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INTERACTIVE CALCULATIONS OF ELECTRIC FIELDS*

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ABSTRACT

In many experimental design situations it is valuable to know what the time-dependent electric and magnetic fields are likely to be so that such things as electric breakdown and ohmic heating as a result of magnetic field penetration can be estimated. Because of the advent of extensions in the speed and memory of large electronic computers it has become easier to extend the scope of these calculations. Even so, it is necessary to use advanced sparse matrix techniques and to take as much advantage as possible of vectorization of code loops. In developing these codes extensive use has been made of the 2-D counterparts to test various aspects of the algorithms and of the code architecture. In addition, attempts have been made to make the user interface to these codes as simple and easy as possible. This paper addresses the problem of implementing this system for the 2-D calculation of electric fields.

I. INTRODUCTION AND GOALS

In the past few years, much of the engineering drafting has been moved from the drafting table to the computer. Digital CAD/CAM systems running on Digital Equipment VAX's and workstations are rapidly becoming the standard technique for engineering design. With the size and speed of our present computing machines, it would seem that an easy connection between the drafting CAD programs and the "physics" calculational programs is necessary and appropriate. A major complication to this objective is that all of the CAD programs run on small machines while the physics codes all run on supercomputers. Thus, for this kind of a system to be viable, a CAD-like code that runs on the supercomputer had to be constructed.

II. THE CAD PROGRAM

The CAD-like code that has been written is presently about 12,000 lines of FORTRAN and has been constructed to take advantage of both the CRAY architecture

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and the rich vector drawing/manipulation capability of the Tektronix 4100 series graphic workstations. In its present state of completion it contains the following modules:

1. Control module
2. Tektronix 4100 driver module
3. Data base handler module
4. Line/curve construction/modification module
5. Automatic mesh generator module
6. Link modules to "Physics" codes
7. Graphics module to display results

The control module handles initialization, the general bookkeeping of memory management and the interrelationship of the other modules.

The Tektronix driver controls the encryption of the various escape codes necessary to communicate between the CRAYS and the workstation. Associated with this drive is another 10,000 line library containing the specific 4100 series instructions.

The data base handler links between the other CAD code outputs (to serve as input for this code) and sets up its own random access file structure on the CRAY for its own use. This separate data base structure was set up for reasons of efficiency.

The heart of our CAD system lies in the Line/curve construction/modification module. This module does the actual line drawing or modification. Straight lines, arcs, circles, conic sections, sines and cosines can be entered via either a thumbwheel or mouse and then modified, moved, erased, rotated or copied. Color is used extensively to indicate differing parts of the drawing.

The automatic mesh generator allows the user to interactively pick any element or sets of elements of the drawing and link these elements together to form the boundaries of the calculational mesh. Once a complete boundary is formed, an approximate grid spacing is entered. The code then automatically zones up the boundaries. At this point the user can manually modify this zoning if desired. Once the boundaries have been zoned the interior region can be gridded. Several different methods exist for this function two of which include the Amsden Hirt[1] method and the Thomsen Thames and Mastin method. It should be noted that the mesh produced is in general non-rectangular and non-orthogonal. This allows us to generate close fitting boundary fitted coordinate systems that maintain excellent detail of the particular problem being analysed.

Upon completion of a calculational mesh, the link module is activated where various boundary conditions are interactively set. The link module will then set up a link file and proceed to execute the particular physics code selected. At present there is only one link module. This connects with the 2-D, R-Z electrostatic solver code described in the next section.

The final module, the graphics output module, will then read a different link file produced by the physics code and produce desired output such as contour plots, or vector field plots.

It should be noted that the entire code has been written to be a multi- window mouse driven program in which the user never has to enter a standard 80 column computer card image. An example of these CAD capabilities is shown in Fig. 1.

