New Vanes for RFQ1: Fabrication, Installation, and Tuning†

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Abstract

The Chalk River RFQ1 accelerator was built with replaceable vanes, and the design of a new set of vanes was described at the 1990 Linear Accelerator Conference [1]. The vanes have now been fabricated. They are identified as RFQ1-1250, while the original vanes are identified as RFQ1-600. The RFQ1-600 vanes were designed with a peak surface electric field of 1.5 times Kilpatrick, which is now viewed as being too conservative. The new design uses a peak field of 1.8 Kilpatrick and a modified tip profile to increase the output energy from 0.6 MeV to 1.25 MeV. Computer simulations have been done using PARMTEQ and RFQCOEF to assess the effects of higher order harmonics of the potential on beam losses. The vanes have been machined out of GlidCop® AL-15 [2] (an alumina dispersion-strengthened copper) with the cooling channels gun drilled. Details of the fabrication, including details of the tip profile cutting, installation and tuning are described.

I. Introduction

The new vanes for RFQ1 had to be designed within constraints imposed by the existing structure. The principal changes are in the vane tip shape and modulation, but there are some changes in the vane body related to the structural material and machining techniques. The basic parameters are given in Table 1.

TABLE 1
RFQ1 Basic Parameters

Frequency	267.0 MHz
Input Energy	50 keV
Vane Length	146.88 cm
Beam Current	75 mA
Beam Emittance (rms, norm)	0.05 π cm mrad
RF Power	200 kW max
Peak Surface Electric Field	1.8 * Kp

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II. Mechanical Design

The differences in cross-section shape between the RFQ1-1250 vanes, as shown in Fig. 1, and the RFQ1-600 vanes occur at the tip and at the widening near the base (hip). The hip profile adjusts the resonant frequency to compensate for the smaller beam aperture.

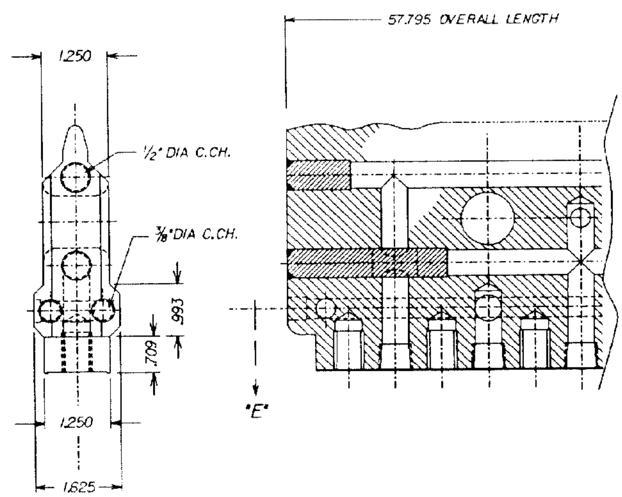

Figure 1 New vane design.

The vanes are machined from single blocks of GlidCop AL-15. The cooling channels are gun-drilled and the ends are closed with welded OFHC copper plugs [3].

III. Vane Tip Profile

The design procedure was as described in reference 1, except for minor changes in the final cell. The vane length is constrained to be exactly the length of the old vane. The preliminary design did not have an exact number of cells within this length and the final cell was simply truncated. It was decided to use the same final cell shape as used in the RFQ1-600 vane and this involved adjusting parameters to make the vane contain an exact number of cells. Design parameters are given in Table 2.

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TABLE 2
RFQ1-1250 Design Parameters

Output Energy	1.274 MeV
Number of Cells	120
Vane Voltage	77.4 kV
Peak Field	1.75 * Kp
Transmission	87%

IV. VANE FABRICATION

RFQ1-1250 vanes were made by Westinghouse Canada Inc. on the same n/c milling machine that had been used for the RFQ1-600 vanes. Thus previous experience in coding for the milling machine was directly applicable to the new vanes.

A. Cooling Channels

Four cooling channels were gun-drilled through the full length of the vane: two 12.7 mm (½ inch) diameter holes and two 9.53 mm (⅜ inch) diameter ones. These channels have a combined water flow of 140 L/m at a velocity of 6.0 m/s.

