MAFIA RELEASE 3: THE NEW VERSION OF THE GENERAL PURPOSE ELECTROMAGNETIC DESIGN CODE FAMILY

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Abstract

The MAFIA group of fully three dimensional computer codes for the solution of Maxwell's equations is already well established. The system has demonstrated its accuracy and usefulness in the successful design of many accelerator components. The 3D capabilities have now been extended beyond the original frequency and time domain solutions to include a new static solver for electro-and magnetostatic fields, a particle-in-cell code and an eddy current module for the treatment of laminated and/or solid iron cores excited by low frequency currents. In addition the two dimensional codes URMEL and TBCI together with the self consistent version, TBCI-SF, that solves the field equations and the equations of motion in parallel, have been implemented in the new program family. This creates a wide-ranging CAD package which will enable many aspects of a problem to be investigated within a unified computing environment.

Introduction

The MAFIA family of codes which solve **MA**xwell's equations by the **F**inite **I**ntegration **A**lgorithm is widely used in the computer-aided design of accelerator components. Rf cavities and vacuum junctions, collimators and magnets (to name but a few) have been successfully designed using these programs. The programs use Maxwell's equations in their integral form and produce a set of matrix grid equations which are then solved. A full description of the derivation of these equations can be found in the literature [1].

The allocation of the three dimensional field components is on a rectangular grid, using the Yee lattice [2]. The analytical properties of the matrix operators are preserved on the discrete grid [3]. Hence this method has the advantage that, after the eigenvalues of the problem are calculated, the numerical results can be tested for their physical correctness and any spurious solutions removed automatically.

The Programs

The 2D Programs

It is very useful to have 2D versions of the 3D programs available for cylindrically symmetric structures and for exploratory tests before a large 3d model with many mesh points is calculated. The MAFIA package includes 2D versions of the 3D programs using the same user interface, mesh generator and post processor.

The Mesh Generator, M

The Mesh is defined in cartesian coordinates and allows a non-equidistant grid. r-z, r-ϕ and r-ϕ-z coordinates will be available in release 3.1 for use with 2D versions of the programs. Each rectangular cell may be divided in half along a diagonal to give a better approximation to the input geometry. Within this mesh of rectangular cells material fillings may be defined in various ways. Rectangular bricks may be filled with material. Cylinders with arbitrary cross-section with axis parallel to one of the co-ordinate directions and figures of revolution obtained by rotating an arbitrary plane shape through a given angle may be generated. A large choice of pre-defined shapes is available. Filaments, representing line currents or wire electrodes, can also be used.

At all stages *Diagnostics and Interactive Graphics Display* is provided to facilitate the visualisation of the geometry and to allow the user to check the input. Each input shape can be displayed superimposed on the approximated mesh model. Then mesh lines can be interactively added or deleted and the effect of the regenerated mesh on the mesh model is immediately displayed. Two dimensional cuts along any mesh plane can also be plotted. Finally the mesh model can be viewed in three dimensions with or without hidden lines and can be arbitrarily rotated.