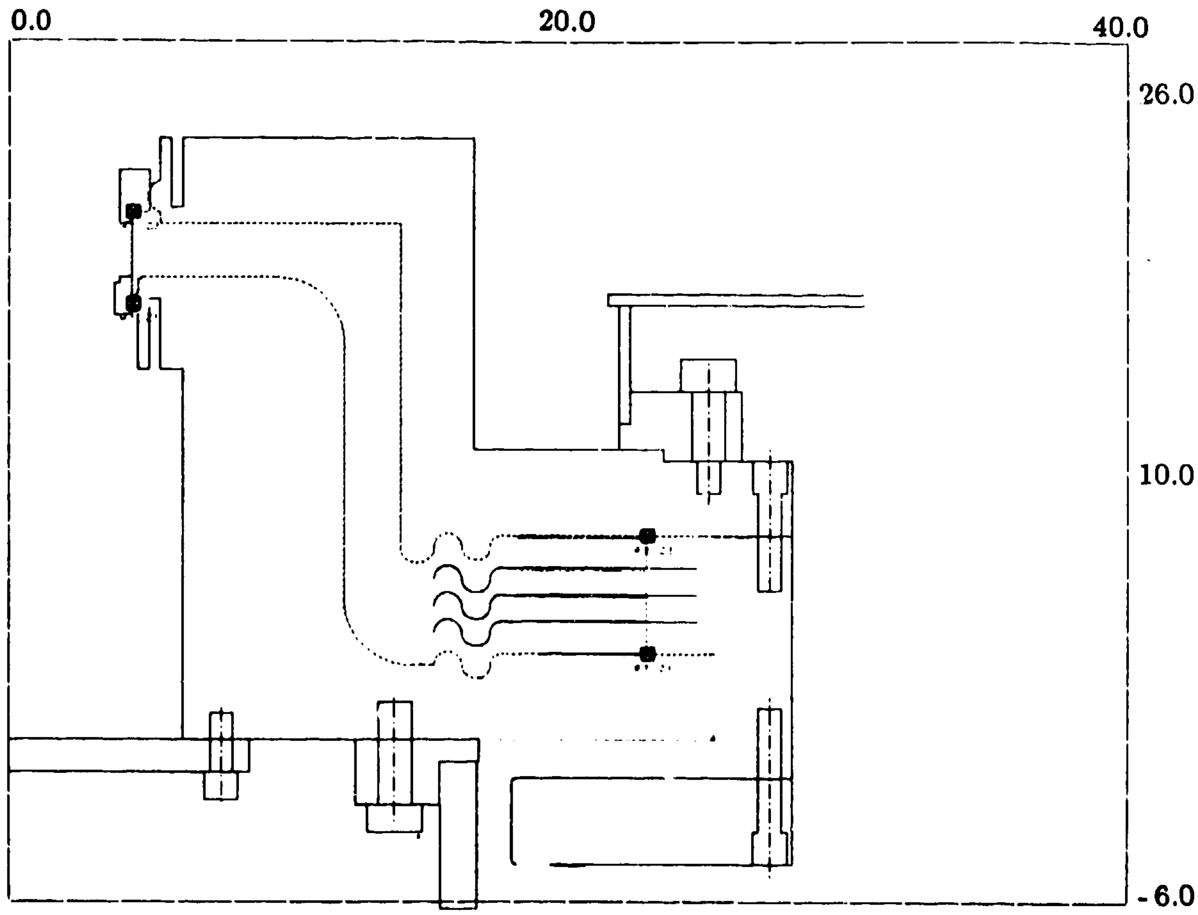

Fig. 1. CAD generated power flow diode.

III. ELECTROSTATIC SOLVER

The electrostatic equation in SI units is

$$\nabla \cdot \vec{E} = \frac{\rho}{\epsilon_0} \tag{1}$$

With the definition of the electrostatic potential

$$\vec{E} = -\nabla V \tag{2}$$

Eq. (1) becomes

$$\nabla^2 V = -\frac{\rho}{\epsilon_0} \tag{3}$$

In Z,R coordinates Eq. (3) can be written as

$$\partial_Z \partial_Z V + \frac{1}{R}(R\partial_R V) = S \tag{4}$$

with the source S given by

$$S = -\frac{\rho}{\epsilon_0} \tag{5}$$

In order to get Eq. (4) into a form suitable for symmetric differencing, the whole equation is multiplied by R and this R in the first term is moved inside the first of the Z derivatives. Thus,

$$\partial_Z(R\partial_Z V) + \partial_R(R\partial_R V) = RS \tag{6}$$

A general grid in Z,R space is shown in Fig. 2. The corresponding logical grid is shown in Fig. 3. Physical space is related to the logical space in the functional relationships,

$$Z = Z(z, x) \quad R = R(z, x) \tag{7}$$

The logical variables are defined in terms of integral indices by

$$z = k - 1 \quad x = i - l \tag{8}$$

with $1 \leq k \leq k_{max}$ and $1 \leq i \leq i_{max}$.

