NEW VANES FOR RFQ1

B.G. Chidley, F.P. Adams, G.E. McMichael, T. Tran Ngoc
AECL Research, Chalk River Laboratories
Chalk River, Ontario, Canada, K0J 1J0
T.S. Bhatia
Los Alamos National Laboratory,
Los Alamos, NM 87545 USA

Abstract

The RFQ1 accelerator was built with replaceable vanes; the option has always existed to replace the existing vanes with new ones having a revised geometry or construction. The original 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 will use a peak field of 1.8 Kilpatrick and a modified tip profile to increase the output energy from 0.6 MeV to 1.3 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 vane will be machined out of GlidCop AL-15[1] (an alumina dispersion-strengthened copper) with the cooling channels gun drilled. Heating calculations have been done using MARC and MENTAT with rf currents calculated by MAFIA and SUPERFISH.

Introduction

The new vanes for RFQ1 must be designed within constraints imposed by the existing hardware. 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 I
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
Peak Surface Electric Field	18 * Kp

The differences in shape between the new vanes, as shown in Fig. 1, and the existing ones are in the tip (which doesn't show in the figure) and in the widening or hip near the base. This hip is to accommodate cooling channels and adjust the resonant frequency to compensate for the smaller aperture.

Vane Tip Cross Section

The vane tip, as shown in Fig. 2, is the only part of the vane of interest to beam dynamics. Specifically, most of the design procedure involves finding the aperture α as a function of z. The dimensions common to the old and new tips are CL = 12.70 cm, A = 0.60 cm, and B = 11.045 cm, where CL is the distance from the vane base to the tank centre line and B is the distance from the vane base to the numerically profiled part of the tip. The dimensions to be determined are ρ and α. The radius of curvature of the tip does not directly affect beam dynamics, but is significant because it

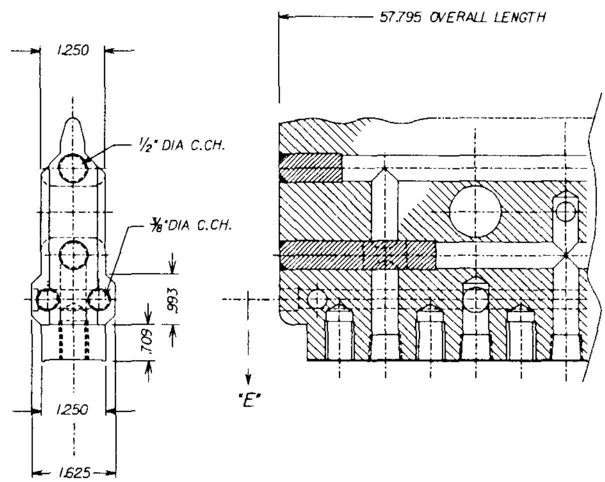

Fig. 1 New vane design.

affects the peak surface field (enhancement factor), the structure resonant frequency, and the harmonic terms of the potential near the beam axis.

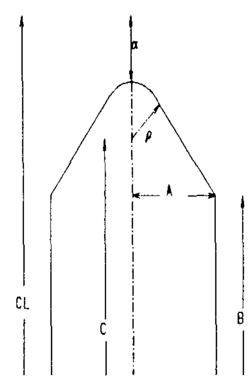

Fig. 2 Vane tip cross section.

Enhancement Factor

The enhancement factor is shown as a function of ρ/r_o in Fig. 3. The peak surface electric field is EFACT * (V/r_o), where V is the intervane voltage and r_o is the mean aperture. For highest current limit and accelerating gradient, one wants (V/r_o) to be as high as possible. However, the peak electric field is limited by sparking, so a minimum EFACT is wanted. If this were the only consideration one would choose ρ/r_o = 0.75. However, modification of the potential harmonics or a desire to maintain constant intervane capacitance may force other choices.

