RFQ1 FABRICATION AND LOW POWER RF TUNING*

G.E. McMichael, B.G. Chidley, R.M. Hutcheon and T. Tran Ngoc
Atomic Energy of Canada Limited, Research Company
Chalk River Nuclear Laboratories, Chalk River, Ontario, Canada K0J 1J0

Abstract

RFQ1, a 600 keV, 75 mA proton RFQ is the major component of a research program at the Chalk River Nuclear Laboratories (CRNL) to study high current 100% duty factor accelerator systems and develop improved accelerator technology. Features of the 270 MHz RFQ include removable vanes, vane coupling rings, and loop coupling to the rf drive line with the option of two drive loops. The main RFQ tank and vane bodies are fabricated from carbon steel which will be copper plated following machining of the OFHC copper vane tips and initial low power rf tuning. Details of the mechanical fabrication and low power tuning will be presented and rf characteristics compared with computer code predictions.

Introduction

The mechanical design concepts adopted for RFQ1 and results of preliminary tests of the flexible vane-to-tank seal were given in a previous paper[1]. Details of the rf design, computer calculations and results of cold-model tests have also been presented[2]. Fabrication of the RFQ has been completed, and low power rf tuning checks are underway to verify that the necessary resonant frequency, field flatness and stability can be achieved.

Mechanical Fabrication for RFQ Tank and Vanes

The RFQ is a 1.5 m long welded carbon steel structure, with four OFHC copper tipped carbon steel vanes that mount through longitudinal slots that extend for almost the whole length of the structure. Upon completion of the low power tuning checks, the tank and vanes will be shipped to GSI, Darmstadt, for plating (≈ 100 microns of copper) on all steel surfaces exposed to the rf fields and then returned to Chalk River for final tuning, installation and commissioning.

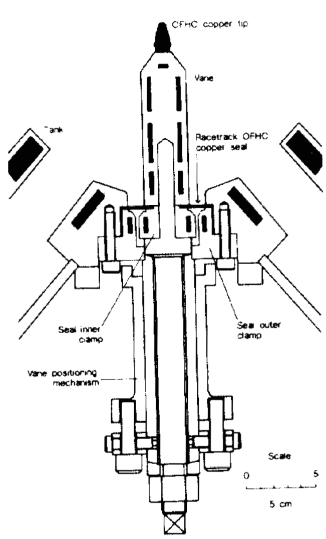

Fig. 1 Section view of RFQ showing cooling channels and details of vane supports and the vane-to-tank seal.

Figure 1 is a section drawing of a vane and segment of the tank at one of the three vane support locations. The vane-to-tank joint is made by clamping a 1.5 mm thick, OFHC copper "racetrack" gasket between knife-edge type flanges on the tank and vane base. The supports are used to align the vanes or to displace the vane tips by up to ± 0.5 mm both radially and laterally (the lateral movement is obtained by rotating the vane about an axis through the seal plane). A full scale test of the gasket and vane mount using the test jig shown in Fig. 2 demonstrated that the desired vane movements could be obtained while maintaining the vacuum integrity of the seal.

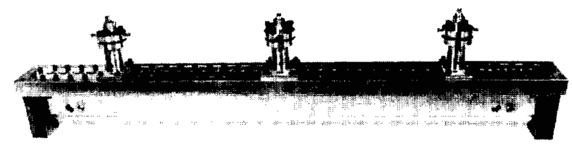

Fig. 2 Full scale vane seal and vane mount test assembly.

The RFQ is designed for an intervane voltage of 78 kV (peak surface electric field of 24.8 MV/m or 1.5 Kilpatrick[3]), but the cooling has been designed for surface heat fluxes up to 11 W/cm (corresponding to an rf power dissipation in the tank of ≈ 150 kW/m and fields of 33.1 MV/m or 2 Kp). Water cooling channels were milled in the vanes and tank body, and cover plates welded over these channels as shown for the vanes in Fig. 3. Although the vanes shrunk in length almost 5 mm and warped badly in both planes during this welding process, two cycles of straightening to < 0.5 mm in a hydraulic press and stress relieving at 625°C were sufficient to prevent appreciable distortion during subsequent machining operations. The OFHC copper tips (section dimensions ≈ 15 mm wide by 25 mm deep) were attached to the vane bodies using Cusil braze alloy and a furnace temperature of 793°C. Warping of the vanes due to differential contraction of the steel and copper was ≈ 0.2 mm and posed no problems. There was very little distortion of the tank during welding, but a number of the welds cracked on cooling, requiring extensive hand grinding and rewelding before all channels were vacuum leak tight.