Carrying out the metric algebra one obtains

$$\begin{aligned} DRS = {} & \partial_z(h_{zz} d_z V) + \partial_z(h_{zx} d_x V) \\ & + \partial_x(h_{xz} \partial_z V) + \partial_x(h_{xx} \partial_x V) \end{aligned} \tag{9}$$

where

$$\begin{aligned} h_{zz} &= \frac{R(R_x^2 + Z_x^2)}{D} \\ h_{xz} = h_{zx} &= \frac{-R(R_x R_z + Z_x Z_z)}{D} \\ h_{xx} &= \frac{R(R_z^2 + Z_z^2)}{D} \end{aligned} \tag{10}$$

with

$$D = Z_z R_x - Z_x R_z \tag{11}$$

These equations are then written in simple difference form. Because of the way the logical mesh is defined we have the important simplification that $\Delta z = \Delta x = 1$. These equations are then solved by either and ADI or Multi-grid, Achi-Brandt technique.[3]

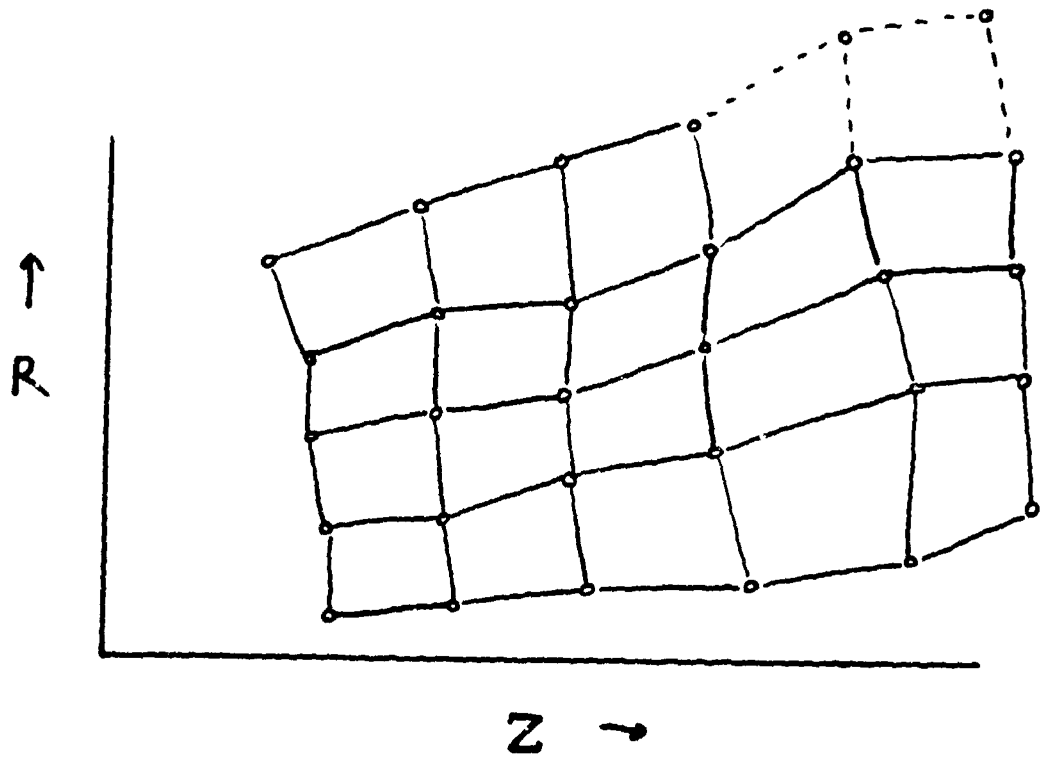

Fig. 2. Physical mesh.

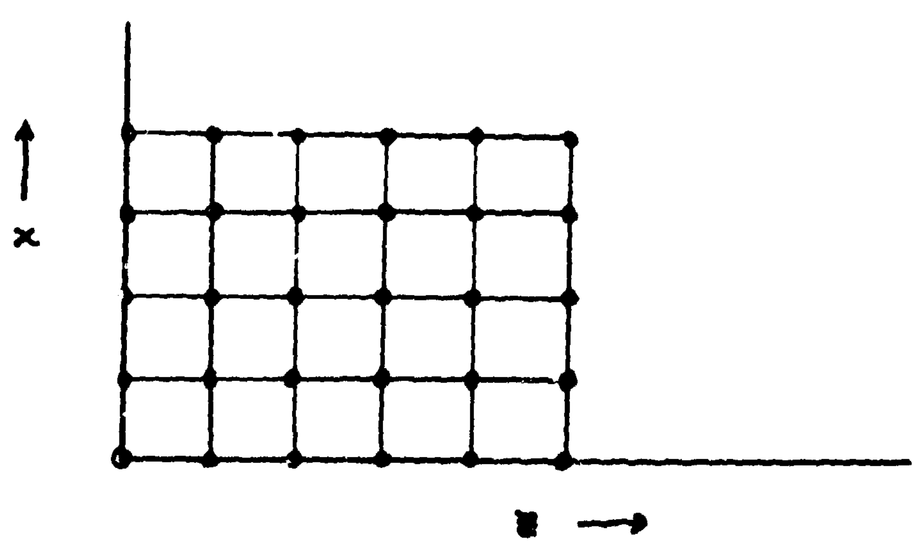

Fig. 3 Logical mesh.

