines. The role of numerical modeling in accelerator R&D is widely recognized, and its importance will only increase as the machine designer is faced with greater complexities as he strives to meet tougher design requirements. For example, considerable efforts have gone into simulating the RF cavity for SLAC's B Factory (PEP-II)[2] which has a complicated geometry containing three damping waveguides to suppress HOM's. We will later show how modeling plays a vital role in designing the damped, detuned accelerator structure (DDS)[1] for the NLC.

The advent of more powerful computers at ever lowering costs has driven the development of sophisticated simulation software in many engineering disciplines. There is a definite trend towards virtual prototyping, automatic optimization, and system-scale studies. These advanced capabilities would enable, for instance, the accelerator designer to achieve cost reduction, higher performance, and improved reliability. This paper reports the progress of development work at SLAC towards incorporating such high-level functionalities in a RF simulation tool. The goal is to model the next-generation accelerators with realism and to unprecedented accuracy.

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2 ADVANCED RF MODELING

There are several significant features necessary for a numerical tool to have in order to support the advanced modeling we described above. First on the list is realistic geometry representation. Next is the ability to generate a parametric model to automate dimension changes. Then the tool should provide efficient algorithms to obtain optimal solutions. Finally, the solvers can utilize massively parallel computers for large-scale simulations.

While many popular electromagnetic codes such as SUPERFISH[3], MAFIA[4], HFSS[5] and others have been used extensively in the accelerator community, none of them presently has ALL the features envisioned for an advanced tool. Nonetheless the accelerator designers will continue to benefit from their use for years to come because these are established, time-tested and well-supported software. The effort at SLAC, on the other hand, is a research project targeting at developing the next generation of electromagnetic codes for accelerator use. It originated from the NLC R&D in response to the need for better modeling tools in the accelerator cell design development. Presently it receives additional support from the DOE Grand Challenge Applications[6] program in which SLAC's Numerical Modeling Group (NMG) is a major participant in a collaboration that involves also LANL, Stanford, UCLA, LBNL. The group is responsible for the electromagnetics component of this “Advanced Computational Accelerator Physics” project while LANL leads the other component in beam dynamics.

3 CODE DEVELOPMENT AT SLAC

The NMG is developing a set of electromagnetic codes to satisfy the requirements for advanced modeling with the following approach: (1) employ formulations of Maxwell's Eqs. based on unstructured grids for better geometry fidelity, (2) develop optimization procedures to take advantage of parametric models, (3) derive adaptive refinement techniques to improve solution accuracy, and (4) implement parallel processing to enable large scale simulations as needed in system-level design and analysis. Taken separately, these technologies are not new but combining them to work in concert is a challenging task. To apply adaptive refinement on parallel computers involving unstructured grids is a topic of continuing research. The procedure entails the iteration between a mesh manipulation step and a solution step that provides the feedback as to where the mesh quality needs to improved. Doing so efficiently on parallel architectures requires a domain decomposition strategy that preserves load balancing from one refinement to the next. We will show the results from a 2D application for which this is accomplished with reasonable success.

The tool set under development includes modules both in the time and frequency domains as well as 2D and 3D versions. The time-domain modules (Tau2, Tau3) adopt the modified Yee[7] algorithm for non-orthogonal grids. They are useful for matching RF components and in dealing with transient effects such as wakefields and bunch heating. The frequency-domain modules (Omega2, Omega3) use the quadratic, mixed finite element formulation. These compute normal modes, and are needed for designing and analyzing accelerating cavities. They can also be generalized to scattering matrix solvers when boundary ports are included. Of all these modules, Omega2 is furthest along while Omega3 and Tau3 are presently being worked on at a vigorous level.

4 APPLICATIONS TO THE NLC

This section presents a brief summary of applications that have been carried out with the tool set for the NLC. Details on the code development and simulation results will be reported elsewhere. First we will describe the activities involving the Omega modules.

Figs. 1 is a synopsis of the accelerator structure modeling on a component versus system comparison that covers the 2D detuned structure (DS) as shown in Figs 1a & 1b and the 3D damped, detuned structure (DDS) as depicted in Figs. 1c & 1d. For the DS, Omega2 was used to optimize the cell shape to obtain 20% higher shunt impedance over the standard cell (Fig. 2). The transverse wakefield due to a entire 206 cell DS section was found for the first time with the parallel version of Omega (Omega2P). Fig. 3 displays two levels of meshing for the 206 cell section as a result of adaptive mesh refinement. The wakefield result reveals the effect of higher dipole bands which cannot otherwise be calculated with equivalent circuit methods.

The complex 3D geometry of the DDS cell as represented by a solid modeler and discretized on a finite element mesh is shown in Fig. 4. The accelerating mode frequency of the cell computed by Omega3 is within a few MHz of measured data, a difference dictated by mesh size. This implies that with finer mesh resolution, accuracies to within fabrication tolerances can be obtained and suggests the feasibility of virtual prototyping. The wakefield analysis for the 206 cell DDS section awaits the parallel version of Omega3 (Omega3P) which is due to be completed within the year.

