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MODELING OF THE END REGIONS OF RFQs USING THE 3-D SOS CODE

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Abstract

The end region of a RFQ accelerator is essentially a 3-D structure in which the ends of the vanes must be undercut to allow the electromagnetic fields to penetrate between quadrants. The dimensions of the undercuts critically affect the resonant frequency and field homogeneity in the RFQ. RFQ modeling results utilizing the 3-D SOS code are presented. Preliminary results using coarse grids have provided a rough estimate of the RFQ geometry. In the near future the dimensional resolution of the code will be significantly increased. It is expected that the final vane dimensions can be calculated precise enough that the number of machining iterations required to resonant an RFQ can be reduced.

1. Introduction

In this paper, we present modeling results utilizing the three-dimensional (3-D) SOS[1] code for the end region of an radio frequency quadrupole (RFQ) accelerator. This paper closely parallels the work of Browman *et al*[2] in which the MAFIA[3] code was used. The purpose of this work is to investigate the usefulness of the SOS code running on a mini-supercomputer for modeling of 3-D structures such as RFQs. The ultimate goal of this work is to reduce the number of machining iterations required to resonant an RFQ. The SOS code has been installed on the Grumman Stardent Titan computer. This is a relatively inexpensive (~$150K) UNIX computer with 3 CPUs, 96M of memory, and a vector processing unit. Grids on the order of 120^3 can be stored in memory. At present the largest simulations we have been successful with are 62 x 62 x 30. Though not limited by memory, enhancements are being made to the Eigenvalue solver in order to converge for finer and finer grids. In addition, upgrades to the computer's file system and CPUs are also planned.

The method for determining the dimensions of the end region of the RFQ is described in section 2. Section 3 presents modeling results to date. The conclusions of this work are given in section 4.

2. Method

The two-dimensional transverse dimensions of an RFQ are routinely determined utilizing the SUPERFISH[4] (SF) code. This code was used to design the 348 Mhz RFQ shown in Figure 1. A difficulty in modeling RFQs

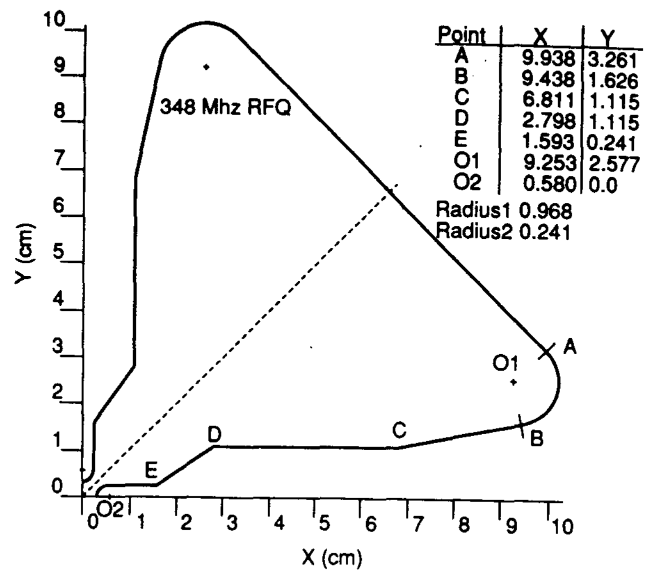

Figure 1. 348 Mhz RFQ as determined by SF.

is that the resonant frequency is critically determined by the capacitive coupling between vane tips, hence a disproportionate number of grid cells is allocated to this region. Computationally, this means that the largest frequency that the grid can support is often greater than 1000 times the resonant frequency. Hence high frequency contamination can cause the solution to converge slowly.

In order to reduce the number of iterations required for the code to converge, a preset field option has been added which allows an initial guess of the fields to be inputted. For the RFQ, the fields:

$$E_r(r,\theta) = 0 \quad (1)$$

$$E_\theta(r,\theta) = (r + r_o)^{-1} \quad (2)$$

have been used. r_o is the vane tip radius. After the resonant frequency has been found, the fields are stored in a file. These files can be read in for successive runs in which slight variations in the geometry can be made.

Figure 2 shows a perspective view of the RFQ geometry. Only one quadrant of the RFQ need be modeled to determine the quadrupole modes. So called mirror boundary conditions are imposed on the transverse boundaries and the longitudinal boundary opposite the undercut region. These mirror boundary conditions ensure

