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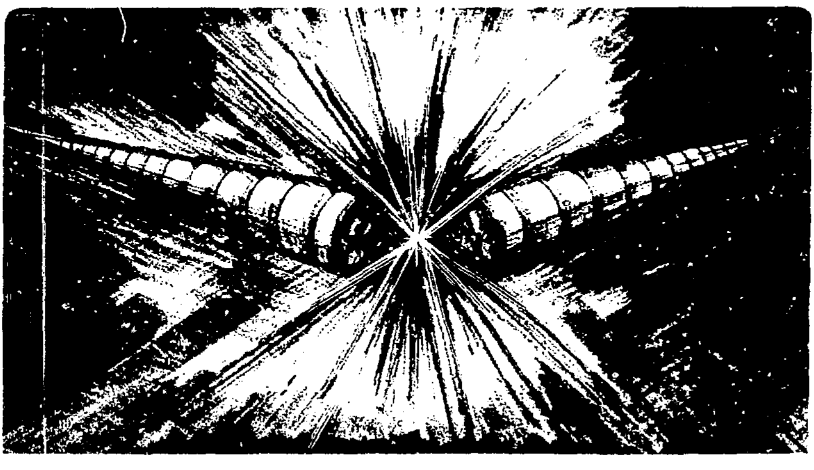

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MECHANICAL DESIGN OF A HEAVY-ION RFQ*

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Summary

The mechanical design and construction of a 199.3-MHz heavy-ion RFQ for charge states q/A as low as 0.14 is described. The vane supports and positioning adjustments are signifcant features of this design. They provide the capability of achieving the precision vane alignment required. The maximum difference between calculated and measured apertures between the vanes is 0.0035 inches, and the average difference is 0.0010 inches. Various important aspects of the design and construction including material selection and plating, RF joints, thermal loading and vacuum system are described. Assembly techniques, methods of mechanical measurement, alignment and structure stability are discussed in detail.

Introduction

The radio frequency quadrupole (RFQ) linac structure represents a significant advancement in accelerator design applicable to low beta linac structures[1]. At LBL, RFQ linacs are planned for incorporation into two projects[2]. The recently constructed RFQ, discussed below, will be a significant component in the improvement of the local injector at the Bevatron, while another RFQ is planned as part of a future heavy ion accelerator to be dedicated for medical use. The RFQ design requirements for both projects are essentially identical. Optimization for heavy ion applications of interest at LBL has led to the requirements for a high degree of dimensional accuracy in the positioning of the vane tips. The RFQ has now been assembled and tuned at low RF power and holds promise for reliability and simplicity of operation. Early tests indicate that the structures' stability, dimensional accuracy and adjustability meet the requirements which are critical for successful beam acceleration and transmission.

Mechanical Design

Table 1 shows the required design parameters. Figure 1 shows a typical cross section of the RFQ. Each vane is mounted to the cavity using six cylindrical plugs equally spaced along the length of the cavity. These plugs fit into bored holes in the base of the vanes and are aligned against precision ground flats on the outside of the cavity. This design provides for axial, radial and transverse degrees of freedom for precise vane alignment. Fiducial notches are located on each side of the vanes to facilitate accurate positioning of the vane tips. A numerically controlled mill with a 96 inch (2.44 m) bed was used to machine these fiducials during the same set up used to produce the modulated surface on the vane tips[3]. Bars are mounted at the base of each vane for coarse frequency tuning. Provision has been made to install as many as five sets of vane coupling rings along the length of the RFQ. These aid in field stabilization of the structure[4]. One RF drive loop and one frequency tuner loop are located in opposing quadrants at the longitudinal center of the cavity. The frequency tuner penetrates the vacuum using a Ferrofluidic seal and is driven with a d.c. gear motor. Ports for RF monitoring loops are located at six places along each quadrant. These are fixed position loops attached to coaxial, type N connectors modified for vacuum penetration.

