MECHANICAL DESIGN CONSIDERATIONS IN FMIT RFQ DEVELOPMENT*

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Summary

The mechanical features of the several rf structures that have been made to test the theory of the radio-frequency quadrupole (RFQ), are briefly described. A 425-MHz structure, designed as a proof-of-principle (POP) test, is described in detail. Methods of coupling rf power into the structure, temperature control, tuning, and mode separation are discussed. The methods and setup of numerical control machinery used to generate the critical geometry surrounding the RFQ aperture are detailed fully.

Finally, the applicability of experience and methods gained from the high-frequency (425-MHz) RFQ development to the 80-MHz prototype and ultimate Fusion Materials Irradiation Test (FMIT) machine are mentioned.

Cold Test RFQ Structures

Recent experiments with RFQ structures by the Accelerator Technology Division, Los Alamos Scientific Laboratory (LASL), have focused on the four-vane geometry. One reason for this selection over other geometries is the four-vane's comparative ease of manufacture, considering the close mechanical tolerances that are required.

The first four-vane cavity was a length of aluminum pipe, 12-in diameter, 40-in long. Vanes were attached inside at 90° intervals. Their penetration into the cavity could be varied using spacers, and several different pole tips were machined and attached (Fig. 1).

This cavity was useful in determining which modes could be excited, how they overlapped, and in suggesting methods of tuning the cavity and separating and suppressing unwanted modes. The hardware was soon outgrown and a better cold model, made to closer mechanical tolerances, was needed.

For low-power testing a four-pipe, or cloverleaf model (Fig. 2), was designed around 4-in o.d. stock aluminum tubing and other readily available materials. Problems caused by wide manufacturing tolerances for such tubing (roundness, straightness, etc.) were avoided by machining reference surfaces along the length and at the ends of the tubes. The end plates were designed and machined to register the tubes and other parts accurately during welding of the

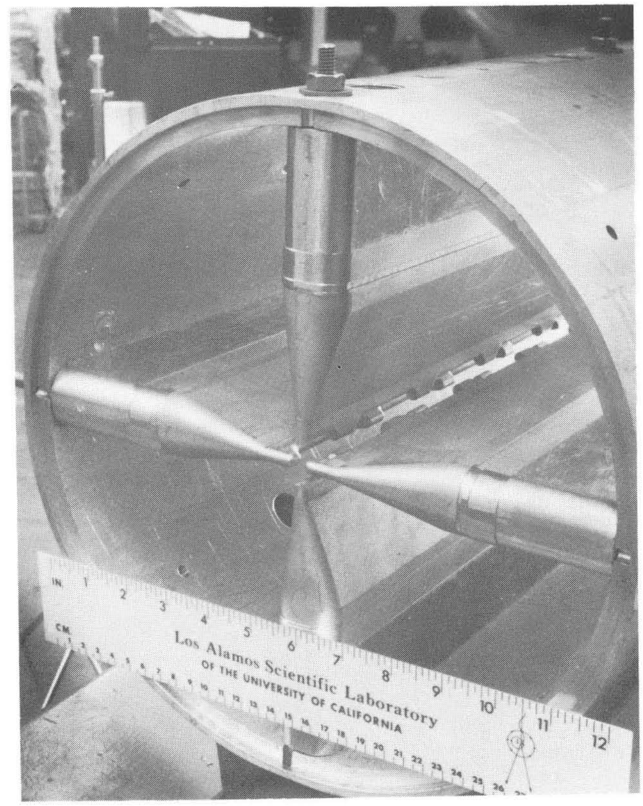

Fig. 1 Four-vane structure.

