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100% DUTY FACTOR RFQ LINAC SYSTEMS AT CRNL

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Summary

An RFQ linac operating at 100% duty factor (cw) and high currents is required for an accelerator breeder. Two high power structures are being built as part of the RFQ development program. Firstly, a copper 270 MHz "sparker" cavity with RFQ geometry is being tested to determine cw field breakdown levels and conditioning characteristics. The design and status of the "sparker" are presented. Secondly, a 270 MHz cw RFQ linac (RFQ1) is being designed to accelerate a nominal 75 mA from 50 to 600 keV, to study beam quality and stability as well as resonator field tuning and leveling requirements under conditions of high beam loss at high average power. For example, the combination of cw operation and restricted space at the entrance require new approaches in end terminations and tuners. The status of RFQ1 is presented and design innovations outlined.

Introduction

The low energy beam launching section of an accelerator breeder[1], as now envisaged, requires a 300 mA 100% duty factor RFQ. This presents new design problems, for the current is to be much higher than in existing designs, implying either increased vane voltage or increased bore hole size. Since the rf power increases very rapidly with bore hole radius ($\approx r^4$), it is important to operate at the highest practical voltage gradient, i.e., just safely below the conditioned sparking limit. Although such limits have been studied for relatively high duty factor operation[2], no definite information is available for cw operation, especially under conditions of high beam current, moderate beam spill, and a resulting high background pressure.

For this reason the RFQ development program at CRNL includes two 270 MHz cw structures of increasing complexity:

(1) a "sparker" cavity with RFQ geometry to determine field breakdown levels and conditioning characteristics without beam, and

(2) an RFQ linac (RFQ1) to accelerate a nominal 75 mA from 50 to 600 keV.

The sparker data will have a strong influence on the design of RFQ1, for the choice of voltage gradient greatly effects most aspects of the design.

The CW Sparking Limit Test Cavity

The sparker cavity (Fig. 1) is an unmodulated four-vane structure with 3.9 mm bore radius, 2.6 mm minimum vane-to-vane gap and 36.5 mm long unmodulated vanes with square ends.

To reduce complexity and eliminate a possible source of sparking, the system does not have end tuners. The vane ends are sufficiently distant from the end walls that the power on the end walls is negligible. In this short, unterminated configuration the vane voltage is a maximum at the centre and drops with a parabolic dependence to approximately 70% at the vane ends. Thus sparking should first occur at the vane centre where the fields can be most accurately calculated.

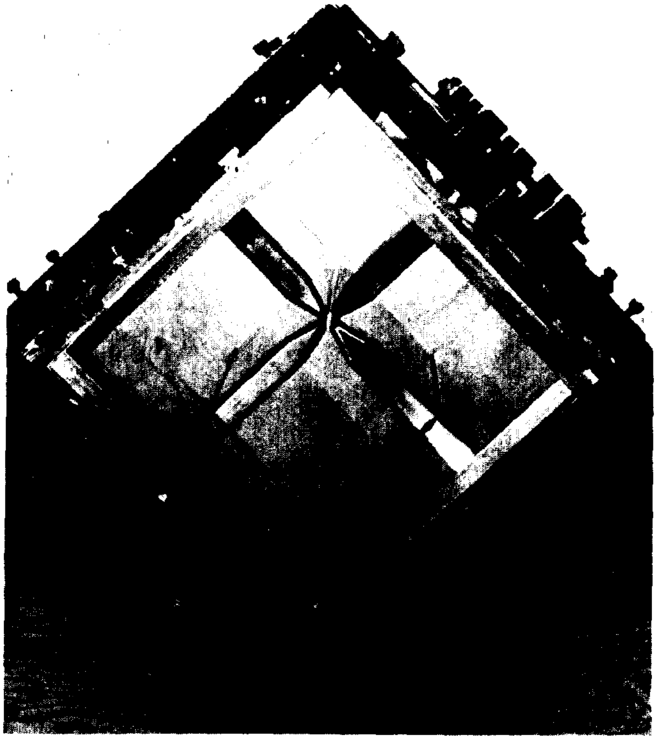

Fig. 1 An end view photograph of the 270 MHz cw water-cooled copper "sparker" test cavity.

