SUPERFISH ACCURACY DEPENDENCE ON MESH SIZE*

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Abstract

The RF cavity code SUPERFISH is extensively used for the design of drift-tube linac (DTL), radio-frequency quadrupole (RFQ), and coupled-cavity linac (CCL) structures. It has been known for some time that considerably finer meshes are required near the nose of a drift tube to ensure accurate calculation of the resonant frequency and related secondary quantities. This paper discusses the results of numerical experiments designed to provide rules to set proper mesh sizes for DTL, RFQ, and CCL problems. During this work, SUPERFISH problems involving more than 100 000 mesh points were solved.

Introduction

The well-known RF cavity code SUPERFISH[1-3] is extensively used by the accelerator community for the design of DTL, RFQ and CCL structures. We have long suspected that SUPERFISH calculations for RFQ's had greater sensitivity to mesh size variation than did calculations for DTL cells. There were some indications that power dissipation results for RFQ's were especially questionable when mesh spacing was large. The mesh spacing sensitivity of side-coupled linac (SCL) cells was even less known (the SCL is one type of CCL).

For a given problem geometry, small mesh spacing requires more memory and more computation time to achieve results. It may also require code modification to handle the larger number of mesh points generated. Guidelines are therefore needed to indicate the maximum mesh spacing for each problem type and particular problem geometry that is likely to yield the desired accuracy. This study is our initial attempt to develop such guidelines.

Method

We selected for study four problem geometries of three different types that are of interest to current linac projects. The four problem geometries are shown in Figs. 1-4. Figure 1 shows one-half of a DTL cell, symmetric about a vertical plane and having rotational symmetry about the horizontal z axis at the bottom of the figure. This is referred to as the DTL-1 problem geometry. The similar DTL-2 geometry is shown in Fig. 2. It differs from the DTL-1 only in the size of its gap. Figure 3 shows one-half of an SCL cell. The full cell is obtained by reflection about the left side and rotation about the z axis. The geometry shown in Fig. 4 is one-quarter of a standardized RFQ cross section. It is symmetric about the x and y axes and infinite in z. The shape shown is one-quarter of the resulting infinite cylinder cross section.

We thought it likely that the magnitude of the smallest dimension near the z axis in the problem geometry would have a significant effect on the adequacy of mesh spacing; therefore, three of the four problem geometries have similar smallest dimensions. The three are the DTL-2, the SCL, and the RFQ. For the DTL and SCL, the gaps were set at 0.28 cm. For the RFQ, the distance between adjacent vanes is approximately 0.28 cm. (The nominal RFQ aperture is more than twice this distance.)

We performed SUPERFISH analyses of each problem geometry, using requested mesh spacings ranging from 0.014 cm to 0.30 cm. We postprocessed the SUPERFISH results using versions of SFOGEN. The number of mesh points in the various problems ranged from 410 to 124 576.

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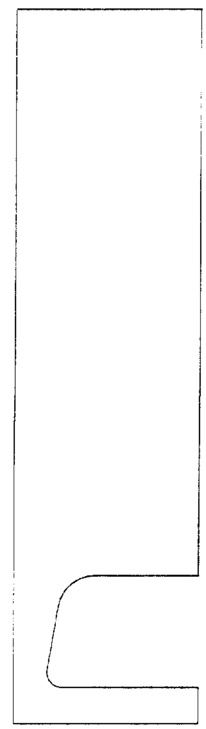

Fig. 1. One-half $r - z$ cross section of DTL-1.

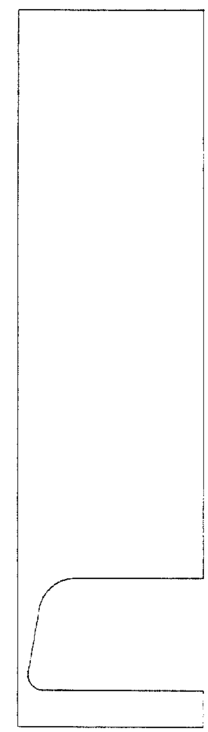

Fig. 2. One-half $r - z$ cross section of DTL-2.

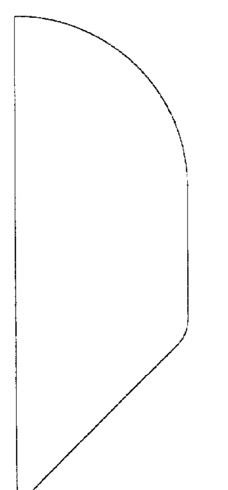

Fig. 3. One-half $r - z$ cross section of SCL.