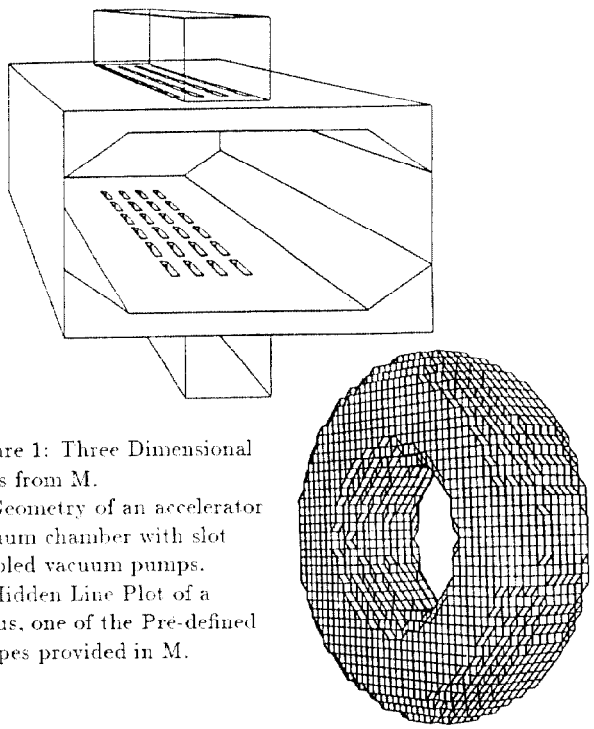
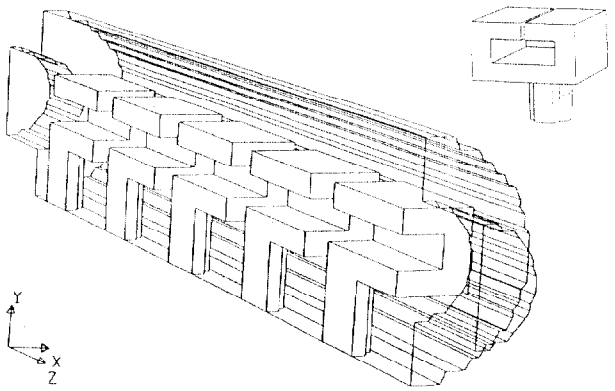


Figure 1: Three Dimensional plots from M.
a) Geometry of an accelerator vacuum chamber with slot coupled vacuum pumps.
b) Hidden Line Plot of a Torus, one of the Pre-defined Shapes provided in M.

The Static Solver, S

The Static code, S, solves Maxwell's Equations for electro- and magneto-static problems [4]. The electrostatic potential Φ, the field **E**, the flux **D** and the electrostatic charge distribution **q** can be calculated, or alternatively the magnetostatic field **H** and

the flux **B**. An "open" boundary condition is included which uses an iterative method to analytically approximate the potential on the boundary, thus enabling a much smaller mesh to be used for the same problem. Ideally conducting or ideally permeable materials may be defined in all the 3D codes. In addition S allows materials with finite, non-zero and anisotropic ϵ and μ or with ϵ and μ dependent on the field strength and the non constant distribution may also be calculated. Filaments may carry linear currents or be defined as lines of constant potential. The solver uses an SOR over-relaxation method where the accuracy of the solution is an optional input parameter. A multigrid solver is also available for large problems.



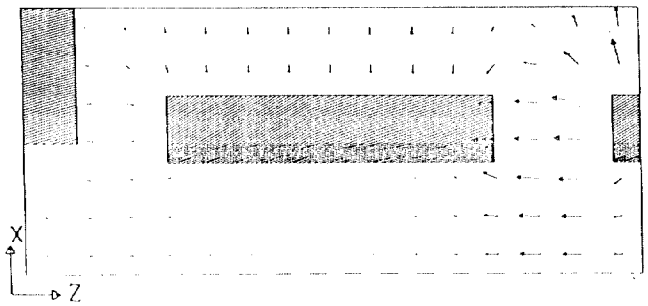


Figure 2: Modelled geometry and arrow plot for the GSI kicker magnets. The arrow plot shows the **E**-field in a horizontal cut in the neighbourhood of the first magnet calculated by S.

The Frequency Domain Solver, R/E

The MAFIA codes R and E run in sequence, solve Maxwell's equations in the frequency domain. The material properties and the boundary conditions are defined in R where the matrices are set up. Periodic boundary conditions have been added in release 3.0. Then E calculates the fields **E** and **B** and the eigenfrequencies. As diagnostics, the accuracy of the frequencies is given and the quantities $div\mathbf{D}$, $div\mathbf{B}$ and $|curl\mathbf{E} - k^2\mathbf{E}|$. The Solver uses the SAP [8] eigenvalue solver or a multigrid solver for very large problems. Several hundred modes can be calculated. *The 2D Version* of R/E (formerly called URMEL) can be used to obtain the frequencies of rotationally symmetric modes with azimuthal field variation and arbitrary angular mode numbers, (monopole, dipole etc.). The cutoff frequencies of waves in longitudinal waveguides can also be calculated using x-y geometry.