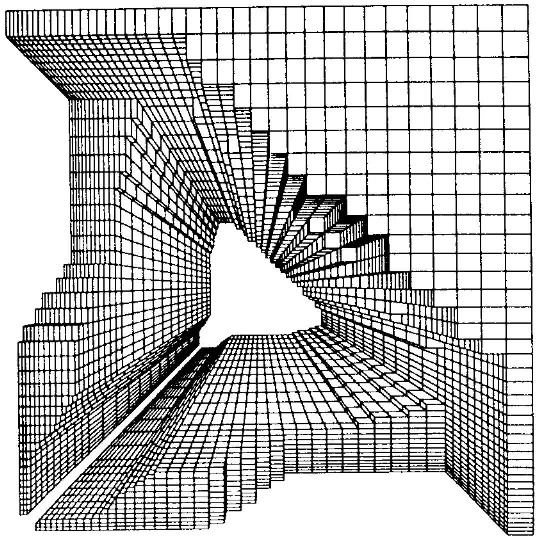

Figure 2. 3-D perspective of the SOS geometry

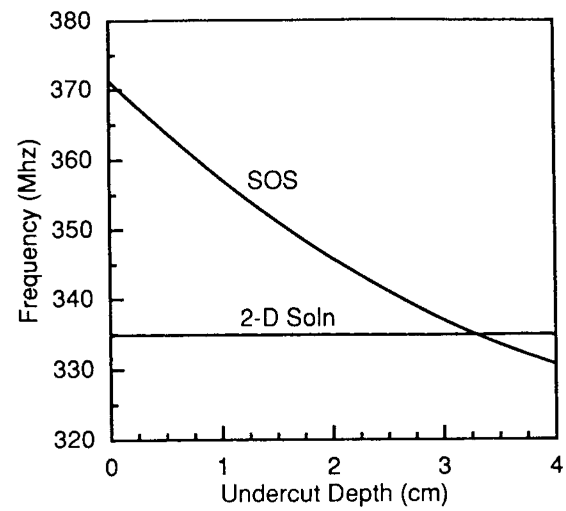

Figure 3. Frequency vs. undercut depth (30cm axial length)

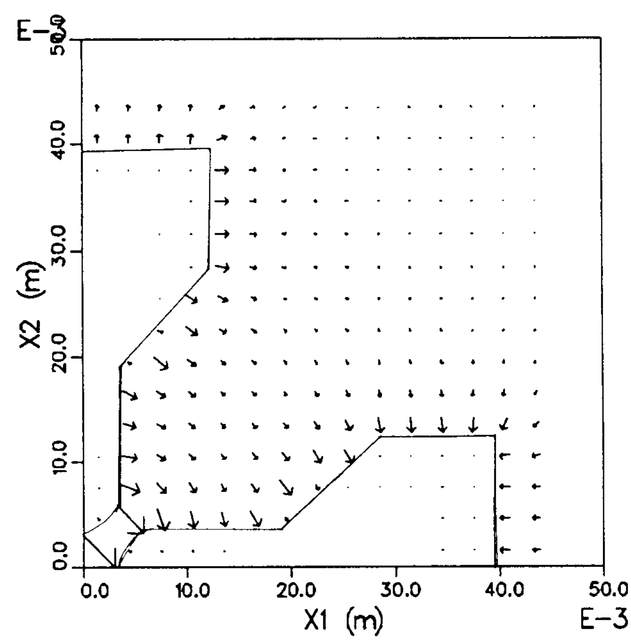

Figure 4. Electric field in the undercut region at an axial location of 2 cm.

that the magnetic field is continuous across boundaries. If a metallic boundary was imposed on one of the transverse boundaries, the dipole modes of the RFQ could be found. At first only one cell is modeled in the longitudinal dimension and 40 x 40 in the transverse dimension. This allows the 2-D resonant frequency to be found. Since the spatial resolution of the 3-D simulations is not as fine as in SF simulations, the resonant frequency will differ. If desired, the vane tips could be moved in order to achieve a resonant frequency closest to 348 Mhz. The SOS code is then run for the full 3-D geometry (40 x 40 x 24). A longitudinal length of 30 cm was chosen. This distance must be long enough that it does not affect the resonant frequency. By contrast, the engineering test (cold) model of this RFQ was 4 m in actual length.

3. Results

The resonant frequency vs. undercut depth is plotted in Figure 3. In these simulations the locations of the start and end of the diagonal cut where keep constant. The depth of the undercut predicted by SOS is 3.3 cm (± 0.3 cm due to the spatial resolution). This is very close to the experimentally determined depth of 3.2 cm. Machining of the undercuts required 4 iterations, each of which consisted of disassembling the RFQ, machining, reassembling, and performing bead-pull measurements. In the future it is expected that the dimensional resolution of the code can be increased to predict the final dimension within ± 0.1 cm. This could possibly reduce the number of machining iterations.

The electric and magnetic fields in the undercut regions are shown in Figures 4 and 5. As expected the electric field is concentrated in the vane tip region and everywhere normal to the vanes. Magnetic field coupling between adjacent quadrants is clearly shown in Fig. 5. In order to determine the expected power dissipation on the vanes, the magnetic field tangential to the vane surface was determined. From the magnetic field, the power loss was calculated according to:

$$P(\mathrm{w/cm^2}) = \frac{B^2}{\mu_0^2 \delta \sigma} \qquad (3)$$

where δ is the skin depth and σ is the conductivity. Figure 6 shows the power loss on the surface of the vane. The

