STUDYING THE END REGIONS OF RFQS USING THE MAFIA CODES *

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Abstract

The three-dimensional MAFIA codes[1] were used to study the end regions of a radio-frequency quadrupole (RFQ). The following determinations were made:

- Undercutting the vane is essential.[2]
- To a point, increasing the distance between the vanes and the end plate decreases the power loss at the ends of the vanes; this effect (assuming we begin with an end gap slightly larger than the distance between the vanes) decreases with distance and eventually reaches a limit.[3]
- The slope of the undercut affects the peak current flow and the power dissipation at the ends of the vanes; in particular it was found that in designing such an end region a tradeoff must be made between minimizing the peak power loss density and reducing the total power loss[4].

This paper gives the details of the calculations leading to the above conclusions.

Modeling the Structure

An RFQ is essentially a waveguide operated at the cutoff frequency, terminated by an end region whose fields must be matched to those of the waveguide. In practice this matched condition is met if the frequency of the end region is tuned to the cutoff frequency of the waveguide.

The cutoff frequency of the waveguide was found by generating a finite length of the structure (Fig. 1), requiring that the magnetic fields be perpendicular to each end, and solving for the lowest resonant frequency (425.9 MHz). Because of symmetry, only one-quarter of the structure need be generated.

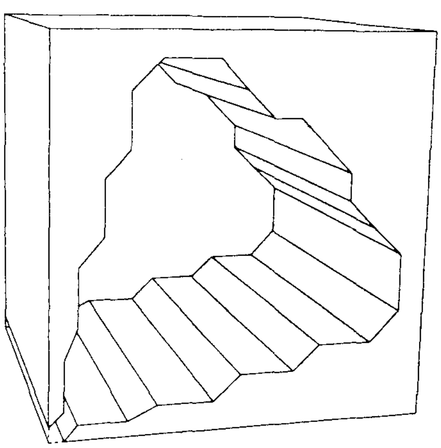

Fig. 1. Three-dimensional computer plot of the structure (one quadrant) used to compute the cutoff frequency of the model RFQ .

Next, the end region was generated by extending the walls of the structure (Fig. 2) and by requiring that the tangential electric field be zero at the position of the end plate. The boundary condition at the waveguide end, of course, remained unchanged.

The Need for Vane Undercutting

Figure 3 shows a plot of the frequency of the structure shown in Fig. 2 as a function of the distance between the ends of the vanes and the end plate. The dotted line indicates the tuned frequency of the end region, i.e., 425.9 MHz. Clearly, the end region cannot be tuned by varying only this distance.

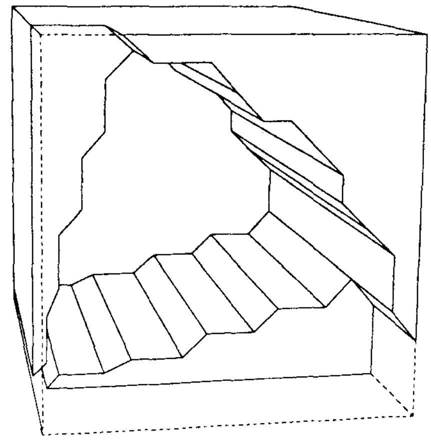

Fig. 2. Three-dimensional plot of one of the geometries of the end region used in this study.

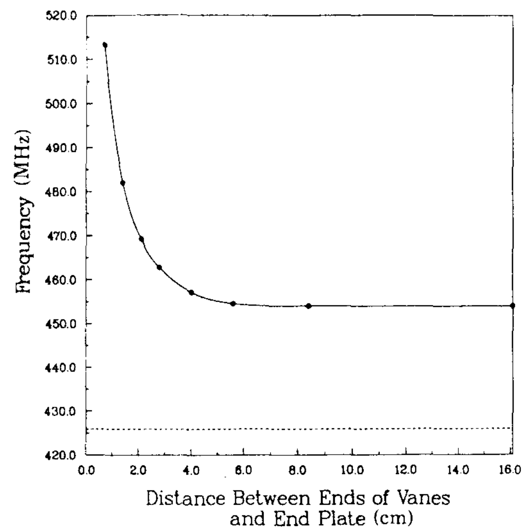

Fig. 3. Plot of the frequency of the end region shown in Fig. 2 as a function of the distance between the ends of the vanes and the end plate. The curve is drawn to guide the eye, and the dotted line indicates the tuned frequency of the end region.