Figure 3 shows results from a bridged loop-gap resonator [5] (BLGR), a resonant structure for pulsed electron spin resonance (ESR) spectroscopy which was investigated using R/E. All dielectric structures were included and the resonant frequencies, the Q values and the 3D field distributions were calculated.

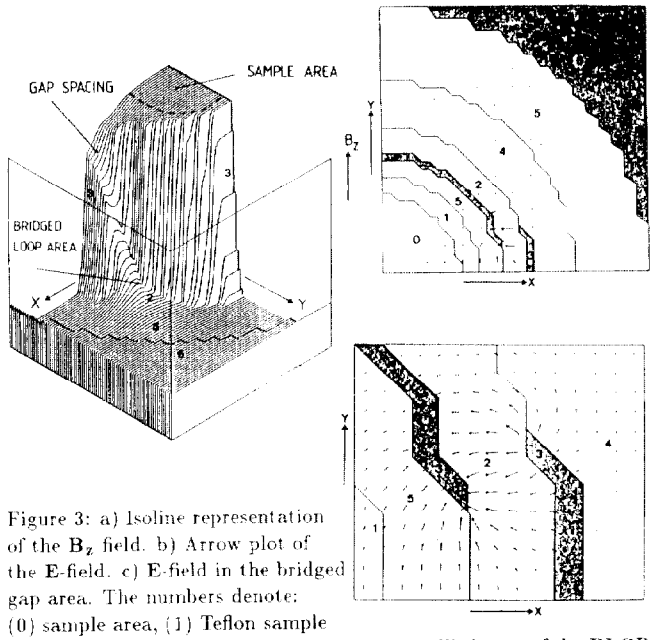


Figure 3: a) Isoline representation of the B_z field. b) Arrow plot of the **E**-field. c) **E**-field in the bridged gap area. The numbers denote: (0) sample area, (1) Teflon sample holder, (2) Resonator quartz support, (3) metallic layers of the BLGR (4) Rexolite resonator holder, (5) air spacings, (6) metallic shield.

The Time Domain Solver, T3

T3 calculates the fields created by a moving, rigid bunch of particles [6] providing the **E** and **B** fields at user-specified time steps, the fields as a function of time at user specified positions and the longitudinal and transverse wake potentials. "Open" boundary conditions are available to simulate an infinite beam pipe or open space. The transverse bunch position, the charge distribution within the bunch, the particle speed and the number of time steps to be performed are all input parameters. A window option is also available for ultra-relativistic particles. *The 2D Version*. T2 (the former TBCI) calculates the diffraction of TM waves in addition to transient fields and transverse and longitudinal wake potentials.

The Hera Vacuum chamber with slot coupled vacuum pumps, Figure (1a), was investigated using T3. The transverse impedance for a slightly off center electron bunch was found to be greater than the design value for all the components of the entire HERA ring. By T3 calculations it was determined that the simple expedient of recessing the slots, as shown in the figure, would reduce the impedance to 10% of the design value. The vacuum chamber was built in that form.

The Self Consistent Time Domain Solver, TS3

TS3 is a particle-in-cell code, which enables the simulation of rf-klystrons, electron sources etc. etc. Maxwell's equations and the equations of motion for the particles are solved self consistently, so that particle trajectories can be calculated taking space charge into account. The charge distribution within the bunch is also calculated. The initial conditions for the velocity, position and charge density of the particles are defined by the user. Static or resonant fields can be preset on the mesh.

In the *2 $\frac{1}{2}$D Version*, TS2 [7] both the initial field and the particle distributions have angular symmetry.

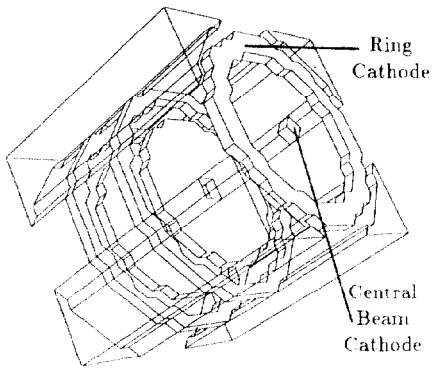


Figure 4: Two cell Wakefield Transformer, beam direction along the z axis,calculated by TS3. The central beam is accelerated by the wakefields which are produced by the ring beam which surrounds it.