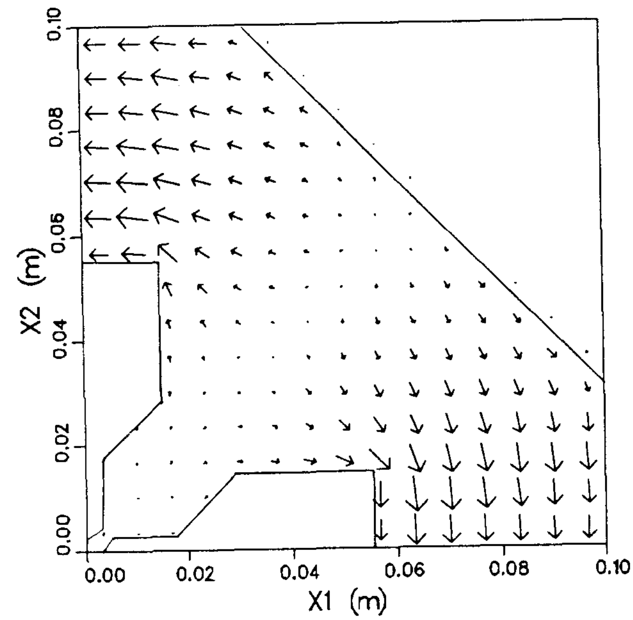

Figure 5. Magnetic field in the undercut region at an axial location of 2 cm.

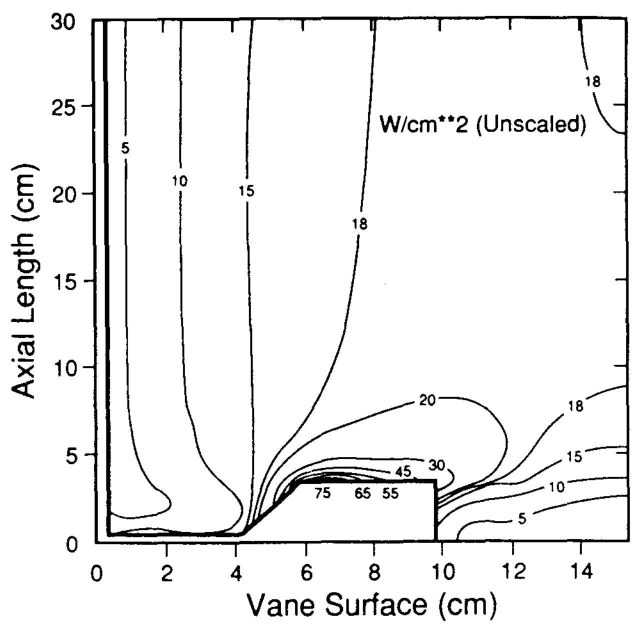

Figure 6. Power loss along the surface of the vane

ordinate is not the transverse dimension, but the arc length is moving along the vane surface to the middle of the back wall. Figure 7 shows the power loss on the end of the vane. The location of the start and end of the vane undercut is indicated. Notice that in both Figs. 7 and 8 the maximum power loss occurs in the back corner of the vane. To compare these results with the 2-D SF simulations, Fig. 8 shows the expected power loss at an axial length of 30 cm (3-D) compared to the expected power loss from SF. Notice the agreement is quite good.

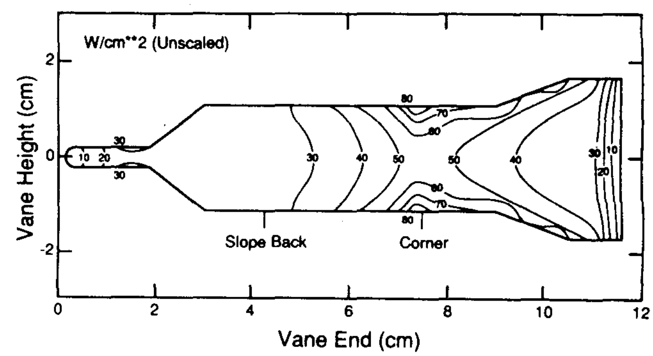

Figure 7. Power loss along the end of the vane

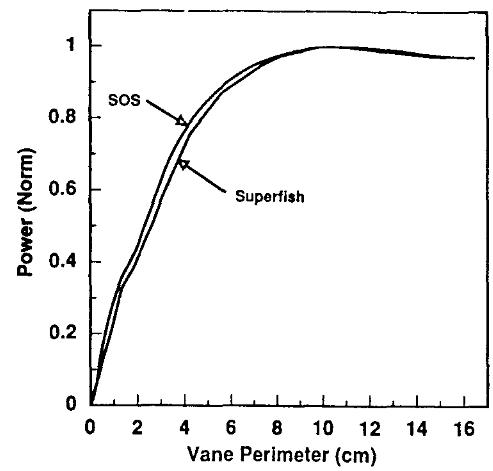

Figure 8. Comparison of the SOS and SF predicted power loss

4. Conclusions

The modeling results presented in this paper suggest that in the future the 3-D SOS code could determine the final dimensions of an RFQ precise enough that the number of machining iterations could be reduced. The 3-D modeling identifies region of high power loss. The power loss in the corner region is about 4 times larger than the peak power loss in the 2-D case, suggesting the need for 3-D modeling. Parametric studies could then be preformed in order to determine optimal geometries.

References

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