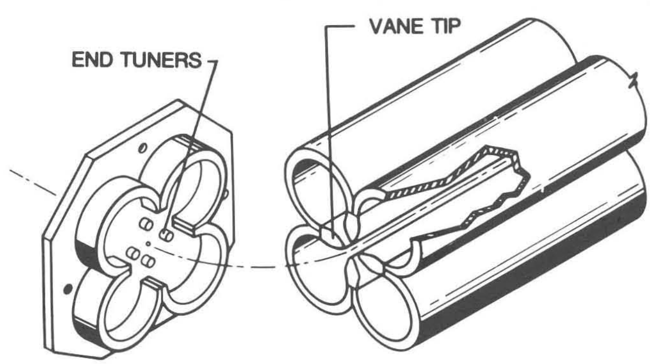

Fig. 2 Four-pipe structure.

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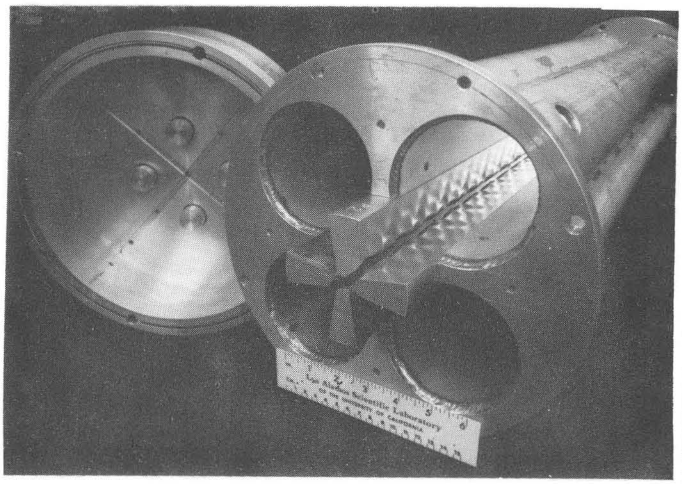

Fig. 3 Four-pipe cavity with vanes installed.

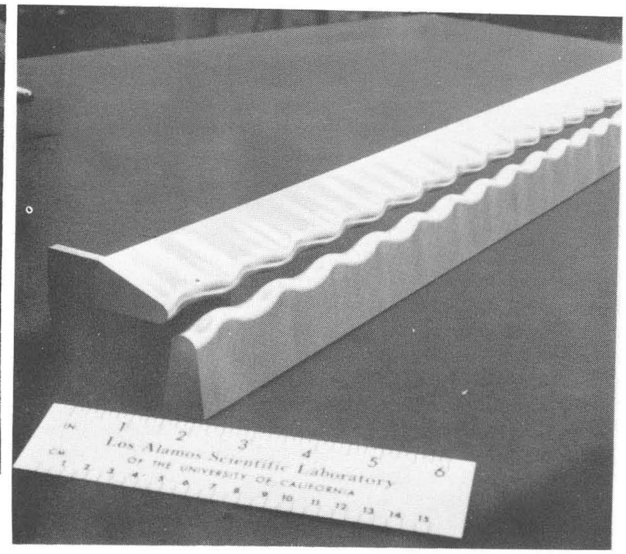

Fig. 4 Constant-$\beta\lambda$ modulated vanes.

assembly. Intermittent welds were used along the length to minimize distortion. A center hole was then bored through the axis of the cavity, forming straight, parallel, accurately machined surfaces on which to mount the electrodes. The concept of the center bore to form a machined seat for the vane tips continues to be important in designs of future RFQ structures.

A set of four constant-$\beta\lambda$, modulated vanes was made for this cavity (Figs. 3 and 4) using a numerically controlled three-axis milling machine. The test results were very encouraging and were reported by Potter and Williams.[1]

In these cold test models, cooling and vacuum were not factors because the experiments were at atmosphere and at low rf power. Further, at low power, the quality of rf surfaces and the contact between parts were not critical. Now, however, a POP test structure through which a beam will be accelerated is being designed. This is the next step in the development of an 80-MHz RFQ for the FMIT accelerator (a full-scale prototype will be constructed and installed at LASL).

