SPACE AND IMAGE CHARGE CALCULATIONS FOR THE CHALK RIVER RFQ1-1250 ACCELERATOR USING THE RFQTRAK BEAM SIMULATION PROGRAM

N. J. Diserens
AECL Research, Chalk River Laboratories
Chalk River, Ontario, Canada KOJ 1JO

Abstract

The RFQTRAK program has been used to study the effects of space and image charges on the beam transmission and output emittance of the Chalk River RFQ1-125 radio-frequency quadrupole accelerator. Comparisons have been made with calculations for the PARMTEQ code and with available experimental measurements. For low input emittance, of around 0.01 π cm mrad (rms normalized), the beam transmission appears be above 80% at the design input of 90 mA. This agrees with predictions produced by PARMTEQ. However, with input emittance of 0.05 π cm mrad, RFQTRAK indicates a transmission of 75%, compared with a forecast of 86% using PARMTEQ.

Introduction

Accurate calculation of space and image charge effects in radio-frequency quadrupole (RFQ) accelerators has proven to be difficult. Over recent years there have been various computer codes written, using either differential or integral methods. For designs where space charge has had only a small contribution to the beam dynamics, these calculations show reasonable agreement. However, when high current devices or off-axis beams have been required to be simulated, there has been wide variation between results.

The RFQTRAK [1] code uses the finite element method to model the cell geometry in an RFQ accelerator. Space and image charge electric field components are calculated using a 3D finite element solution. The radio-frequency (rf) fields are computed from a harmonic expansion using a set of predetermined coefficients, as in the time-stepping version of the PARMTEQ [2,3] code. Particle dynamics calculations are performed after adding the rf and space charge fields.

The Chalk River RFQ1-1250

RFQ1-1250 [4,5] is an RFQ proton accelerator with an input energy of 50 keV, an output energy of 1.25 MeV, and a beam current of 75mA. There are 120 cells.

The original design studies were made using the PARMTEQ package. Plots of beam loss and output emittance were made over a range of input currents and emittances. This paper gives a comparison of RFQTRAK predictions compared with some of the results from those studies.

Recent Software Development

A number of improvements have been made to RFQTRAK since the first version was produced in 1984.

The user now has the option to mesh either one quadrant of the beam cross section or the whole beam aperture (with the mesh in the third dimension extending to the length of either one or two cells). This gives the opportunity to simulate non symmetric beams or geometries. In addition, space charge effects, but not image charges, are now computed in the input matching section.

Field smoothing has been applied so that the space charge fields are no longer discontinuous across the finite element boundaries. Recently, the method of calculation of the matrix right hand side terms from the particle distribution has been updated to give improved accuracy.

An interactive pre- and post- processor package RFQGRAF has been written to assist in the preparation of data and the display of results.

Coefficients for the rf potential representation are obtained with the RFQCOEF [6] package which uses a finite element model with a least squares fit. This program has recently been extended to include dipole and sextupole terms which may be used to represent rfq vane misalignment. Thus a 12 term expansion may be used. The first 8 terms comprise the usual mutipole expansion; terms 9 and 10 are the dipole term and its angle with the x axis; terms 11 and 12 are the corresponding sextupole terms.

In the results which follow, only the 8 term expression is used, as correct alignment has been assumed.

Results

The Chalk River RFQ1-1250 accelerator was simulated using 2000 macroparticles.

The finite element model of the rfq cell pair used in these calculations had 1152 quadratic 'brick' elements and 5488 nodes, with meshing over the full beam aperture. The running time on the Cyber 990 is about 1 minute cpu per (λ/2) cell.

Two input emittances have been used, 0.05 π cm mrad and 0.01 π cm mrad. These represent the two different input beam configurations which have been used in the test rig.

Table 1 shows a comparison between output emittances computed for beams with these two configurations using RFQTRAK and PARMTEQ.

TABLE 1
Output Emittances (normalized, rms, π cm mrad)

Input	Output With 82 mA Input	
	RFQTRAK	PARMTEQ
0.05	$\epsilon_x = 0.066$ $\epsilon_y = 0.047$ $\epsilon_z = 0.0041$	$\epsilon_x = 0.049$ $\epsilon_y = 0.049$ $\epsilon_z = 0.0040$
0.01	$\epsilon_x = 0.028$ $\epsilon_y = 0.030$ $\epsilon_z = 0.0041$	$\epsilon_x = 0.026$ $\epsilon_y = 0.025$ $\epsilon_z = 0.0031$

The beam with the larger emittance, which was used in the first simulation runs, was assumed to be matched and had PARMTEQ ellipse parameters (α, β, ϵ) of 2.32, 6.77 and 0.02906 at the input to the vanes. (ϵ_{rms} = 0.05 π cm mrad.)