Both variable and constant mesh spacings were used. Problems for which the requested mesh size was greater then 0.049 cm were run only with a constant mesh size for the entire region. Problems for which the requested mesh size was less than 0.032 cm were run only with a variable mesh. For the variable mesh, the mesh spacing in one or both coordinates is doubled near specified positions.[1,2] These positions were held constant for each problem type. The variable mesh spacing was allowed to change smoothly rather than making a step change at a line at the specified position. For the RFQ, the mesh varied in both x and y. In the cells, the mesh was varied only in r. For requested mesh sizes of 0.032 and 0.049, problems were

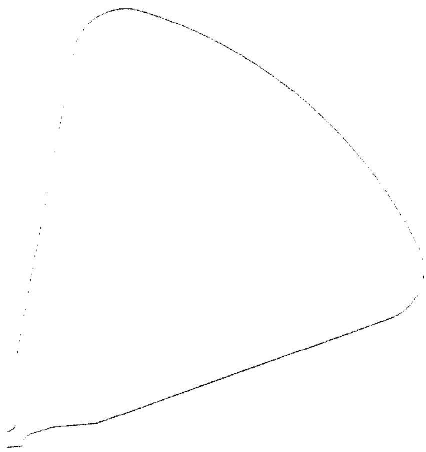

Fig. 4. One-fourth standardized $x - y$ cross section of RFQ.

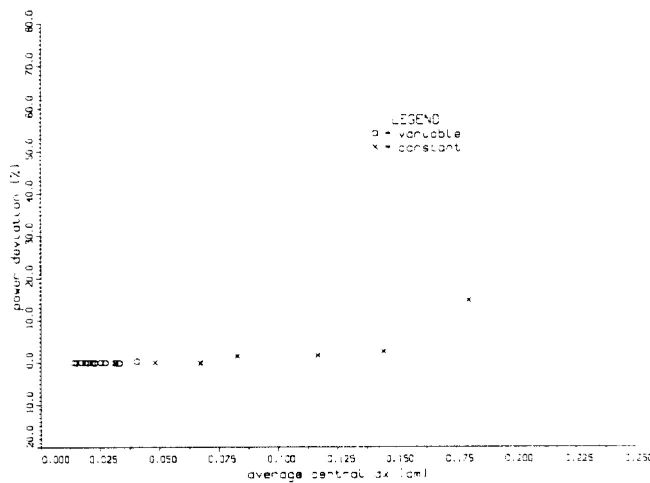

Fig. 5a. Frequency deviation vs mesh size in SCL.

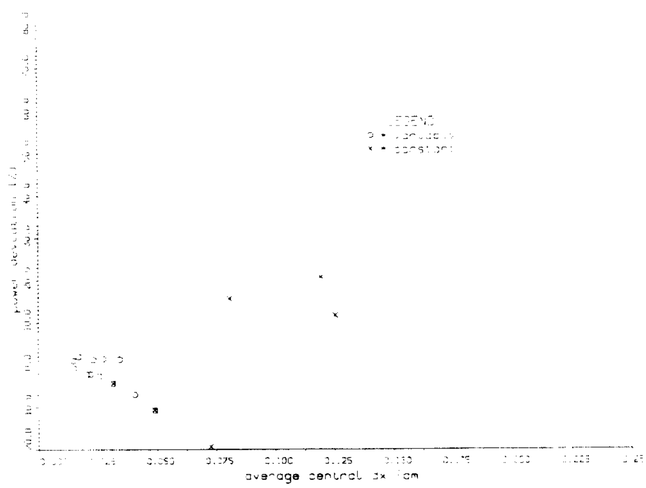

Fig. 5b. Frequency deviation vs mesh size in RFQ.

run with both a constant mesh and a variable mesh to allow comparison of results obtained by the two methods.

Because the mesher does not produce a mesh spacing exactly equal to that requested, we recorded the average dx or dz in the area within 0.28 cm of the origin as a reasonable representation of the unperturbed mesh spacing. This average is the "average central dx" shown on the result plots, which ranged from 0.0139113 cm to 0.250436 cm.

In a study of this type, it would be desirable to compare calculated results to a closed-form solution. Unfortunately problems of the types in which we are interested don't have closed solutions. Therefore, we chose to select a value to which the small mesh spacing runs appeared to be converging and to designate it as the probable true value, to which we would compare. In most cases, the average of the four solutions using the smallest mesh spacings that were run was chosen. For frequency and quality factor the single value from the smallest mesh spacing used was chosen.

