Using the CAVE Virtual-Reality Environment as an Aid to 3-D Electromagnetic Field Computation*

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Abstract - One of the major problems in three-dimensional (3-D) field computation is visualizing the resulting 3-D field distributions. A virtual-reality environment, such as the CAVE, (CAVE Automatic Virtual Environment) is helping to overcome this problem, thus making the results of computation more usable for designers and users of magnets and other electromagnetic devices. As a demonstration of the capabilities of the CAVE, the Elliptical Multipole Wiggler (EMW), an insertion device being designed for the Advanced Photon Source (APS) now being commissioned at Argonne National Laboratory (ANL), was made visible, along with its fields and beam orbits. Other use of the CAVE in preprocessing and postprocessing computation for electromagnetic applications is underway.

I. Introduction

Electromagnetic field analysis and design is more difficult in 3-D than in two dimensions not only because the mathematics is more complex (multiple-valued scalar potentials, gauge conditions on vector potentials) and because the amount of data is greater (more mesh points, three components per mesh point rather than one), but also because visualizing the computational mesh and the results of computations present equally great difficulties.

The CAVE virtual-reality system [1] provides stereoscopic images from any viewpoint of choice, and so can make visualization easier. To this end a demonstration of the CAVE using a rather complex magnet system was undertaken.

For the demonstration one half-period of the APS EMW [2] was chosen. It has a superposition of horizontal fields from electromagnets and vertical fields from hybrid magnets. (In a hybrid magnet, magnet material provides the field, and steel shapes the field.) The CAVE demonstration depicts the magnetic geometry, the field pattern from the combined magnets, and the trajectory of a positron beam traversing the EMW. This paper describes the demonstration and suggests other uses for the CAVE in the process of electromagnetic field computation.

II. The CAVE

The CAVE is a surround-screen projection-based virtual reality system being developed at the Electronic Visualization Laboratory (EVL) at the University of Illinois at Chicago. Computer-generated images are rear-projected onto two walls and the floor of a 3 m x 3 m x 3 m cube. Alternating images are displayed for the left and right eyes in synchronization with stereo shutter glasses, as seen in Fig. 1. The viewer-centered perspective is calculated constantly from tracker data.

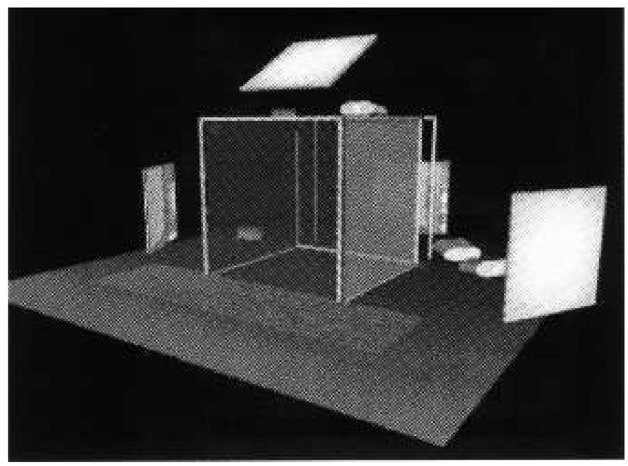

Fig. 1. The CAVE virtual reality environment. Mirrors reflect stereoscopic computer images from the projectors onto two walls and the floor of the cave.

TABLE I Parameters for the APS EMW

Parameter	Value
Minimum Hybrid Magnet Pole Gap	24 mm
Peak Vertical Field with 24-mm gap	0.9 T
Number of Vertical Pole Pairs	33
Horizontal (Electromagnet) Pole Gap	71 mm
Peak Horizontal Field	0.1 T
Number of Horizontal Pole Pairs	36
Maximum Current	1000 A
Number of Turns per Pole	4
Period Length	160 mm
Total Length of Magnet Structure	2.88 m

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III. The Elliptical Multipole Wiggler

The Advanced Photon Source is a synchrotron radiation source now being commissioned at ANL and funded by the U. S. Department of Energy. In the APS, a beam of high-energy (7 GeV) positrons create x-rays by passing through arrays of magnets called insertion devices ("wigglers" and "undulators"). In a wiggler or undulator, the magnetic field periodically alternates in direction, and the transverse acceleration of the positrons by this alternating field produces the s-rays. One of these insertion devices for the APS is the EMW, which produces circularly polarized x-rays. The use of circularly polarized radiation is advantageous for the study of magnetic materials using x-ray scattering techniques. The EMW consists of a hybrid-magnet wiggler providing a vertical field and an electromagnet wiggler providing a horizontal field, with the poles of the two magnets located 90^o apart. (In a hybrid magnet, permanent-magnet material generates the field, and steel poles shape it.) The parameters of the EMW are shown in Table I, and Fig. 2 shows one half-period of the geometry.