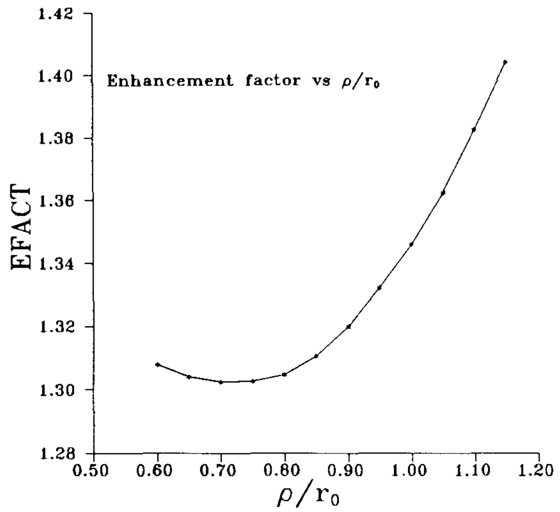

Fig. 3 Typical enhancement factor vs ρ/r_o.

Resonant Frequency Stabilization

One of the design optimizations requires a small variation in r_o with z. This will cause a change in resonant frequency and a field tilt unless compensated by some means. There are several ways to do this, but a convenient means is to vary ρ as indicated in Fig. 4. This shows the variation in ρ/r_o required to maintain the resonant frequency as calculated by MAFIA as r_o is changed.

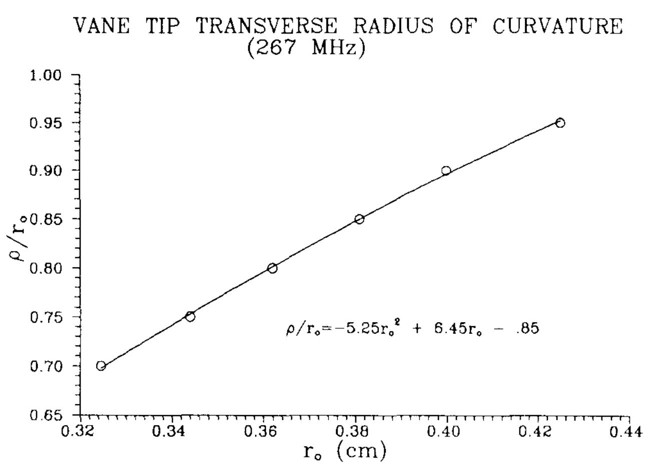

Fig. 4 Variation of ρ/r_o to maintain frequency.

Harmonic Terms of Potential

The potential in an RFQ near the beam axis may be written

$$U(r,\theta,z) = \sum_{s=0}^{\infty} C_{0s}(kr)^{\lambda} \cos(\lambda\theta) + \sum_{m=1}^{\infty} \cos(kmz) \sum_{s=0}^{\infty} C_{ms} I_{\lambda}(kmr) \cos(\lambda\theta)$$

where $k = \pi/L$
$\lambda = 4s$ for odd m
$= 4s+2$ for even m

or in the notation used by PARMTEQ :

$$\begin{aligned} U(r,\theta,z) = {} & A_{01}\ r^2 \cos(2\theta) \\ & + A_{10}\ I_0(kr) \cos(kz) \\ & + A_{03}\ r^6 \cos(6\theta) \\ & + A_{12}\ I_4(kr) \cos(4\theta) \cos(kz) \\ & + A_{21}\ I_2(2kr) \cos(2\theta) \cos(2kz) \\ & + A_{23}\ I_6(2kr) \cos(6\theta) \cos(2kz) \\ & + A_{30}\ I_0(3kr) \cos(3kz) \\ & + A_{32}\ I_4(3kr) \cos(4\theta) \cos(3kz). \end{aligned}$$

The idealized two-term potential is
$A_{10} = (V/2) * (1/r_o)^2$
$A_{01} = (V/2) * A * I_0(2\pi r/\{\beta\lambda\})$
where $A = (m^2-1)/[m^2 I_0(2\pi a/\{\beta\lambda\}) + I_0(2\pi ma/\{\beta\lambda\})]$

The actual A_{10}, A_{01} can be calculated with RFQCOEF and vary with ρ as shown in Figs. 5 and 6. Care must be taken to control the higher order terms, some of which can affect beam spill.