RFQ Proof-of-Principle Cavity

Copper tubing, 6.125-in o.d. by 0.192-in wall, was chosen as the main structural element for the POP four-vane cavity (Fig. 5). Square ends are brazed to the tube, then accurately machined and faced to length. The ends form three mutually perpendicular planes; two are parallel to, and equidistant from, the cavity center line. In this form, the part is easily indexed and clamped in jig boring and other machine tools, where dowel pin and screw holes can be accurately located and drilled.

The vane bases are machined from solid OFHC copper. Slots are made to receive 0.25-in o.d. copper refrigerator tubing for cooling water. The bases, including water tubes, are located in the cavity with dowels and screws and the whole assembly is then furnace brazed.

Next, a 2.250-in diameter center hole is bored through the cavity on a horizontal mill (Fig. 6). This bore becomes a datum surface for subsequent machining operations. Dowel holes and screw holes for the vane tips are jig bored with their locations measured relative to the squared ends.

Next, rf coupling slots are machined into each of the cavity's four chambers at 45° to the axis. Finally, the square ends are rounded and the entire outside of the cavity cleaned up to 6.095-in diameter.

The RFQ is suspended inside another cylindrical rf cavity by means of two copper disks (Fig. 5). Contact fingers connect the inner surface of the outer cavity through the disks to the outer surface of the RFQ, forming a coaxial line terminated at each end by an electrical short circuit. The outer cavity, or manifold tank, is connected to vacuum and cooling water services.

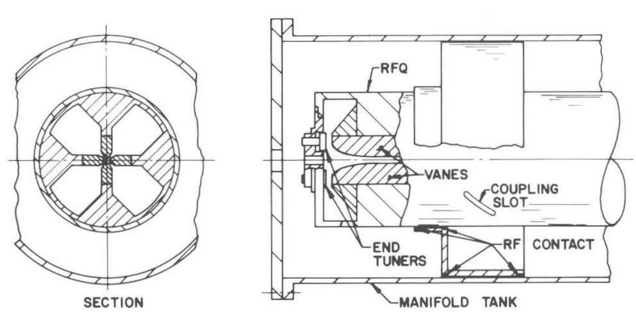

Fig. 5 The RFQ POP test cavity.

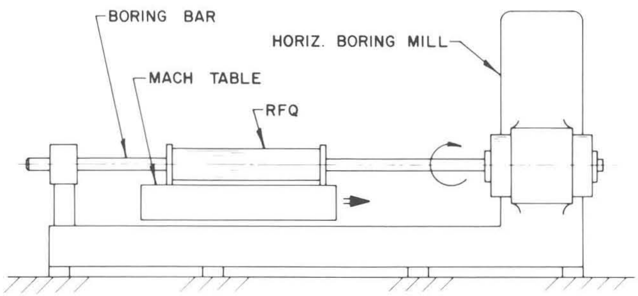

Fig. 6 Center-bore machining.

The rf power is fed through a waveguide to the manifold tank. The magnetic field couples through the angled slots in the RFQ side walls to magnetic fields inside the RFQ. Power is uniformly distributed to all four chambers of the RFQ.[2]

Each end of the cavity is closed by a disk assembly containing four small tuning slugs. The slugs vary the capacitance between the vane ends and the cavity and they are used to adjust the electrical field distribution along the axis of the RFQ.

Vane Tip Numerical Control Machining

With properly shaped vanes, the fields in the RFQ are perturbed to produce a longitudinal component of the electric field. This longitudinal component bunches and accelerates the beam in preparation for its injection into a drift-tube linac. The correct vane shape is necessary to obtain the proper field distribution for accelerating the beam with minimum losses. The shape is described by an equipotential surface in the electrostatic solution for the structure.[3]

Figure 7 illustrates sections from one of four vanes to be made for the POP test cavity. Each diagram represents 10 cells; there are 165 cells in the vane design. The first segment shown (Fig. 7a) is the radial-matching section. In this region, the beam is exposed to gradually increasing radial-focusing forces formed by the decreasing aperture radius. Near the center of the RFQ, the vanes have the appearance of those in Fig. 7b. The modulations are about 15% of their final value. In this region, the beam is bunched and is radially focused with little longitudinal acceleration. Figure 7c shows the vane near the exit of the RFQ. The modulation reaches its maximum amplitude and most of the beam acceleration occurs around this exit region.