Results

We evaluated the effect of mesh size on several variables: the resonant frequency; the shunt impedance, Z; the power dissipation; the stored energy; the quality factor, Q; and the maximum electric field on the boundary. We also examined the RFQ vane voltage, for which there is not an equivalent quantity calculated for the cells. The results for each of these quantities are discussed in the following sections. Plots of frequency (Fig. 5) and power (Fig. 6) are given. Because of insufficient space, the remainder of the data is not plotted in this paper. An internal report is in preparation that does include the full data. In Figs. 5 and 6, part (a) provides the results for the SCL cell described by Fig. 3 and part (b) shows the results for the RFQ described by Fig. 4. The results are given as percent deviation from the probable true value described above. The results for the DTLs resemble those for the SCL.

Variable mesh results are indicated with an open circle and constant mesh results are shown with a cross.

In the discussions of each quantity, we will often refer to the three rotational geometries that are models of accelerator cells as the cells; we will refer to twice the distance from the left edge in Figs. 1-3 to the nearest surface as the gap. The smallest dimension near the axis for an RFQ is the closest distance between adjacent vanes. For convenience, we sometimes refer to this distance as a gap. Note that this is neither the RFQ aperture nor the distance between opposite vanes, both of which are usually much larger.

Frequency

The resonant frequency found for two problem geometries with various mesh spacings is shown in Fig. 5. Frequency is the primary quantity for which SUPERFISH solves. The figures show what is already well known about SUPERFISH, namely that it calculates the frequency quite well even with poor meshes. Even for the worst case (the RFQ), a mesh spacing one-quarter the distance between adjacent vanes is sufficiently small to give the frequency to within 1%. The DTLs are much less sensitive than the RFQ, while the SCL is intermediate. Note that when the frequency is within 1%, it invariably decreases as the mesh step gets smaller.

Shunt Impedance

This quantity is derived from the SUPERFISH solution matrix. Oscillation is seen in all problem types, but it occurs over a much narrower range in the three cells: the DTL-1, DTL-2, and SCL. These three geometries appear to exhibit a decreasing trend in value with increasing mesh spacing. For the cells, results are very good if the mesh spacing is no larger than one-seventh the gap size. In the case of the RFQ, this is not so. Even for the smallest mesh spacings we used, oscillation of $\pm 2\%$ is seen. Values can be off by 20% at moderate spacing of one-third the gap width. With large mesh spacing, the RFQ results can be off by nearly 50%, which compares to less than 15% error for the cells at similarly large mesh spacing.

Power Dissipation

Power dissipation results are shown in Fig. 6. Oscillation is seen for all problem geometries studied, but it is relatively narrow for the cells, all of which show an underlying upward

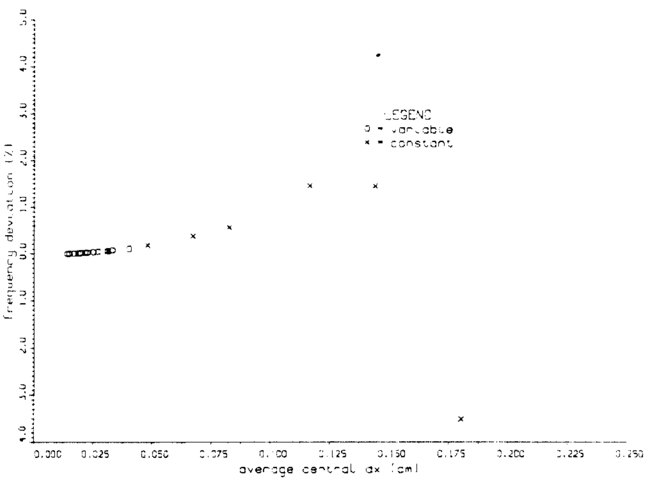

Fig. 6a. Power dissipation deviation vs mesh size in SCL.

