TILTED FIELD RFQ'S - AN ALTERNATIVE DESIGN APPROACH

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Abstract

A conventional RFQ uses a constant beam aperture and a constant intervane voltage. The mean accelerating gradient can be increased by using a beam aperture varying along the length proportional to ion velocity, and adjusting the intervane voltage to maintain a constant transverse electric field. The 4-vane configuration was studied both theoretically using RFQ3D and by cold model measurements to determine if the required voltage tilts could be achieved within practical mechanical design limitations. Results indicate that a voltage tilt of 2.5 is possible with a 1.5 m long four-vane RFQ having a 14% longitudinal variation in individual quadrant cross-sectional area[1]. The four-rod configuration can also achieve similar voltage tilts with a factor of two longitudinal variation in inductor dimensions.

Introduction

A paper[1] at the 1986 Linear Accelerator Conference described a conceptual design study of a heavy ion accelerator for the TRIUMF ISOL facility. This 23 MHz 4-rod RFQ used lumped inductor geometry and it was noted that a 35-40% length reduction could be realized by using a tapered bore design with a tilted rf field. Field tilt control can be obtained easily in the lumped inductor design by altering inductor sizes. Similar results can be obtained with a more conventional 4-vane RFQ by altering the quadrant areas. This paper examines the benefits of tapered bore design on conceptual designs "RFQA" and "RFQB" which are 270 MHz RFQ's for 100 mA cw of 2.5 MeV protons.

Beam Dynamics Considerations

The axial field in an RFQ for a particle with synchronous phase angle ϕ is

$$E_z = kAV \sin(kz) \sin(\omega t+\phi)$$

where $k = 2\pi/\beta\lambda$ and V is the inter-vane voltage. The RFQ is usually designed with A approximately 0.6 and V as large as permitted by sparking limitations (for cw operation this is typically 1.75 * the Kilpatrick criterion). If the mean bore radius r_o is increased with ion velocity, then V can be increased at constant V/r_o without affecting the sparking field. This allows E_z to be increased, resulting in a shorter accelerator. Transverse beam focusing is reduced by this change and although it results in a larger diameter output beam, emittance is not increased appreciably and the larger bore can yield slightly improved transmission over the untapered design.

Longitudinal Field Tilt Studies for the Four Vane Structure

The generation of longitudinal field tilts was studied experimentally using an existing 1.5 metre long cold model[2] of a 270 MHz strapped four vane RFQ. Measurements were made to demonstrate that the field could be tilted in a predictable manner by altering the cross sectional area as a function of length. Ideally one would use a tapered outside shell but this would require complex machining both of the shell and the vane bases. As a simple test to demonstrate the principle, rods of varying diameter and length were inserted into each quadrant from one end. This produced a single step change in quadrant area along the length using the arrangement shown in Fig. 1.

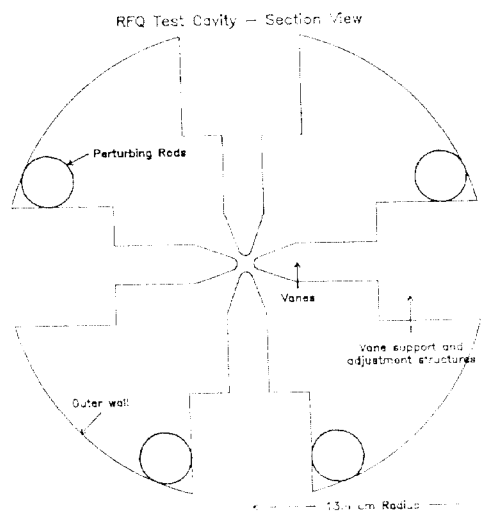

Fig. 1 Positions of perturbing rods in RFQ cavity.

The position of a perturbing rod within a quadrant is relatively unimportant and they were positioned as shown for mechanical convenience. The effective reduction in quadrant area is greater than the geometric shadow of the rod because rf fields will be excluded from the region between the support structure and the rod. Three sets of 609.6 mm long aluminum rods were inserted into one end of the RFQ; 25.4 mm, 31.75 mm and 38.1 mm diametersgave effective area decreases of 7.1%, 10.7%, and 15%, respectively.

The intervane voltage distributions were measured (Fig. 2). The vane shorting straps and strap compensating end plugs were adjusted for zero longitudinal field tilt with no rods inserted (i.e., the unperturbed state). The relative longitudinal field distributions were determined by taking the square root of the frequency perturbation produced by pulling a shaped dielectric plug through the uniform centre bore of the structure. Each curve is labelled with the fractional reduction in quadrant area.

The longitudinal field tilts may also be predicted using the code RFQ3D which is based on an equivalent circuit model of the general three dimensional RFQ[3]. All equivalent circuit values had already been determined and verified for the cold model[2]. Only the distributed value of the equivalent

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"single turn solenoid" quadrant inductance was varied for each of the rod sizes. The fractional reduction in quadrant area was translated directly into the same fractional reduction in local quadrant inductance. The predicted field distributions and frequency shifts are shown in Fig. 3.

The effects of the field perturbations are summarized in Table I. They show that a longitudinal variation of intervane voltage up to a factor of 3.8 can be produced by resonator area reductions up to 15%. This is more than adequate for the specific example described in the next section.