Fabrication of the vanes incorporates an EX-CELL-O, three-axis, numerically controlled, vertical mill (Fig. 8). Normally, this machine reads its control data from a punched paper tape that has a capacity of about 800 data blocks. The vanes require approximately 20,000 data blocks for an adequate description. Equipment and software exist for converting the mill control system to use cassette magnetic tapes instead of paper tape. This scheme reduces the volume of the data set to a few cassette tapes and simplifies handling.

A spherical tool is used to cut the vanes. The path that the tool center follows is in the xy plane (Fig. 9) and is constrained to consist only of straight lines and circular arcs. As each cross section is cut, the machine table moves an increment Δz along the vane's longitudinal axis. The process is slow (Δz = 0.020 inches), moving 1-2 inches per hour in the z direction.

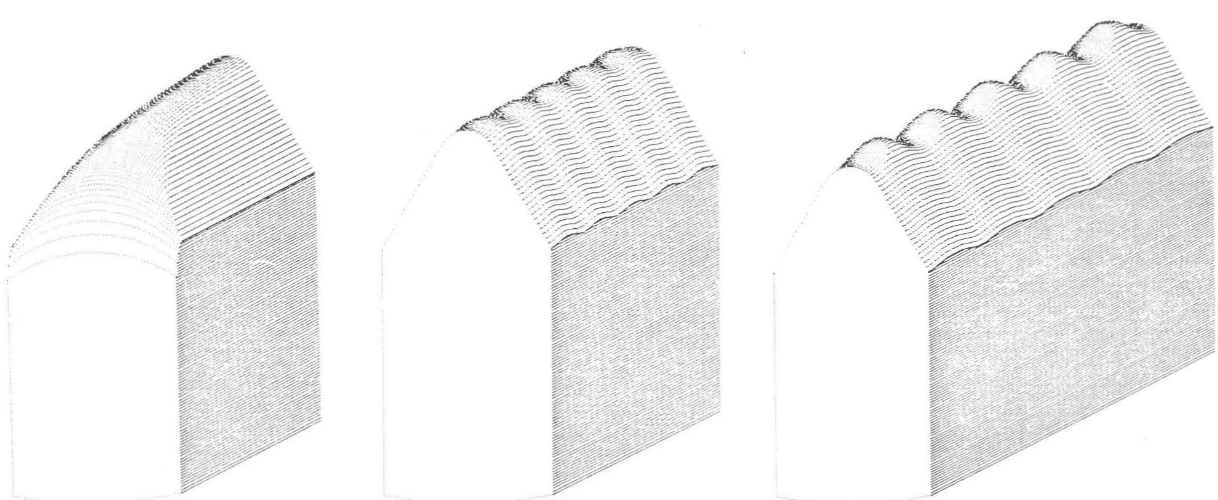

Fig. 7a Cells 1-10. Fig. 7b Cells 101-110. Fig. 7c Cells 151-160.

Fig. 7 Segments of POP vanes.

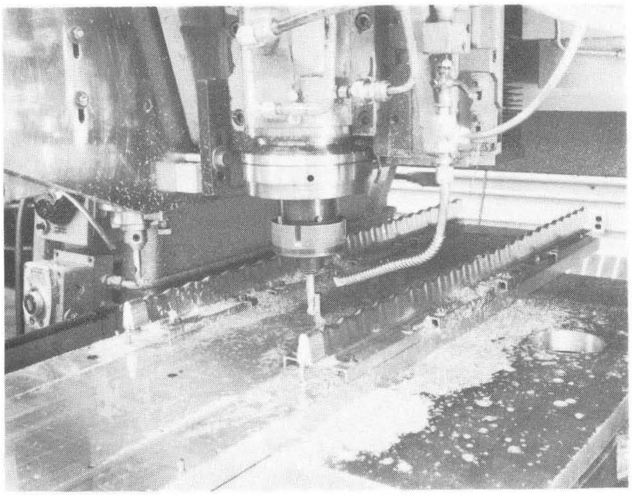

Fig. 8 Vane machining operation.