In another tuning experiment, the end plate was placed 8.4 cm from the end of the vanes and a nose cone was added to the end plate. Figure 4 shows a plot of the frequency of the structure as a function of the distance between the nose cone and the end of the vanes. Notice that even when the distance is as small as 0.35 cm (less than the distance between the vanes), the frequency has dropped to only 445.8 MHz. Thus for a reasonable gap between the end of the vanes and the nose cone, the end region cannot be tuned using only a nose cone.

On the other hand, the structure was easily tuned by undercutting the vane, or, equivalently, by adding an overhang (Fig. 5). An overhang of 2.45 cm tuned the end region to the desired 425.9 MHz.

The Effect of the End-Gap Distance on Power Dissipation

Figure 6 shows a cross section of the model RFQ (with undercutting) taken along the center of the vanes. An ample 9.2 cm was allowed between the waveguide end and the beginning of the overhang to guarantee that the fields had stabilized at the waveguide end. The end-gap distance was varied, and the model structure was tuned to 425.9±0.1 MHz by varying the length of

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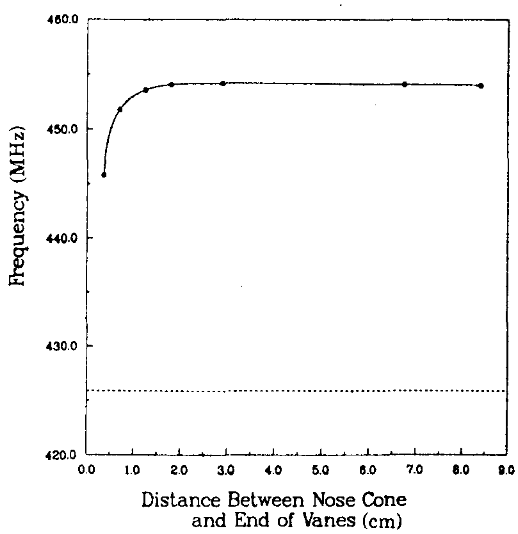

Fig. 4. Plot of the frequency of the end region with nose cone as a function of the distance between the nose cone and the end of the vanes. The curve is drawn to guide the eye, and the dotted line dictates the tuned frequency of the end region.

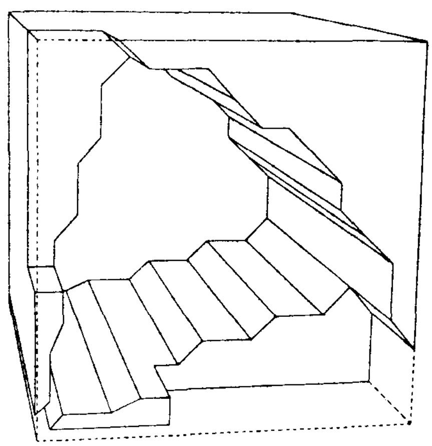

Fig. 5. Three-dimensional computer plot of an end region tuned by vane undercutting.