The water-cooled copper vanes and side plates are designed for 170 kW average power dissipation, sufficient to allow operation at voltages of twice the Kilpatrick limit[3] without serious thermal detuning. The rf drive is supplied by a single water-cooled rf loop located at the centre of one quadrant and fed by a standard "6 inch" coaxial line.

Initial low power measurements on the clamped but unbrazed structure showed, as expected, large azimuthal asymmetry and depressed frequency, both caused by the rf loop penetration hole. Removal of material had caused a local increase in quadrant inductance.

This was solved by allowing the outer walls of the rf loop penetration cylinder to project into the quadrant. Final field balancing was done by fine-trimming the penetration (Fig. 2(a)). A measurement of the quadrant fields and mode frequencies versus the penetration into the quadrant (Fig. 2(a) and (b)) show the dipole modes straddling the quadrupole mode with 4.7 MHz mode separation at the point of azimuthal field balance.

Brazing of the sparker box structure is almost complete, with only the rf penetration remaining unbrazed. High power operation should start by early summer, 1983.

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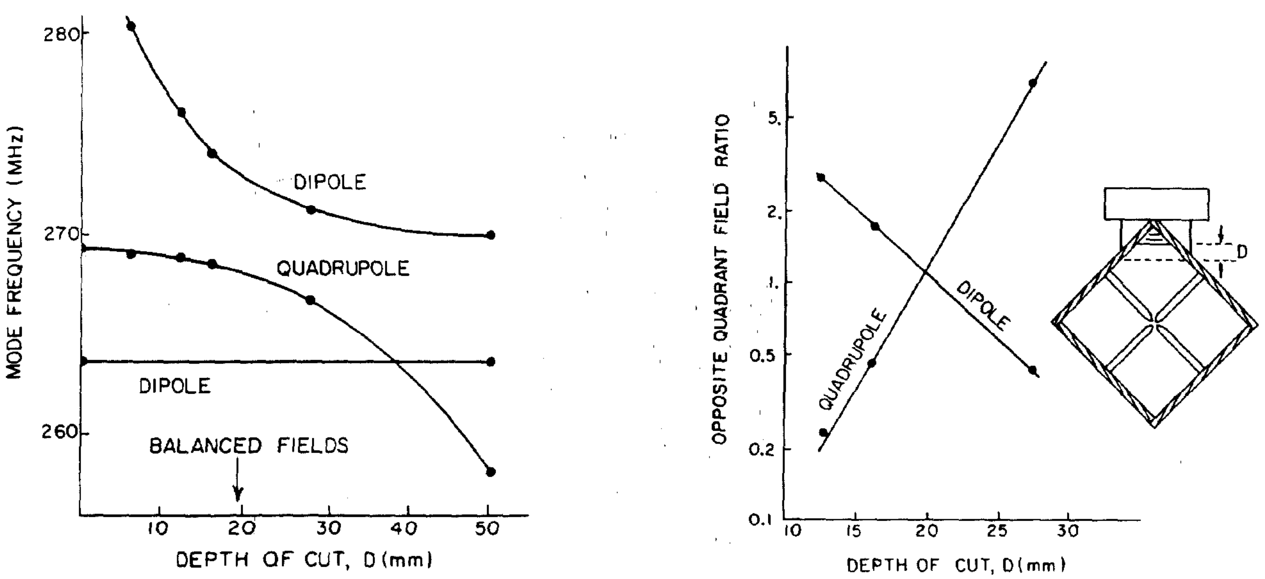


Fig. 2 Measurement of (a) the ratio of opposite quadrant fields and (b) the mode frequencies as a function of the rf outer cylinder penetration depth, D.