Many of the modeling activities with Tau3 are still in progress so we will discuss some preliminary calculations

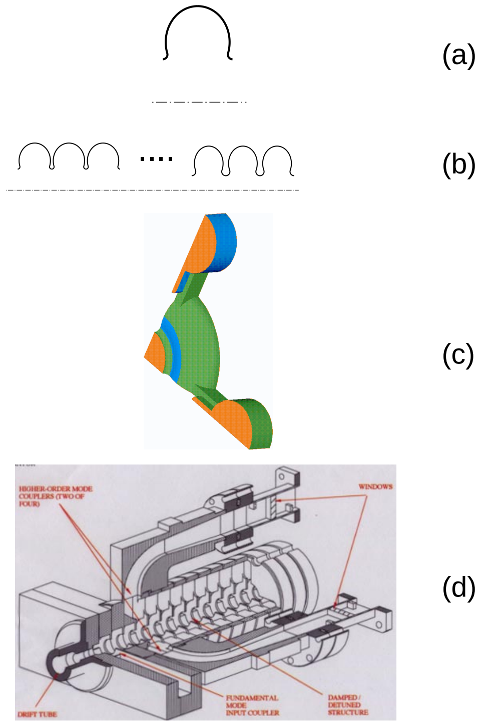

Figure 1: (a) Optimized, detuned cell design (Omega2), (b) Detuned structure of 206 cells wakefield analysis (Omega2P), (c) Damped, detuned cell design (Omega3), (d) Damped, detuned structure (Omega3P)

on two typical accelerator components (Fig. 5). First is a bifurcated waveguide feed to a dual input coupler. The Tau3 results agree with HFSS which also simulates on an unstructured grid.

Such a curved geometry would not be approximated well by orthogonal meshes. Next is the power input coupler and work is continuing on comparing the Tau3 result with previous calculations from MAFIA and with measurement. The module can handle pulse propagation which allows for broadband analysis of traveling wave structures.

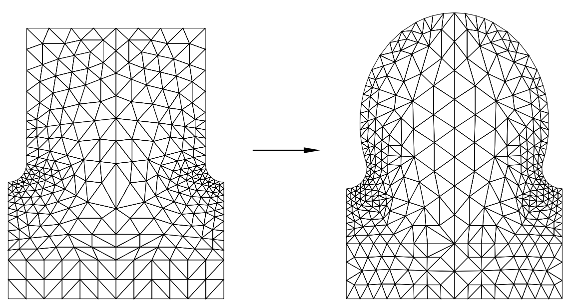

Figure 2: Cell optimization using Omega2.

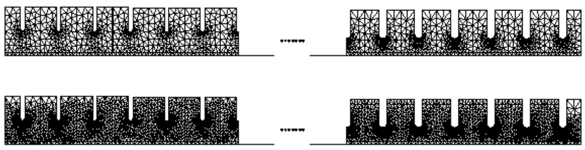

Figure 3: Adaptive mesh refinement of 206 cell section on parallel computer using Omega2P.

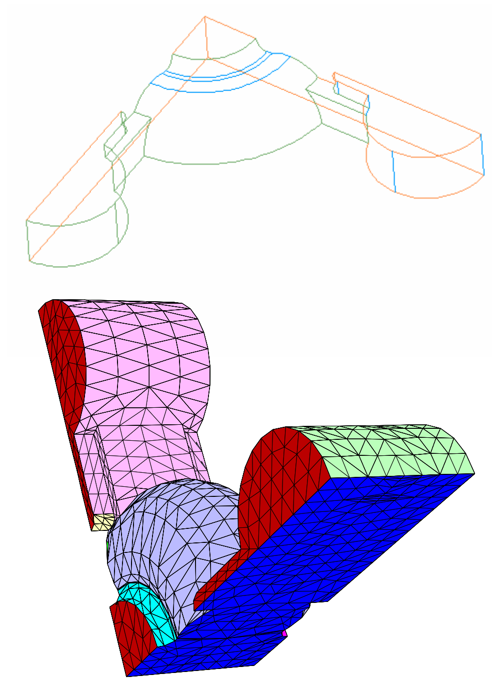

Figure 4: DDS cell: solid model (top) , finite element mesh (bottom) as computed with Omega3.

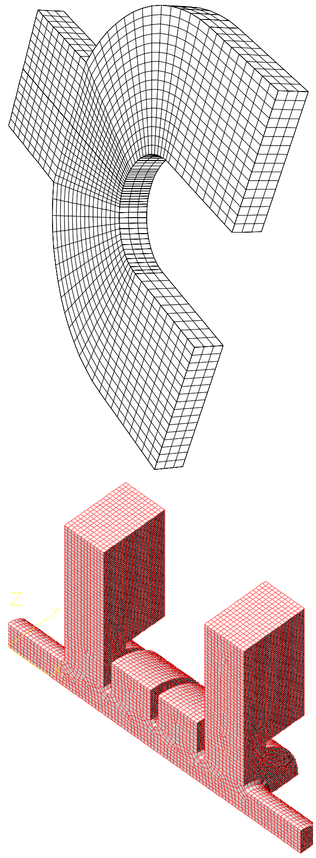

Figure 5: Tau3 modeling of bifurcated waveguide feed and power input coupler to accelerator structure.

5 FUTURE PLANS

Much progress has been made in the development of an advanced electromagnetic tool set that will not only be a vast improvement over existing capabilities, but will also expand the scope of accelerator applications dramatically. This new resource will significantly impact future accelerator designs such as the NLC and others, on the important issues of cost, performance, and reliability. Already encouraging results have been obtained from the use of some modules that led to considerable benefits for the NLC accelerator structure design. In addition to the Tau and Omega modules, a statics module and the inclusion of particles are being planned.

6 REFERENCES

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