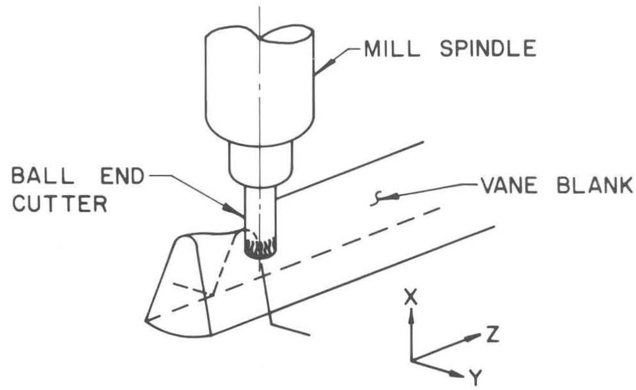

Fig. 9 Cutter path.

If the radius of the tool were zero, the tool path would be identical to the cross section of the vane. However, with a finite tool radius, the cutting path of the tool is not always in the same plane that the tool travels (Fig. 10). The deviation depends on both the cutter radius and the slope of the vane. The program that computes the machine instructions compensates for this error.

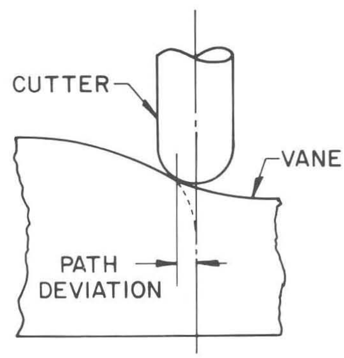

Fig. 10 Cutter-path error.

80-MHz RFQ

The 80-MHz RFQ is still evolving. It has nearly doubled in length from 3.5 m a year ago, to 6 m now, to keep transverse emittance growth small. Several methods of coupling rf power from another cavity into the RFQ have been studied. A very promising scheme uses a concentric outer coaxial tank operating in the TEM mode. Magnetic fields in the coaxial tank cross-couple to fields in the RFQ through angled slots, as in the POP test cavity.

At least one mechanical technique which was developed in the high-frequency RFQ work will be useful in building an 80-MHz system; that is, the precision machining of the vane electrodes. It is expected that tolerances in the critical aperture of the RFQ will scale with the frequency; i.e., larger structures should accommodate more generous machining tolerances. Computer studies are planned to determine the effect of machining tolerances on beam dynamics.

Acknowledgments

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References

1. J. M. Potter, S. W. Williams, F. J. Humphry and G. W. Rodenz, "Radio-Frequency Quadrupole Accelerating Structure Research at Los Alamos," IEEE Trans. Nucl. Sci. NS-26, No. 3, 3745 (June 1979).
2. J. M. Potter, "An RF Power Manifold for the RFQ Linear Accelerator," proceedings this conference.
3. R. H. Stokes, K. R. Crandall, J. E. Stovall, and D. A. Swenson, "RF Quadrupole Beam Dynamics," IEEE Trans. Nucl. Science NS-26, No. 3, 3469 (June 1979).

Discussion

Mittag, Karlsruhe: Do you expect any problems with the brazed rf joints?

Fuller: Probably not with this proof of principle test. I think the currents may not be so high that we would have trouble.

Meads, Brubeck: What is the ratio of your machining tolerance to the aperture of the P.O.P. structure?

Fuller: The milling machine has, of course, finite accuracy, around ± .0002. Other sources of machining errors are holding fixtures and the behavior of the vane material under tool pressure. I expect that we'll be able to hold to within 2 or 3 thousandths (± .002 or .003) of the desired dimensions in the aperture region. The aperture diameter at the smallest point is about 100 thousandths (.100) so that's about 3%.