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Machining of the tank and vanes was done by Canadian Westinghouse Limited (Renfrew, Ontario). The vane tips were machined on an NC Line Vegamill Model B112/NU using a 25.4 mm diameter (1 inch) ball end mill and machining instructions generated on the CRNL computers. The tip profile[4] is corrected for higher order field harmonics, and has a peak field almost independent of modulation. Centre-line profilometer measurements for a typical vane are given in Fig. 4, and show that the deviation from the desired profile is < 0.05 mm, well within acceptable tolerances based on rf field calculations.

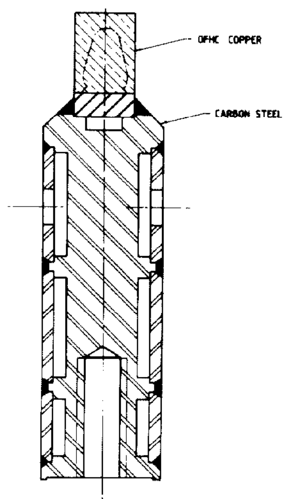

Fig. 3 Section view of vane showing details of the cooling channels.

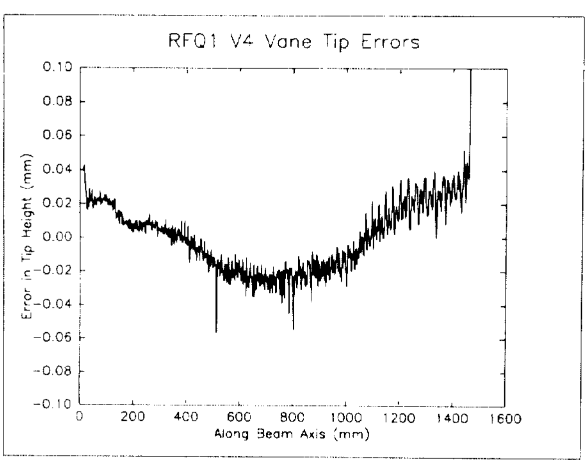

Fig. 4 Profilometer measurements of a typical vane showing deviation from desired profile.

Low Power RF Tuning

The purpose of these tuning checks is to confirm, before copper plating, that the necessary resonant frequency (268 ± 2 MHz) and field flatness (longitudinal tilts < 5%, dipole component < 5%) can be achieved by vane positioning and machining of the copper end and centre-plane tuning plugs. To avoid the problem of sliding rf joints operating at 100% duty cycle (cw), RFQ1 will use only fixed tuners to maintain required fields (although provision is made for the addition later in the program of two movable slug tuners at the midplane for bulk frequency adjustment). To facilitate the low power tuning, end flanges with screw-adjustable tuning rods and movable slug tuners for the centre ports were fabricated from aluminum. Assembly and alignment proved extremely easy, requiring less than two days to install the vanes, VCR's (vane coupling rings) and end flanges and align the vane tips to 0.05 mm. Figures 5, 6 and 7 show the RFQ with the vertical vanes installed.

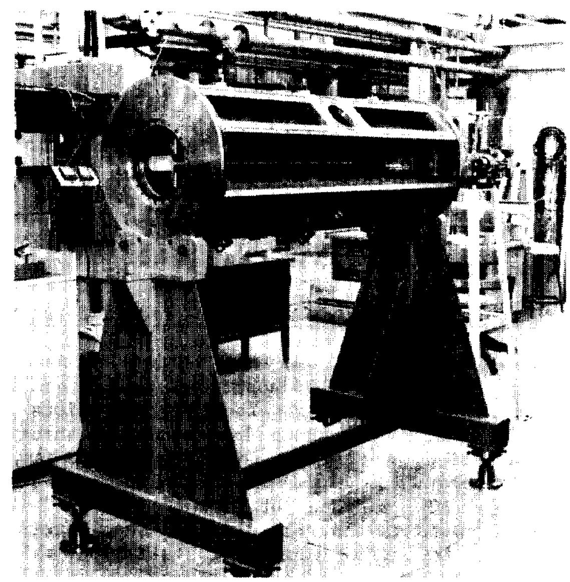

Fig. 5 RFQ1 during assembly for rf tuning tests. OFHC copper tips of the two installed vertical vanes are visible through the slots in the tank wall where the horizontal vanes will be mounted.