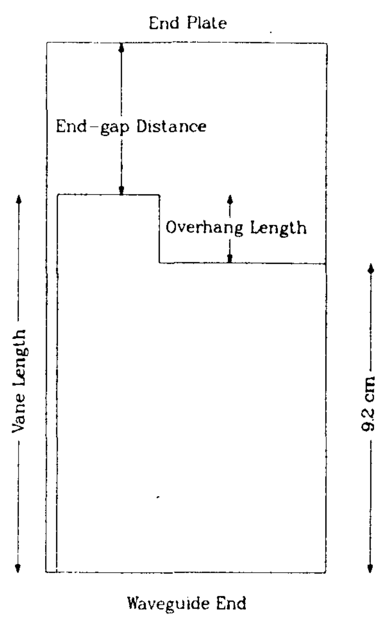

Fig. 6. Cross section of the RFQ end region used to study the effect of the end-gap distance.

the overhang. The relative overhang length, the peak current density, and the power dissipation caused by the end region were plotted as a function of end-gap distance (Fig. 7). All values are normalized so that the maximum value is 1. The "power loss caused by the end region" was calculated by computing the total power loss of the model structure and subtracting the power loss of an equivalent length of the RFQ waveguide. Figure 7 shows that all three quantities decrease at first, but eventually reach a limit. Figure 8, a plot of the magnetic field lines along the center of one of the vanes for an end gap of 5.6 cm, indicates why this limit is reached. The magnetic field is almost zero at the end wall, so further increasing the end-gap distance will have little effect. In Fig. 8 the circles with dots indicate that the field lines are directed out of the paper, and the radii of the circles are proportional to the magnetic field strength.

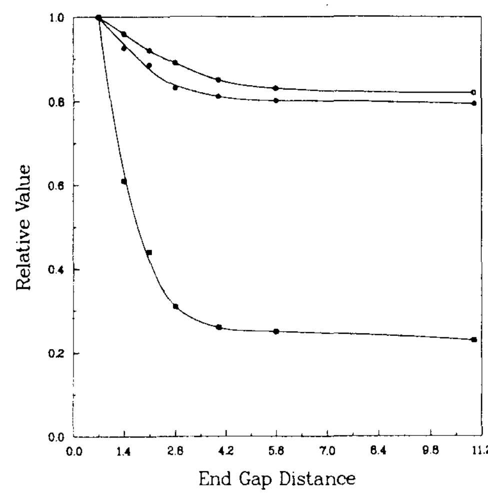

Fig. 7. Plots of the relative overhang length (top curve), the peak current density (middle curve), and the power loss caused by the end region (bottom curve) as a function of end gap distance. The curves are drawn to guide the eye.

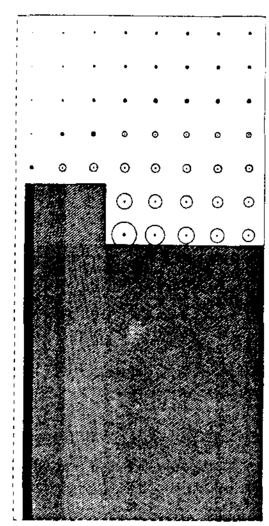

Fig. 8. Plot of computed magnetic field lines for an end gap of 5.6 cm. The cut is taken along the center of one of the vanes. The circles indicate that the field lines are perpendicular to the plane of the paper.

The Effect of the Shape of Vane Undercutting

Next, the power loss in the end region was studied as a function of the slope of the undercut (Figs. 9 and 10). Four slopes were used: 0°, 22.5°, 30.2° and 39.2°. In each case the length of the overhang was varied until the frequency of the model structure was tuned to 425.9±0.1 MHz. Table I shows that the overhang length and the power loss on the overhang decreases as the slope increases.

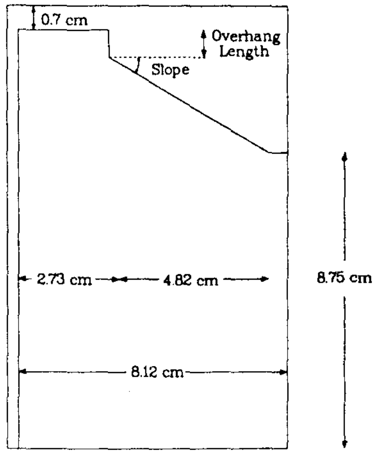

Fig. 9. Cross section of the RFQ end region used in studying the effect of the slope of the vane undercut.