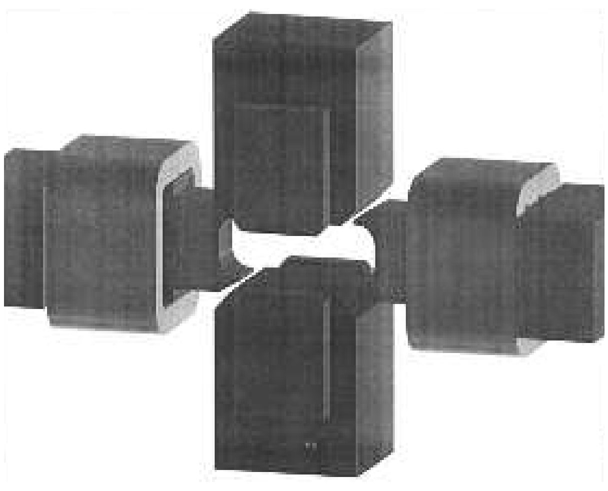

Fig. 2. One half-period of the elliptical multipole wiggler. One pair of poles and coils of the electromagnet are shown on the left and right. One pair of permanent magnets are on the top and bottom. One pair of half-poles for the hybrid magnets is at the front, and another pair is at the back. Note that the poles of the hybrid magnet and electromagnet are a quarter-period apart.

IV. The Demonstration

Field Computations

The field computations were carried out using the 3-D magnetostatics program TOSCA [3], and the geometry was reconstructed from an OPERA [3] data set with the code CORAL [4]. Regular tables of computed field values were then input into other software that was customized at the Electronic Visualization Laboratory.

Field Display

A number of half-periods from zero through six can be shown. (Four half-periods are shown in Fig. 3 and 4.) Magnitude and direction of the magnetic field are indicated by the length, color, and orientation of cylindrical rods located on a 3-D grid of points in the bore of the wiggler magnets. The viewer may also choose to use cones rather than rods to represent the field, and may vary the spacing of display points within the bore of the EMW. The current in the electromagnet may also be changed.

Beam Trajectory

The elliptical trajectory of a positron traversing the wiggler is computed from the field values, and is shown in Fig. 3, along with the field display. Displacements normal to the beam direction are multiplied by a large scale factor to make the micron-scale motion visible. In the demonstration, a tracer sphere dynamically follows the trajectory. At the extreme horizontal excursions, the points of maximum acceleration, the simulation displays a flash to indicate that an x-ray is emitted.

With no current in the electromagnet, the beam oscillates in a horizontal plane. As the current increases in the electromagnet, the beam follows a helical path, and circularly polarized x-rays are emitted. Although the field levels of 0.9 T for the hybrid magnet and 0.1 T for the electromagnet produce a very non-circular helical trajectory, as seen in Fig. 3, the demonstration permits a field of electromagnet of up to 1.0 T, to better demonstrate the nature of the trajectory.

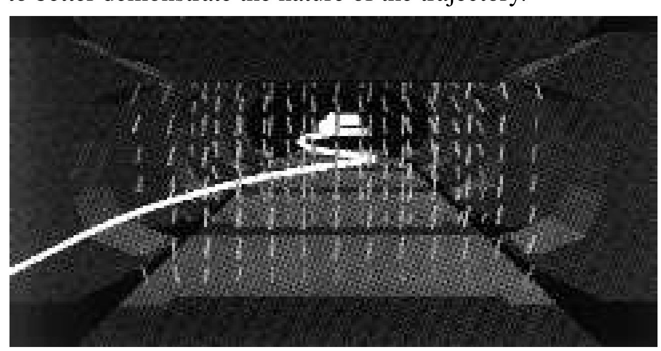

Fig. 3. Trajectory of the positron beam through four half-periods of the EMW, as visualized with the CAVE. The short rods show the combined field of the hybrid magnet and electromagnet.