The holes were drilled approximately halfway through from each end with a 20 mm overlap at the centre. Offset of the two holes was checked by pushing a 2 inch (50.8 mm) long standard cylindrical plug through the channel, and with an ultrasonic flaw detector. Typically, a 0.495 inch (12.57 mm) diameter plug could be pushed through the 12.7 mm holes, and a 0.364 inch (9.25 mm) one through the 9.53 mm holes.

The fact that a plug can be pushed through does not guarantee that both holes have not run out to the same side, so the wall thickness was measured ultrasonically. A special sensor was developed at Westinghouse Canada for this inspection, and calibration was done on shim stock made from GlidCop AL-15. Measurements for the worst case showed that the 12.7 mm holes meet with a 0.5 mm error and have a 0.7 mm run-out, leaving a minimum distance to the surface of 2.56 mm. The 9.53 mm holes meet with a 1.25 mm error and have a run-out of 1.6 mm, leaving a minimum distance to the surface of 1.57 mm.

The location accuracies of the cooling channels are acceptable; however, the above ultrasonic inspection results show that not enough material is left between the 9.53 mm diameter channel and the widening hip surface to allow metal to be shaved off vertically for a tuning adjustment. This will have to be done on the 45° surface above or below the channel.

The cooling channels connect to feeder channels drilled from the base of the vane and the ends of the holes are closed with welded AL-15 plugs. Experience has shown that this type of water-to-vacuum seal has high reliability.

B. Vane Coupling Rings

A pair of vane coupling rings is used similar to those of RFQ1-600. Spigots with stainless steel inserts have been used to reduce thermal conduction to the vane body, while retaining mechanical strength. This allows the rings to be soldered in-situ using a propane torch.

TIG welding of the original design of the spigot to a vane test piece failed, but a new design, as shown in Fig. 2, yielded a good joint and facilitated the job of dressing up the weld bead. Local distortion at the end of the vane after welding the spigots is in the order of 0.013 mm. This confirms that the welding operation on the vane can be done after finish machining of the vane, which would simplify fabrication.

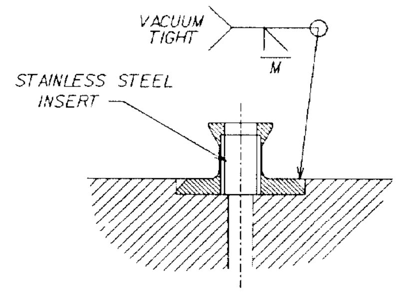

Figure 2 Welded joint between VCR spigot and vane body.

C. Mounting

The vane is mounted in the same manner as the RFQ1-600 vanes, using a copper "racetrack" gasket as a combined vacuum and rf seal. Tests indicate that AL-15 is hard enough to bite into the copper gasket and make a good seal. The holes for the mounting and adjustment bolts have HELI-COIL® inserts in them and tests have confirmed that these are suitable for the high torque used in clamping the "racetrack" gasket.

D. Tip Profile

The tip was machined with a spherical tipped end mill with a 0.5 inch (12.7 mm) radius. The cutter followed a transverse path, as indicated in Fig. 3, with longitudinal steps for the final cut of 0.5 mm. The cutter axis of rotation was inclined at 45° to avoid scuffing at the tip of the vane. The cutter radius was chosen to be the largest standard size which would not exceed the radius of curvature at the saddle point between modulation peaks. The 45° inclination of the cutter axis allows the rounding of the input end of the vane to be done, but limits the rounding at the output end to 45°. Since the rounding at the output end is arbitrary and needed only to prevent sparking, it is planned to break the sharp edge with a hand tool. The longitudinal profile has no portion where the tangent exceeds 45°, so no problems arise.

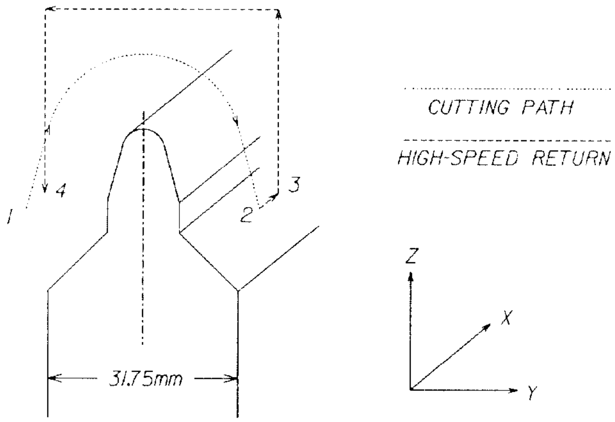

Figure 3 Path of milling machine cutter.