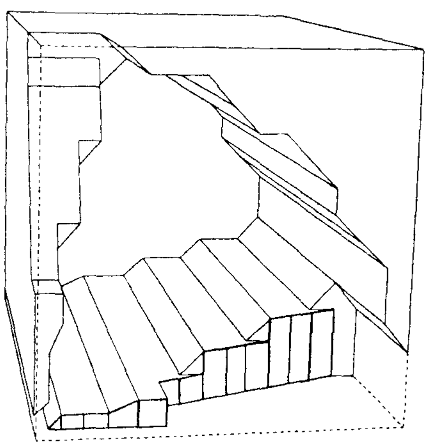

Fig. 10. Three-dimensional computer plot of the end region with a sloped undercut. The strips of surface area shown on the sloped cut and on the end of the overhang were used in computing the average power loss plotted below in Fig. 11.

TABLE I
OVERHANG LENGTH AND RELATIVE POWER LOSS
AS A FUNCTION OF SLOPE

Slope (deg.)	Length of Overhang (cm)	Relative Power Loss on Overhang
0.0	2.45	1.00
22.5	1.30	0.54
30.2	0.79	0.41
39.2	0.00	0.18

Figure 11, which plots the the average power loss density as a function of distance from the RFQ axis for each of the four slopes, shows that the average power loss at the base of the overhang also decreases with increasing slope. Because the surfaces and base of the overhang are the hardest regions to cool, the ease of cooling increases with the slope of the overhang.

In Fig. 11 the power loss densities at the top of the overhang and on the sloped undercut were averaged over the strips of surface shown in Fig. 10. The multiple points at the boundary between these two regions represent the average power-loss density along the sides of the overhang, which are not visible in Fig. 10. Notice that as the slope increases, the power-loss density becomes more evenly distributed in the sloped region. In other words, as the slope increases, the power-loss density increases in the region where the vanes are the widest (see Fig. 10), and thus it is not surprising that the total power loss in the end region also increases. (See Table II below.)

In Table II, power losses are normalized so that the value corresponding to 0.0° slope is 1. Because increasing the slope

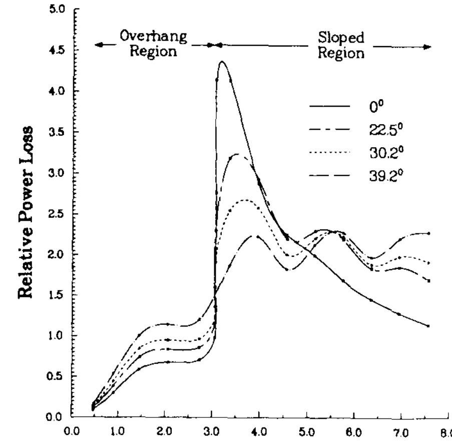

Fig. 11. Plots of the average power loss density, for four different slopes, as a function of distance from the the RFQ axis. The curves are drawn to guide the eye.

TABLE II
RELATIVE POWER LOSS IN END REGION
AS A FUNCTION OF SLOPE

Slope (deg.)	Relative Power Loss in End Region
0.0	1.00
22.5	1.13
30.2	1.17
39.2	1.23

makes the structure easier to cool but increases the total power loss, a tradeoff must be made when designing the end region of an RFQ.

Conclusions

The study of the model end regions showed the following:

- Undercutting the vane is essential.
- To a point, increasing the distance between the vanes and the end plate decreases the power loss at the ends of the vanes; this effect (assuming we begin with an end gap slightly larger than the distance between the vanes) decreases with distance and eventually reaches a limit.
- The slope of the undercut affects the peak current flow and the power dissipation at the ends of the vanes; in particular it was found that in designing such an end region, a tradeoff must be made between minimizing the peak power-loss density and reducing the total power loss.

Acknowlegment

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3. M. J. Browman and G. Spalek, "The Effect of the End-gap Distance on Power Dissipation in the End Regions of RFQ's," Los Alamos National Laboratory internal report, AT6-ATN-87-14.
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