IV. RESULTS AND CONCLUSIONS

The system presently has set-up, calculated, and displayed the results for arbitrary 2-D meshes. An example of this is shown in Fig. 4. The boundary conditions for this figure and a constant voltage of 100 volts on the top and bottom boundary (R) and a zero potential on the sides (Z). Equipotential contours are plotted at increments of 5 volts. The calculational mesh for this example was neither rectangular nor orthogonal, in some spots there were even a few bow-tie zones. The solution set for this figure was arrived at via the ADI method. In general, we have developed the first step in a fast convenient and flexable system for setting up and running codes of the electrostatic potential type. The next step is to link into the time-dependent magnetic field solver (which already exists) and then to go to a fully 3-D system (for which some "physics" codes also presently exist).

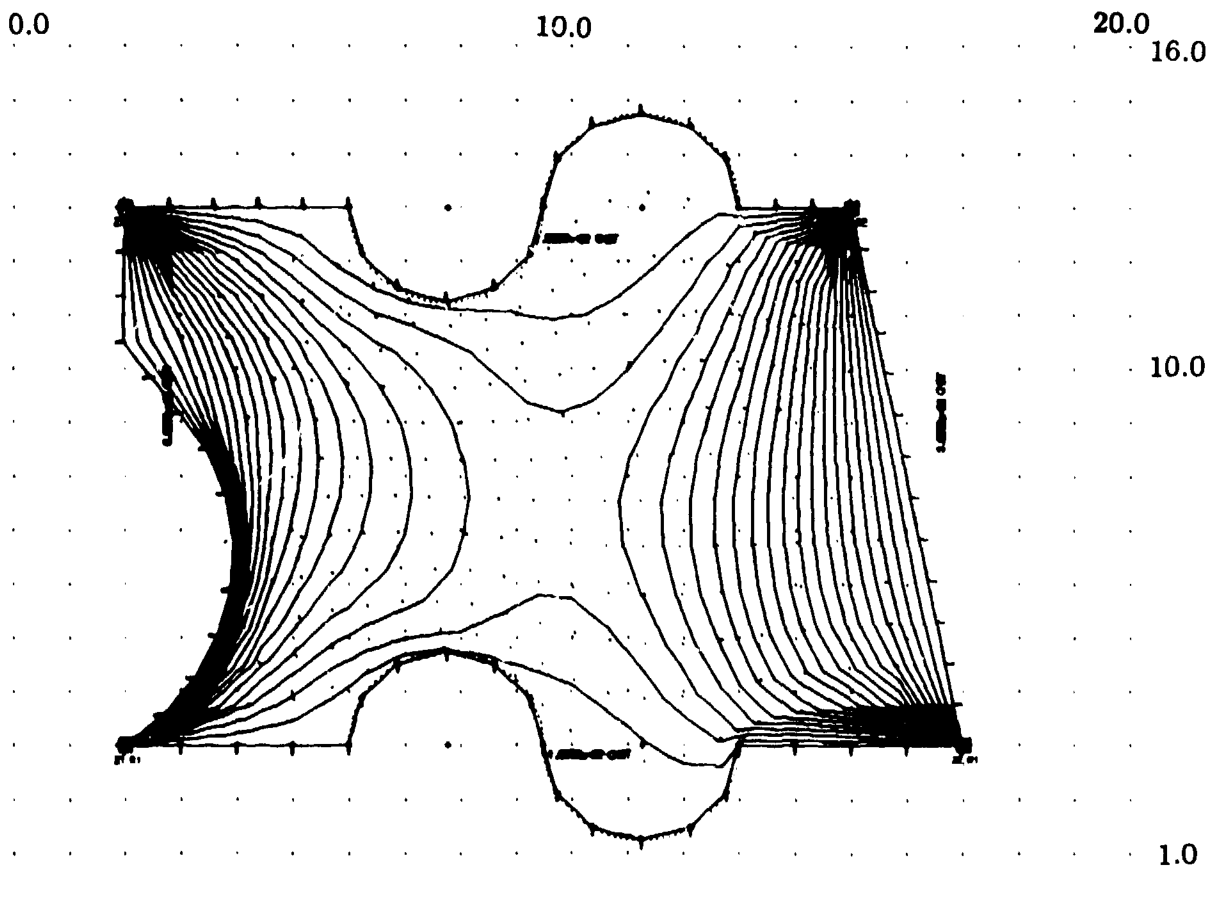

Fig. 4 Sample electrostatic calculation.

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