Options and User Interface

Among the options available to the viewer are the number of half-periods (from 0 to 6), the representation of field (rods, cones, or none), a displacement or rotation of the whole magnet geometry, a scale factor for the current in the electromagnet (range 0 to 10) and the display of the trajectory. The viewer makes these selections from a menu on the left wall, as shown in Fig. 4, by using the 3-D wand. The wand is a hand-held device with three buttons and a joystick. The user points the wand at the desired menu item and clicks the left button to toggle the corresponding mode on or off. When a menu item is selected, the wand can execute actions corresponding to that mode. Multiple users can share the virtual environment by entering the CAVE and wearing shutter glasses, although they all share the viewpoint of the user who is being tracked.

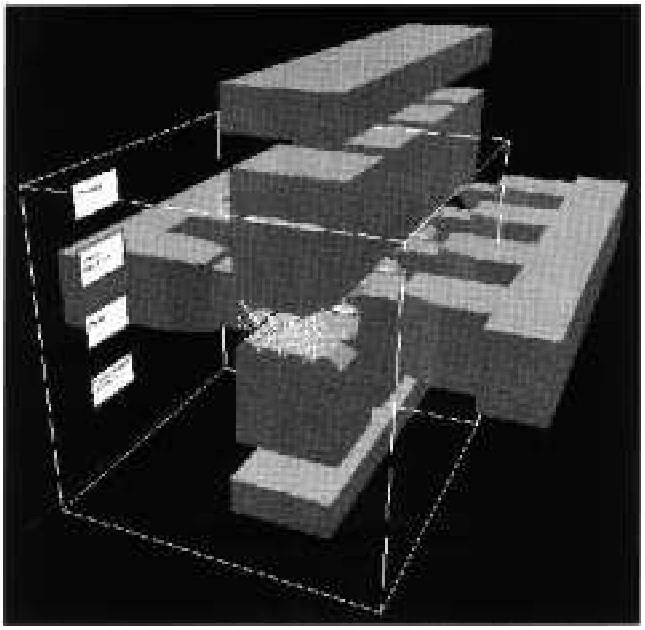

Fig. 4. CAVE display of four half-periods of the EMW. The menu on the left wall provides user interaction with the demonstration.

V. Further Use of the CAVE for Mesh Generation and Field Visualization

In the process of developing the EMW demonstration for the CAVE, several other uses for the CAVE were recognized.

Preprocessing

The ability to observe the mesh stereoscopically and from any chosen viewpoint would enable the user to examine the grading and possible pathology of a 3-D mesh, especially if a particular region could be highlighted to make it stand out from the regions in front of or behind it. Likewise, looking at a pathological mesh element stereoscopically would allow it to be corrected immediately; at present, with2-D graphics, it sometimes can take hours.

Postprocessing

Some extensions of the post-processing would require very little extrapolation beyond what was done for this demonstration. For example, the field could be represented by flux lines or flux tubes. Cutting planes could be introduced at any position and with any orientation to show how the field varies, using color contour plots, arrows or other means. These planes could be superimposed over a wire-grid model of the geometry, avoiding the confusion that often arises with color contour plots and 2-D projections. If the region of interest is homogeneous (e.g. air), a this can be done by interpolating over a 3-D grid of field values. For inhomogeneous regions (e.g. part air, part iron), the basis functions of the finite elements could be used. The cutting could be moved around interactively to find the region of saturated iron, for example.

In all the above example, the effect of changing magnet current could be approximated by storing two sets of tables for two different currents, and interpolating between them interactively.

The beam-tracing of the demonstration could be extended to permit initial position and direction of the beam to be varied interactively. This could be particularly instructive for the case of a particle beam traversing two or more magnets.

Interactive and Dynamic Solution

In dynamic solution, some parameter such as the magnet end geometry or the spacing between neighboring magnets is varied interactively, and the solution of the problem is repeated. In the future the CAVE can be used with real-time supercomputer simulation to study issues such as magnetic and mechanical interference between neighboring accelerator magnets or tracing trajectories through a series of accelerator magnets.

Acknowledgment

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