The frequency shifts and field variations predicted by the code RFQ3D are in reasonable agreement with the measured values, and it appears that a single step change in quadrant area may be sufficient to produce an acceptable field tilt. Note that the longitudinal field tilts also necessitate longitudinal rf currents along the vane tips. For the 0.15 perturbation case with 100 kV peak intervane voltage this would result in a peak longitudinal current at the middle of 380 A. Such currents might be a problem for a long structure with mechanical joints between longitudinal vane sections.

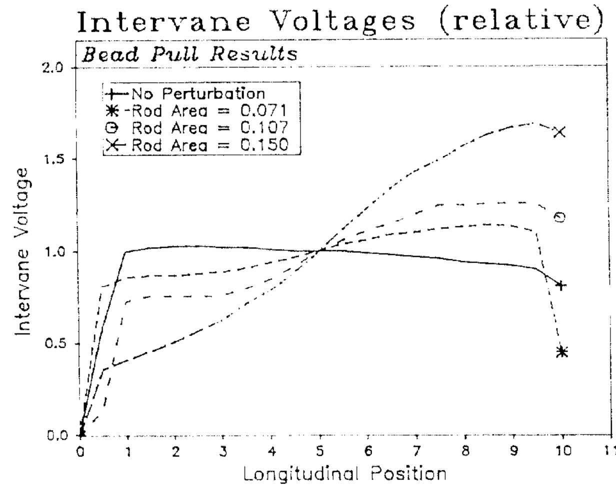

Fig. 2 Measured field distributions.

Table I

Effects of Field Perturbations

	No Decrease	0.071 Area Decrease	0.107 Area Decrease	0.15 Area Decrease
Measured				
Freq. Shift (%)	0	+1.06	+1.70	+2.41
Tilt	0.9	1.3	1.7	3.8
Calculation				
Freq. Shift (%)	0	+1.27	+1.73	+2.21
Tilt	1.0	1.9	2.4	3.6

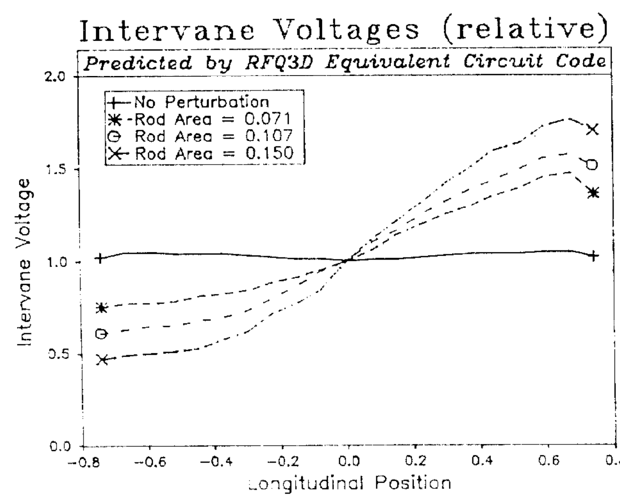

Fig. 3 Calculated field distributions.

Table II

Common Parameters for All Cases

Frequency (MHz)	270
Ion	H^+
Input Energy (keV)	50
Output Energy (MeV)	2.5
Input Current (mA)	115
Peak Field (*Kp)	1.75
Beam Power (kW)	245
RMS Input Emittance (π cm mradians)	0.04

Table III

RFQ Parameters

	RFQA	RFQAT	RFQB	RFQBT
Bore Taper (ratio)	1.0	2.44	1.0	2.3
Voltage Tilt (ratio)	1.0	2.44	1.0	2.3
Length (m)	3.23	2.41	3.53	2.38
Accelerating Phase (deg)	35	35	37.5	37.5
Initial Mean Bore Radius (cm)	0.51	0.51	0.49	0.49
Number of Cells	197	172	264	243
Structure RF Power Loss (kW)	499	817	497	813
Output Current (mA)	99.7	99.7	100.6	100.9
Normalized RMS Output Emittance (π cm mradians)	0.035	0.044	0.034	0.043

Specific Examples

Two RFQ designs were selected to demonstrate the effect of a tapered bore. The common parameters are listed in Table II.

The specific parameters for the designs RFQA (with ϕ=35°), RFQAT, (RFQA with a 2.44 taper over the accelerating section), RFQB (with ϕ=37.5°), RFQBT (RFQB with a 2.3 taper over the accelerating section) are listed in Table III.

The overall length was reduced by 25% for design A and by 33% for design B. The structure power losses are increased by 60% for both designs.

Conclusions

RFQ average accelerating gradients can be increased by tapering the bore in the accelerating section while maintaining constant maximum electric field. For a 4-vane RFQ, this can be accomplished by varying the cross sectional area of the quadrants as a function of length.

References

1. B.G. Chidley, R.M. Hutcheon and G.E. McMichael, "A Heavy Ion RFQ with High Accelerating Gradient", Proc. Linear Accelerator Conf., San Francisco, SLAC Report 303, 361 (1986).

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

3. R.M. Hutcheon, "An Equivalent Circuit Model of the General 3-Dimensional RFQ", IEEE Trans. Nucl. Sci., NS-30 (2), 3524 (1983).