RFQ1 - A 600 keV, 75 mA cw Proton Accelerator

The present RFQ1 structure design is based on the assumption that cw operation will be possible at 1.3 x Kilpatrick. Beam dynamics calculations[4] and SUPERFISH runs yield the following design characteristics and requirements:

(1) mean bore radius, r_0 = 4.6 mm
(2) vane length = 2.3 metres
(3) outer envelope radius ≈ 120 mm
(4) average rf power ≈ 170 kW (3/4 of this is dissipated in the structure)
(5) beam transmission ≈ 80% for pure quadrupole fields. This is reduced if the field has a dipole component (Fig. 3(a)).
(6) a beam transmission only weakly dependent upon changes in the longitudinal voltage distribution produced by end tuner induced frequency changes (Fig. 3(b)).
(7) a large input beam focusing solenoid located within 100 mm of the RFQ input vane tips to provide radial matching.
(8) a lateral vane tip movement of 0.13 mm will introduce a dipole component of only 0.5% if the vane voltages are held equal.

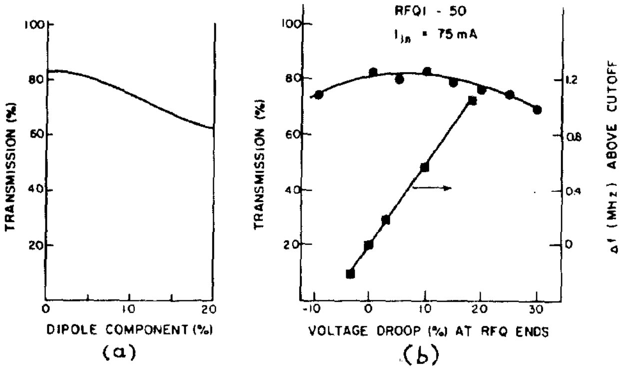
The following discussion shows how the present RFQ design has evolved.

The beam loss in the structure constitutes a 0.8 Pa L/s gas load and alone requires 11,000 L/s pumping capacity to maintain a pressure of ≈ 7 x 10^{-5} Pa. Inclusion of gas streaming from the source increases this to 14,000 L/s and means that at least eight pumping grills are necessary. The system will also have two rf ports in opposite quadrants for eventual experimentation with dual drive.

The pumping manifolds and rf ports dominate the exterior of the structure (Fig. 4), and, together with the requirement for a completely water-cooled structure suggest that mechanical tolerances on the cavity walls will be at best ± 0.5 mm. The field imbalances will be worse than this error implies, unless each of the pumping and tuning ports are individually compensated in a manner similar to the sparker rf port. In fact, trimming of the port projections could be a method for fine field balancing after assembly, much the way the Berkeley group plan to use quadrant tuning bars[5].

The poor mechanical tolerances of the long water-cooled rf envelope make it inappropriate as a base for stable and accurate vane mounting. Instead the vanes will be mounted on separate "picture frame" supports[6] which are independent of the rf envelope and allow accurate, stable vane positioning after final assembly on the beam line. This requires a flexible joint at the vane base, but has the advantage of individual vane positioning to ≤ ±0.1 mm. Slight movement of the vane tips does not appreciably affect the beam dynamics, and so can be used to balance the field tilts caused by cavity wall errors.

The double dipole end termination method[6] has tentatively been chosen for RFQ1. In this configuration, two vanes extend to and are rigidly attached to the end walls, while the other pair of opposite vanes have tuner gaps at the ends. This reduces the number of end tuners to four, gives accurate location and



(a) (b)

Fig. 3 Calculated dependence of RFQ1 beam transmission on (a) percentage dipole field component and (b) changes in longitudinal voltage distribution caused by frequency or tuning changes.

mechanical stability to two vane ends, leaves two opposite vanes free for mechanical adjustment and increases the rf stability.

Calculations with a new equivalent circuit model[7] were done to compare the sensitivity of both the standard and double dipole configurations to a 0.125 mm transverse movement of a single vane tip (Table 1). The average dipole field component is decreased for the double dipole configuration, in agreement with measurements[6]. As a 7% average dipole field component is tolerable in terms of beam loss (Fig. 3(a)), then random vane positioning errors of ≤ 0.1 mm should be acceptable.

Table 1

Effects of a 0.125 mm Transverse Movement of a Single Vane Tip for two RFQ1 Termination Configurations

Configuration	$(f-f_{co})$MHz	% Dipole Left End	 Middle	 Right End	Average Longitudinal Field Bow %
Standard	0.426	19.3	19.3	19.3	6
"	0.273	19.0	19.0	19.0	3.5
"	0.037	19.1	19.1	19.1	0
Double Dipole	0.427	0	10.2	0	6
" "	-0.019	0	11.5	0	-1

After the RFQ is assembled, the movement of the two opposite free-floating vanes is to be used to correct large field imbalances and to fine-tune the frequency. Some of the errors and how they might be corrected, based on the results of equivalent circuit calculations[7] are the following.