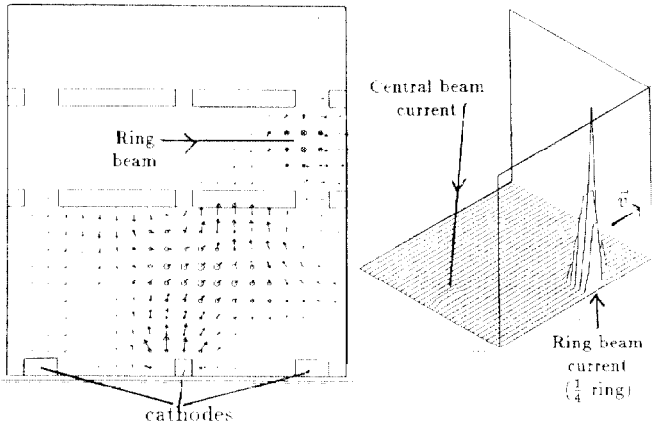


Figure 5: Arrow plot of the E-field and isoline plot of the current in a cut along the beam axis, a quarter of the ring beam current was generated.

The Postprocessor, P

In the postprocessor, secondary results may be calculated from the fields, fluxes etc. which have been calculated. Field energy, power loss, shunt impedance and integrals over lines, areas and volumes can be obtained. The results can also be represented graphically. Arrow plots are used to represent a 3D vector field in a mesh plane, isoline and contour plots show a scalar field or a vector component in a mesh plane and line plots show the variation of the same along a line. All plots and calculations can be restricted to windows.

MAFIA Release 3 - The Environement

Many new features are included in release 3. The powerful *Command Processor* includes a *Macro Facility* and *Symbolic Variables* and enables the construction of *Do Loops* over a range of commands. The *Command Error Checking* facility issues diagnostic messages. *Flexible File Handling* is a feature. Sequential files are used for print output, non-interactive command input and for recording the commands of an interactive session. *Profiles* can be created for particular modules, for individual users or for groups. There is a *Built-in Editor* for all these files. The main MAFIA *Data Base* is a direct access file where all the results are stored. *Graphics output* can be directed to a metafile, a terminal or a plotter. *Mouse Input* is also provided for. The *Menu-controlled User Interface* includes an *On-line Help Facility*. The codes are *Completely Hardware Independent.*

Memory Requirements

The required memory for 32 bit accuracy using 100,000 nodes varies between 3 Mbyte for the mesh generator M and 14 Mbyte for both the eigenvalue solver E and the particle in cell code TS3 (for 100.000 particles). The other codes use 8 Mbytes or less. T3 includes a window option which enables 1,000,000 nodes with 100,000 nodes in the window for 11 Mbyte.

Hardware and Software Requirements

MAFIA Release 3.0 consists of separate source modules for each program and a utility library of routines common to all the programs. These are written in standard fortran77 and will run on any computer with an error-free ANSI-FORTRAN77 compiler. A built in facility will switch operation from single to double precision, avoiding the compatability problems of the standard. All installation dependant operations are called via a system interface and a graphics interface. These latter ensure that the programs are fully portable and installation independent.
Thus MAFIA will run on any machine, e.g. IBM, DEC, SUN, APOLLO, HP, STELLAR, CRAY, NEC, AMDAHL, FUJITSU, HITACHI and many more. Similarly any graphics system may be used, e.g. GKS, PHIGS, PLOT10, DISSPLA, GMR, GPR.

Conclusion

This new release of the MAFIA codes presents a definite step forward in the computer aided design of accelerators. The physical correctness and dependability of the Release 2 MAFIA is combined with the new modules S and TS3 and compatible 2D versions under one unified user interface. Release 3.0 is now ready for distribution, including the programs M, R, E, S, P. The 2D versions of R/E and S and the modules TS3, TS2, T3, T2 will be available towards the end of the year with release 3.1. Release 3.2 will include the eddy current module, W3 and an automesh facility for M.

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