SUPERFISH calculations, corrected for the vacuum pumping holes, VCR's, and slot around the vane base for the racetrack seal, predicted a quadrupole mode frequency of 269 MHz. The actual frequencies were 265.3 MHz for the quadrupole mode, with two dipole modes at 277.4 and 280.6 MHz. There were large overlaps of the modes because of the low cavity Q (Q = 50 for the carbon steel cavity, a factor of 10 lower than the Q of the aluminum cold model[2] and a factor of 100 lower than the expected Q for this cavity after copper plating). During fabrication, one vane tip had to be remachined and as a result the 45° shoulders are currently 0.5 mm higher (closer to the tank centreline) than on the other three vanes. The fields in the segments adjacent to this vane were a factor of two higher than in the other two quadrants.

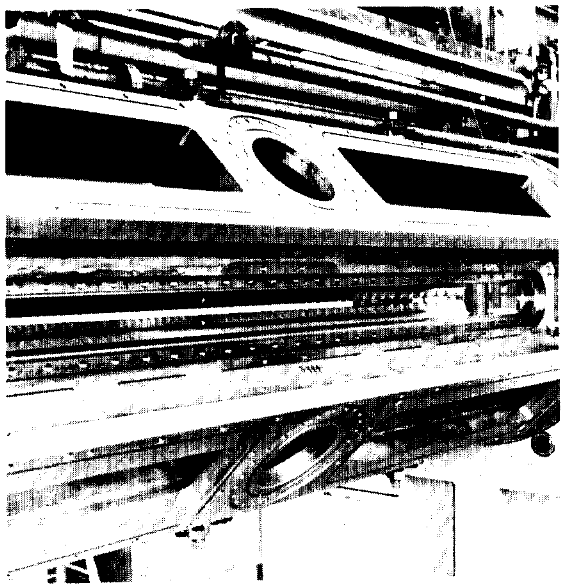

Fig. 6 Side view of the RFQ showing slot for the horizontal vane racetrack seal.

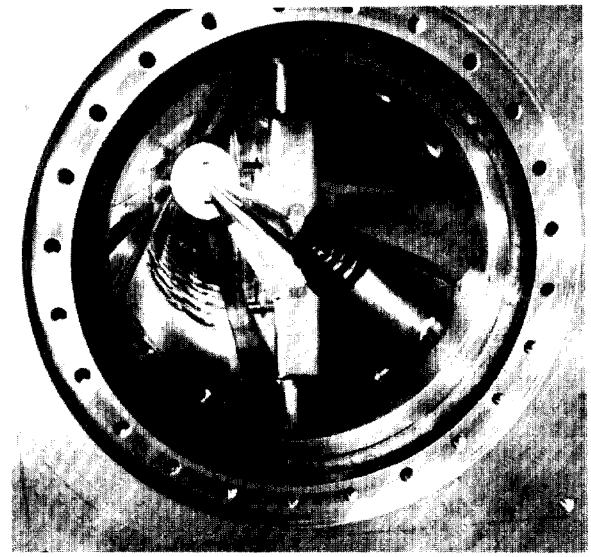

Fig. 7 Inside of the RFQ with vertical vanes installed.

Retracting this vane ≈ 0.25 mm balanced the fields in the 4 segments to within 10%, and increased the tank frequency to 266.5 MHz. By moving the four 10 cm diameter centre-port tuners in tandem, a frequency increase of 1.3 MHz was measured for a tuner insertion of 1.3 cm, in good agreement with the 1.38 MHz shift predicted from the cold model[2].

Attempts to determine the optimum end-tuner configuration to compensate for the VCR's, or even to observe the effect of the VCR's on suppressing the dipole modes, have to date been unsuccessful and it is now expected that observation of these effects will not be possible until the cavity Q has been raised by copper plating. Consequently, this series of experiments will be limited to confirming that the observed initial field imbalance was due to the raised shoulders on the one vane, and to determining if minor modifications to the other vane shoulders can raise the quadrupole mode frequency to between 267 and 269 MHz (the optimum for the rf source).

Conclusions

Trial assembly and mechanical alignment of RFQ1 confirmed that the concept of building an RFQ with vanes that mount through slots in the cavity wall is sound and results in a device that is very easy to assemble and adjust. Although the tank is resonant at a frequency about 3 MHz lower than expected, preliminary measurements indicate that the desired frequency can be obtained by a minor modification to the vane shoulders and a small increase in the bore radius, neither of which is expected to significantly affect the beam dynamics. Because of the low Q, severe mode overlap tends to mask the effect of such things as vane coupling rings and segment end-tuners and it appears that only gross rf properties can be measured before a carbon steel RFQ is copper plated.

Acknowledgments

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References

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