The lower emittance beam, used for the later tests, was a near representation of the actual measured input beam which was not a perfect match. Here the PARMTEQ beam input parameters were 13.97, 40.0 and 0.005812, respectively. This is displayed in Fig. 1 and takes the form of a 'stretched' ellipse. (ϵ_{rms} = 0.01 π cm mrad.)

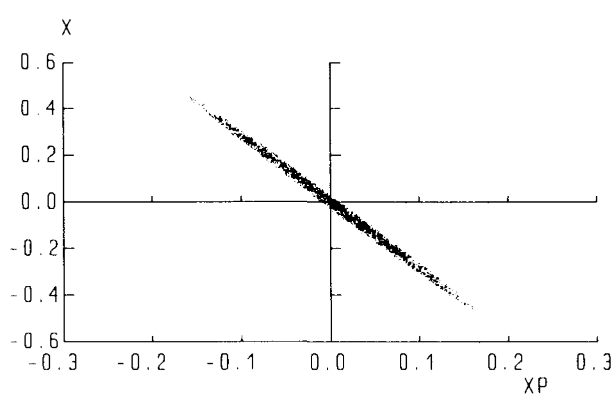

Fig. 1 The 'stretched' emittance input beam.

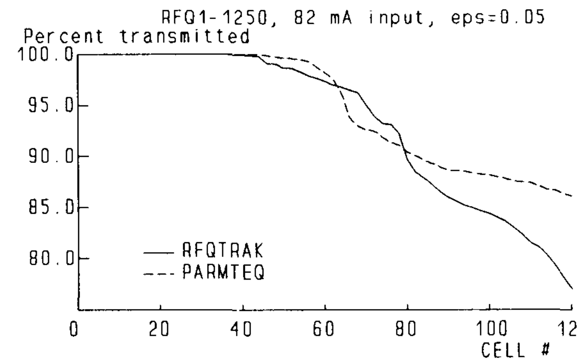

Fig. 2 Beam transmission.
Input ϵ_{rms} = 0.05 π cm mrad

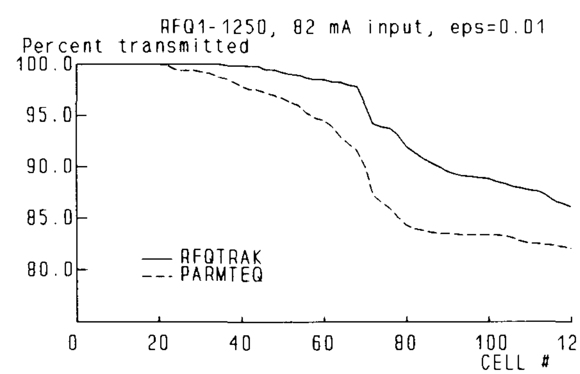

Fig. 3 Beam transmission.
Input ϵ_{rms} = 0.01 π cm mrad
with 'stretched' emittance.

Figs. 2 and 3 show computed beam transmissions for the two input configurations. With the higher input emittance RFQTRAK and PARMTEQ show good agreement for the first 80 cells, and then RFQTRAK indicates increasing beam loss, to 77% transmission, whilst PARMTEQ suggests a final transmission of 86%.

With the lower emittance input, RFQTRAK indicates a lower beam loss throughout the accelerator, with a final figure of 86% transmission, compared to PARMTEQ, which predicts 82%.

In both cases, beam loss starts between cells 30 and 40. A comparison of energy-phase plots at cell 40 for the lower input emittance predicted by the two computer programs is shown in Figs. 4 and 5.

Although the beam profiles and energy spectrum predictions are somewhat similar for the two programs, the phase spectra and energy-phase plots are quite different.