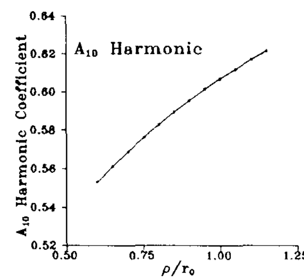

Fig. 5 A_{10} harmonic.

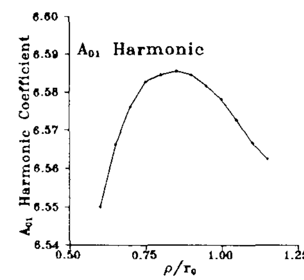

Fig. 6 A_{01} harmonic.

Vane Longitudinal Profile

The design procedure for the longitudinal profile is fairly standard, except that it includes a consideration of harmonics. The computer program CURLI is used first, using a C_x = 150 mA, and $W_g = W_i * (99.5/\phi_g)^2$. ϕ_g is the synchronous phase at the end of the gentle bunching section and is a free parameter chosen to optimize performance. W_g is the energy at this point and is calculated from the injection energy W_i. CURLI selects parameters that give a specified C_x, the longitudinal and transverse current limit. RFQUIK is then used to generate a two-term potential design with an adjustment in the accelerating section, as suggested by Wangler.[2] POTRFQ is used to calculate the harmonic coefficients, and PARMTEQ used to calculate the transmission. The choice of ρ is an iterative process requiring compromises. The final design is given in Table II.

TABLE II
Final Design Parameters

Output Energy	1.237 MeV
Output Current	75 mA
Number of Cells	120
Vane Voltage	77.4 kV
Peak Field	1.75 * Kp
Transmission	87%

TABLE III
RFQ Parameters

CELL	a	m	Lcell	r_o	ρ	Emax	EFACT
10	0.3429	1.0243	0.581	0.3470	0.2638	27.831	1.2474
20	0.3334	1.0825	0.586	0.3467	0.2633	28.361	1.2710
30	0.3252	1.1362	0.605	0.3464	0.2626	28.719	1.2871
40	0.3180	1.1858	0.650	0.3461	0.2622	28.883	1.2945
50	0.3127	1.2224	0.728	0.3461	0.2622	28.803	1.2910
60	0.3082	1.2521	0.846	0.3462	0.2624	28.559	1.2801
70	0.2951	1.3471	1.019	0.3463	0.2625	28.284	1.2677
80	0.2478	1.7536	1.342	0.3464	0.2627	27.904	1.2515
90	0.2484	1.7978	1.769	0.3564	0.2801	27.327	1.2591
100	0.2498	1.8653	2.155	0.3697	0.3036	27.123	1.2955
110	0.2530	1.9448	2.516	0.3874	0.3350	26.562	1.3292
115	0.2558	1.9870	2.691	0.3985	0.3549	26.169	1.3471
120	0.2595	2.0303	2.862	0.4114	0.3780	25.739	1.3667

Table III shows a (minimum aperture in the cell), m (modulation), Lcell (cell length), r_o (mean aperture), and ρ (transverse radius of curvature) every 10 cells.

Note the increase in r_o and the corresponding increase in ρ above cell 100, and note that the maximum field occurs at cell 40, so the rise in enhancement factor at cell 120 is not a problem.

The variation of transmission with intervane voltage is shown in Fig. 7 and the variation with input emittance is shown in Fig. 8.