Eight specially made tungsten carbide tool bits had their diameters measured to the nearest 0.0025 mm. They were all within 0.025 mm and the four best were selected for the finish cuts. Machining was done using sulphur-free Sunicut 150 cutting oil at room temperature.

Milling of the vanes was completed in late April and RFQ1 has been dismantled in preparation for their installation.

V. Tip Profile Measurements

Vane tip profiles were inspected on a DEA coordinate measuring machine using a Renishaw sensor unit. The height of the vane tip at its centre-line was measured in 1 mm steps for three 50 mm long regions (at each end and at the centre) and in 5 mm steps for the remainder. The measurements were made using a 0.980 mm radius ruby sphere. The analysis program corrects for the sensor size and plots the difference between the design and measured values, as shown in Fig. 4.

Transverse profiles were measured at 5 positions corresponding to a peak or valley (where no longitudinal correction for sensor size was required). The cross section is a circular arc to within ± 0.02 mm, and agrees with the design value within the same tolerance. This confirms that the tool bit was not worn appreciably during the machining.

VI. Installation and Tuning

At the time of writing this paper, installation of the new vanes is about to begin. The procedure will be the same as used for RFQ1-600 [4,5], with the option of machining the vane hip if necessary for coarse tuning.

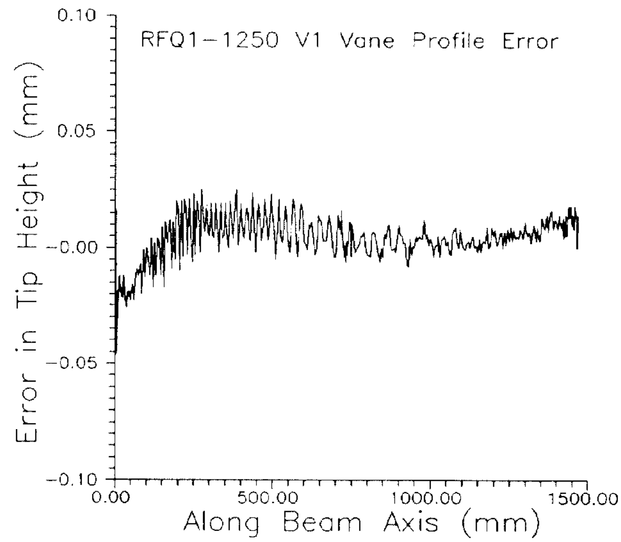

Figure 4 Vane 1 Profilometer measurements.

VII. Summary

The new vanes are within design tolerances. The AL-15 alloy appears to be a suitable material for this application as it has a conductivity near that of OFHC copper, but a much higher yield strength and good machining characteristics. Abrasion of the tool bits by the dispersed alumina is not a problem.

VIII. References

[1] B.G. Chidley et al., "New Vanes for RFQ1", 1990 Linear Accelerator Conference, LANL Report LA-12004-C, 42 (1990).

[2] GlidCop Products Information Bulletin, SCM Metal Products Inc., 1988.

[3] T. Tran-Ngoc and E. C. Douglas, "Mechanical Design of New Vanes for RFQ1",1991 Unpublished report, RC-548, available from Scientific Document Distribution Office, Chalk River Laboratories, Chalk River, Ontario K0J 1J0.

[4] G.E. McMichael et al., "RFQ1 Fabrication and Low Power Tuning", 1987 IEEE Particle Accelerator Conference, Catalog No. 87CH2387-9, 1875 (1987).

[5] R.M. Hutcheon et al., "The RF Design of a 270 MHz, CW Four Vane RFQ", 1985 Particle Accelerator Conference, IEEE Trans. Nucl. Sci., NS-32 (5), 2769 (1985).