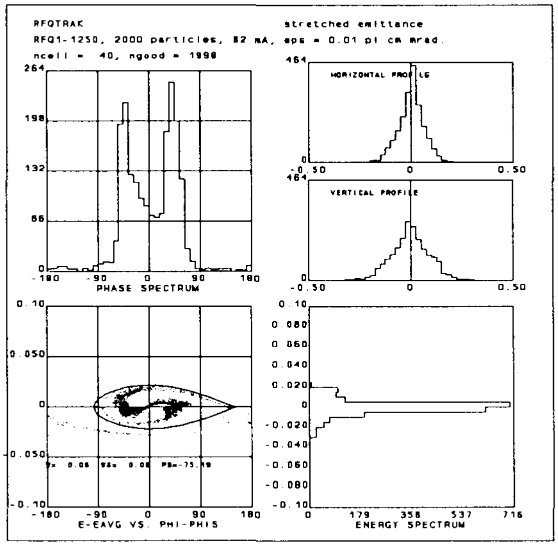

Fig. 4 RFQ1-1250, RFQTRAK cell 40 prediction. Input ϵ_{rms} = 0.01 π cm mrad.

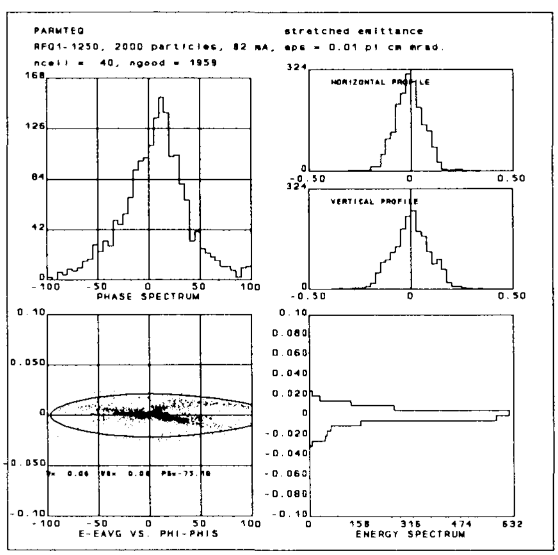

Fig. 5 RFQ1-1250, PARMTEQ cell 40 prediction. Input ϵ_{rms} = 0.01 π cm mrad.

However, both sets of results show that by this stage there are a train of slow particles in the accelerator which are outside the acceptance separatrix and will eventually be lost.

The criteria for regarding a slow particle as 'lost' differs between the two packages. In PARMTEQ a value of the energy limit can be set such that, if the deficit in relation to the synchronous particle energy exceeds this value, the particle is discarded. For these runs the energy limit was set to 120 keV. In RFQTRAK a particle is discarded if it has less than half the energy of the synchronous particle. In practice a particle in the beam makes the same contribution to the space charge, whatever its energy.

No measurements are yet available for output beams of more than 50 mA from the RFQ1-1250 accelerator, but a study of the 32 mA beam output will be made and compared with RFQTRAK and PARMTEQ simulations.

Conclusion

At beam currents of less than 100 mA there appears to be reasonable agreement between PARMTEQ, which is a 2D code, and RFQTRAK, which is 3D. There are, however, differences which vary depending on the input beam emittance.

In order to verify these calculations, further comparisons are required with other computer codes and/or with experimental data.

Acknowledgements

The development of the RFQTRAK software has been supported by Los Alamos National Laboratory, Rutherford Appleton Laboratory and Chalk River Laboratories. The author wishes to acknowledge the help and encouragement of G.E McMichael, B.G. Chidley and other members of Accelerator Physics Branch at Chalk River.

References

[1] N.J. Diserens, "Progress in the Development of a 3D Finite Element Computer Program to Calculate Space and Image Charge Effects in RF Quadrupoles", IEEE Trans. Nucl. Sci., **NS-32**, (5), 2501 (1985).

[2] K.R. Crandall et al., "RF Quadrupole Beam Dynamics Design Studies", Proc. 1979 Linear Accel Conf., Brookhaven National Laboratory, **BNL-51134**, 205 (1979).

[3] G.E. McMichael and B.G. Chidley, "Effects of Higher Order Multipole Fields on High Current RFQ Accelerator Design", Proc EPS Conf on Computing in Accelerator Design and Operation, Berlin, Sept 1983. Lecture Notes in Physics, 215, Springer-Verlag (1984).

[4] G.M. Arbique et al., "High-Current Injection to a CW RFQ using an ECR Proton Source", these proceedings.

[5] G.M. Arbique et al., "Beam Parameter Measurements on the CW RFQ1-1250 accelerator", these proceedings.

[6] N.J.Diserens, "RFQCOEF, a package for extracting the Harmonic Coefficients for the Potential Function in an RF Quadrupole", Proc. 1984 Linear Accel. Conf., Darmstadt, Germany. **GSI-84-11,** 324 (1984)