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Table 1
RFQ Design Parameters

Structure	4 vane loop driven
Design ion	$^{28}Si^{+4}$
Frequency	199.3 MHz
Vane length	224.86 cm
Avg. bore radius	0.254 cm
Cavity radius	15.583 cm
Input energy	8.4 keV/amu
Output energy	200 keV/amu
Total No. of cells	346
Radial matcher	5.4 cm (20 cells)
Exit matcher	54 cm (45 cells)
Normalized acceptance	0.05 pi cm-mrad
Transmission	90%
RF power	100 Kw peak
Stored energy	0.6J
Duty factor	0.002
Vane-vane voltage	51 kV
Max. surface field	27 MV/m

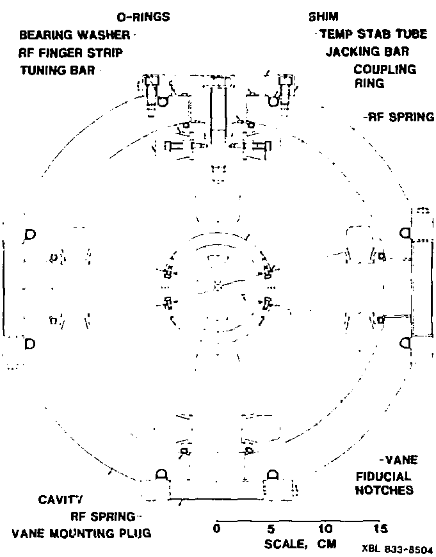


Figure 1: Typical cross section of RFQ

Material Selection and Plating

Fully annealed mild steel (A-1069 and A-36 steel) was the material of choice for the cavity and vanes. Annealing at 870°C after rough machining, and the proper finish machining procedure allowed the vanes and the flats on the outside of the cavity to be maintained straight within 0.005 inches over their full length. The cavity end plates, frequency tuning bars (mounted to the base of the vanes) and the vane coupling rings were manufactured from copper.

All vane and cavity surfaces were plated with bright acid copper 0.001 to 0.003 inches thick except for the modulations and fiducial notches at the vane tips which were cyanide copper plated 0.0002 to 0.0005 inches thick. Thin plating at the tips simplified the procedures required to maintain the dimensional accuracy of the modulations and fiducial notches. Sparking tests[5] showed the "as machined" vane surface on the tips was satisfactory for holding the design voltage of 51 kV between vanes.

RF Joints

Canted coil springs and finger contact strip are the two types of RF joints used throughout the RFQ. The canted coil springs are used for the vane to cavity and vane coupling ring RF joints. These round wire springs are formed into a slightly elliptical cross section. When viewed from the side they are canted over at approximately 52° from the horizontal when unloaded. The springs for the vane to cavity joints are compressed from a height of 0.220 to 0.180 inches without exceeding the yield strength of the spring. The springs make excellent RF contact due to their high point loading as they slightly upset the copper surfaces where they make contact. Springs used for the vane to cavity joints were wound from beryllium copper wire and precipitation hardened to maintain good spring properties under constant loading. Springs used for the RF joints between the vane coupling rings and the vanes were made from strain hardened 302 stainless steel. All springs were silver plated 0.002 to 0.003 inches thick. The canted coil springs were commercially available. The stainless steel springs were standard items while the beryllium copper springs were specially wound to LBL specifications. Commercially available finger contact strip was used for the RF joints on the frequency tuning bars at the base of each vane. The strips were soft soldered to the tuning bars in a position in which they are protected from damage during installation or removal of the bars.

Thermal Loading

Thermal loading of the cavity and vanes is low due to the duty factor of 0.002. The calculated change of the average bore radius between vane tips and the change of the cavity radius from thermal loading is 2.78×10^{-5} inches/°C and 6.95×10^{-5} inches/°C respectively. To insure that the structure would remain dimensionally stable with changes in the ambient temperature thermal stabilization tubes were added along the outside of the cavity. Slots were machined along the full lengh of the cavity into which copper tubes were placed as shown in Figure 1. A mixture of indium, gallium and tin was brushed on the tubes and into the slots prior to assembly to insure good thermal contact between the tubes and cavity. The vane jacking bars which are keyed into the slots also serve to compress the tubes against the cavity. A controlled flow of warm water through the tubes maintains temperature stability of the structure at approximately 35°C.