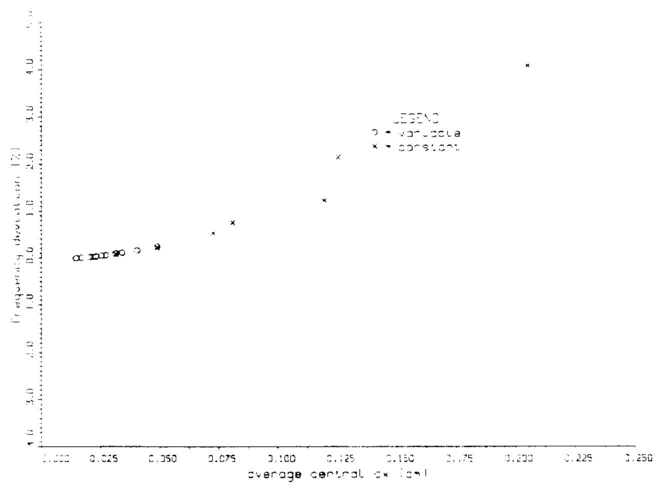

Fig. 6b. Power dissipation deviation vs mesh size in RFQ.

trend in values with increasing mesh size. At moderate mesh spacing, i.e., one-quarter to one-third the gap size, the values can be off by 1% to 2%. The RFQ, on the other hand, oscillates both above and below the probable true value. The oscillation, even at the smallest mesh spacings used, shows swings of ±2.5%. At moderate mesh spacings of one-third to one-fourth the spacing between vanes, the value can be off by 20% and, at large mesh spacing approximating the gap size, by 70%. For the RFQ, our results show that it is imperative to use a mesh spacing no larger than one-seventh to one-tenth the distance between adjacent vanes to get reasonable power results.

Stored Energy

Stored energy behavior is similar to that of power dissipation. The cells give much better results than does the RFQ, which requires a very small mesh spacing giving about 10 mesh points in the gap to give results to within 5%. Cell results are within 1% when the mesh spacing is as small as one-quarter the gap distance.

Quality Factor

This quantity is calculated from the ratio of two others, and much of the error caused by large mesh spacing appears to cancel. The values are nearly constant for small mesh spacings not larger than one-fifth of the gap. Values gradually rise, with the rise being steeper in the order DTL-1, DTL-2, SCL, and RFQ. The SCL and RFQ show oscillation with large mesh spacing. But all of this occurs in a range narrower than ±4%. With mesh spacing no larger than one-fifth the gap, the variation is a small fraction of 1% for all problem geometries.

Maximum Surface Electric Field

Noticeable oscillation is seen for all problem geometries, with the DTL-2 and SCL each actually showing one point further from the probable correct value than any point for the RFQ. The RFQ does, however, exhibit a striking pattern of oscillation even for very small mesh spacing. Mesh spacings not larger than one-fifth the gap are needed to get RFQ results to within 5%. The same spacing will give results to within about 2% for the cells.

Maximum surface electric field is a surface effect whose accuracy is dependent on having a sufficient number of mesh points on the surface on which the effect is being determined. We have examined this problem, particularly as it applied to a DTL cell having very small radii approximating sharp machined corners. A case having radii of 0.05 cm, a cell length of 14.65 cm and a tank diameter of 42.28 cm required 300 000 points for a requested mesh spacing of 0.0176 cm. We were able to perform this SUPERFISH analysis after some modification to the code. We believe at this time that at least three points on the curve defining the surface are required for ± 15% accuracy.

Vane Voltage

Vane voltage results are similar in appearance to RFQ shunt impedance, power dissipation, stored energy, and maximum surface electric field. There is appreciable oscillation even at the smallest mesh spacings. Mesh spacing of about one-tenth the gap is required to give vane voltage results to within $2^1/_2$ %. Mesh spacing of one-half to one-fifth the gap gave results off by about 10%. Larger spacing yielded results off by nearly 35%.

Conclusions

The RFQ was much more sensitive to large mesh spacing than the cells. Power dissipation and stored energy results show this most strikingly. The frequency results are not very sensitive to mesh spacing even for the RFQ. In general, the DTL-1, with its larger gap, showed less variation in all quantities than the DTL-2. For a given mesh size, frequency is likely to be more accurate than the secondary quantities. Quality factor will be quite good even for relatively large mesh sizes and even for the RFQ. Power dissipation and stored energy will be off by much more than frequency. In general, mesh sizes of one-fifth to one-tenth the smallest gap near the axis are desirable for good accuracy.

Varying the mesh by increasing its size away from the axis does not appear to be harmful and can save a very substantial number of mesh points. For the particular cases included in this study, the savings was approximately a factor of 3.

In this study, we have considered only three rotational and one cylindrical geometry. We have not examined the effects of dimensional changes in the individual geometries. We hope to do more work on this problem in the future.

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