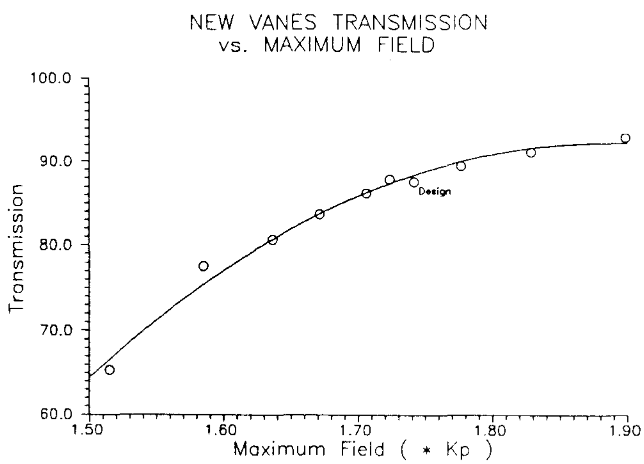

Fig. 7 Transmission vs maximum field.

Vane construction

The vanes will be machined from single pieces of GlidCop Al-15 dispersion-strengthened copper, using gun-bored cooling channels. This material has a strength comparable to mild steel and a conductivity 92% of that of OFHC copper. Tests of this material are described in a companion paper.[3]

Thermal Calculations

Calculations have been done using surface heat fluxes calculated by SUPERFISH to determine thermal distributions, thermal stresses, and deformations. The results indicate an increase in vane height at full power of 0.033 mm and an increase in length along the vane tip

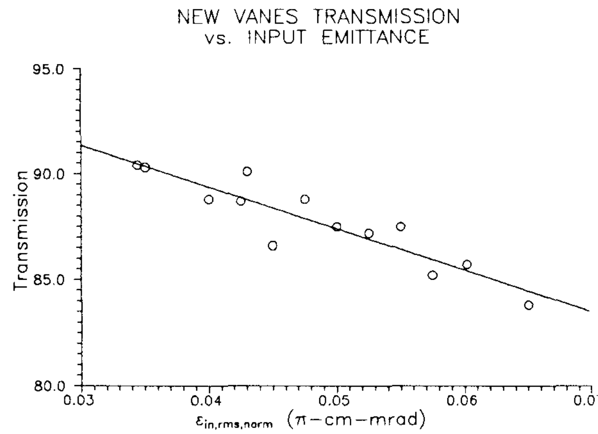

Fig. 8 Transmission vs input emittance.

of 0.142 mm from centre to end. The most severe deformation occurs near the ends of the vane, where the height will increase by 0.076 mm. The results of the calculations are shown in Fig. 9. These deformations are small enough that they will not affect operation of the RFQ.

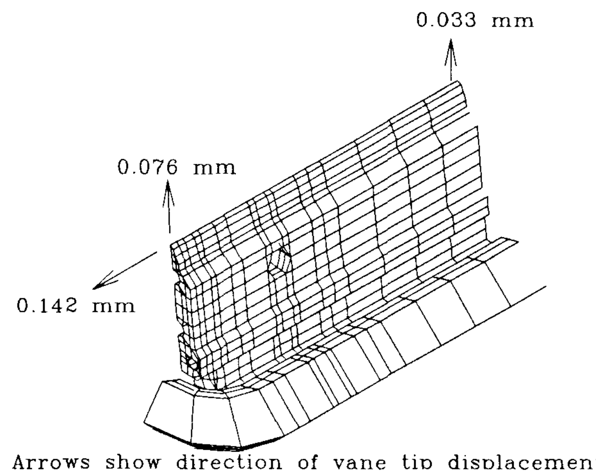

Fig. 9 Distortion of vane due to thermal stress.

References

1. GlidCop Products Information Bulletin, SCM Metal Products Inc., 1988.

2. D. Schrage et al., "A Filght-Qualified RFQ for the BEAR Project", Proc.1988 LINAC conf., Continuous Electron Beam Accelerator Facility report CEBAF-Report-89-001 (1989) 54.

3. T.Tran-Ngoc and R.M. Hutcheon, "Study of High-strength Coppers for RFQ1's New Vanes", these proceedings.