Assembly and Alignment

The RFQ was assembled on a test stand which had roller supports permitting the cavity to be easily rotated 360° about its longitudinal axis. This feature proved to be very helpful during assembly. The assembly procedure was as follows. A thin polyethylene sheet was placed in the cavity, and a vane was slid into the cavity on the sheet. The vane was then lifted and the sheet removed. The vane mounting plugs and Garlock DU (low friction bearing material) washers were then installed, and the cavity and vane bolted together through the plugs. The Garlock DU material is used between the vane mounting plugs and cavity to allow for transverse adjustment of the vane with the mounting bolts fully loaded. Vane jacking bars keyed to the outside of the cavity are mounted on each side of the vane plugs. Jacking screws threaded through these bars are used to push the vane mounting plugs for transverse vane positioning. The vane was transversely centered about the longitudinal axis of the cavity by measuring from the precision ground flats on the outside of the cavity to the fiducial notches on each side of the vane tip as shown in figure 2.

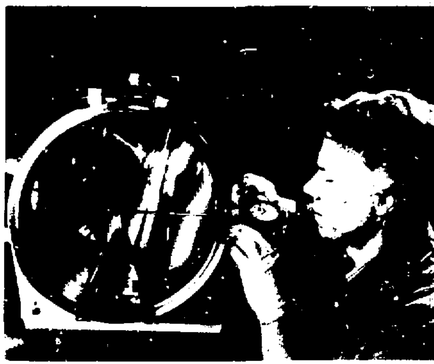


Figure 2: Measuring transverse position of vane

This measurement determined the thickness of the shims which were placed on one side of each vane mounting plug between the plug and jacking bar. Measurements were then taken from the ground flat on the cavity opposite the vane tip to the peaks of modulations on the vane tips at six places along the length of the vane as shown in figure 3. The mounting plugs were then removed, and the height of each plug was machined to its final dimension so that when re-installed the vane mounting plugs located the vane tip at its proper radial location. This procedure was repeated for each of the vanes. All four vanes were then installed along with the RF springs. A 60 inch long Diatest bore measuring instrument with a special modified probe tip was used to measure the aperture between opposing vane tips as shown in figure 4. Measurements were taken at six places equally spaced along the length and are shown in table 2. A 10 inch long Diatest bore instrument was used to measure the vane spacing between adjacent vanes which were within 0.002 inches of the average adjacent gaps at each location. Repeatability of measurements after removal and reinstallation of a vane or vanes was within 0.0005 inches.

Figure 3: Measuring radial position of vane

Figure 4: Measuring aperture between vane tips

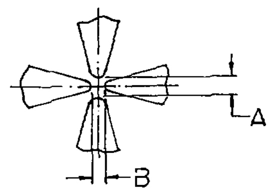
Vacuum System

A pressure requirement of 10^{-5} Torr in the beam aperture has been calculated using experimentally measured[6] charge exchange cross sections. Each quadrant of the RFQ is pumped through radial ports located in the cavity 150 cm from the entrance end using Cryo-Torr 7 cryogenic pumps. Aluminum wire is used for making the vacuum seals on the end covers and pump ports so as to minimize outgassing. Viton O-rings are used everywhere else except on the RF drive loop where Teflon seals are used. Vacuum measurements have not yet been made.

Table 2

Difference Between Measured and Calculated Vane Tip Spacing Taken at Six Locations Equally Spaced Along RFQ Length

	1	2	3	4	5	6
ΔA	-0.0007	-0.0035	-0.0025	-0.0015	-0.0015	+0.0008
ΔB	+0.0009	-0.0002	-0.0003	-0.0012	-0.0010	-0.0011



Where ΔA, and ΔB are equal to the measured values minus the calculated values (in inches) of A and B.

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