(a) A frequency shift of + 0.59 MHz can be corrected by retracting each of the two vanes 0.065 mm, without affecting the azimuthal field distribution

(b) If the average wall radius of one quadrant is 0.5 mm larger than the others, then ≈ 15% average dipole component is introduced. This can be completely eliminated by moving one vane tip 0.15 mm laterally in the direction away from the perturbed quadrant and then retracting it radially by about the same amount.

(c) A systematic variation of the average bore hole radius of 0.075 mm along the length of the RFQ will produce a 16% longitudinal tilt. This can be exactly corrected by reversing the tilt of the two opposite adjustable vanes.

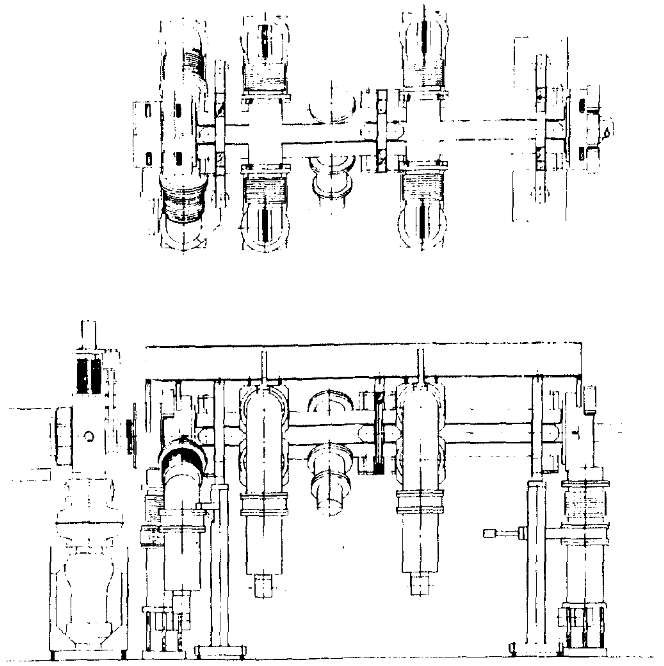


Fig. 4 Top view and side view of the proposed RFQ1 radiofrequency quadrupole accelerator.

The high average dissipated power in the structure means that, even with extensive cooling, some thermal expansion of components will occur. If the "picture frame" supports are maintained at constant temperature, then the vanes will expand inward reducing the frequency. Assuming reasonable pressure drops and flow rates, the input-output water temperature differential during full power operation is approximately 10°C. This is estimated to produce a 0.016 mm change in vane height which will produce a frequency decrease of 0.30 MHz. The longitudinal field "bow" introduced by this has no appreciable effect on the beam dynamics (Fig. 3(b)), but a method is required for correcting the frequency shift. The long term adjustment may be accomplished by vane cooling water temperature control or by regulating the "picture frame" temperature. However, a fast frequency correction method is required which does not use sliding metal-to-metal contacts and which does not introduce unacceptable field imbalances.

The Bourdon tube principle provides an elegant way to achieve fast frequency variation. Low power model tests[6] have demonstrated the excellent reproducibility of Bourdon tube based tuners, but also indicate that the amount of movement achieved may not be sufficient to meet both thermal and field balancing requirements. Present full scale models achieve ≈ 1 mm movement, which will produce a total frequency tuning range of ≈ 0.23 MHz. Considerable development remains to be done to find a broader range tuning method.

Conclusions

A cw sparking limit test cavity with four-vane geometry is being constructed, and operation is planned for mid-1983. These tests will provide information necessary for the design of RFQ1, a 75 mA cw proton RFQ accelerator. New design approaches are required for such an accelerator, and several new features have been tentatively incorporated, including a "picture frame" vane mounting system, a new end termination configuration, floating vanes for alignment in situ on the beam line, and an end tuner system that eliminates moving mechanical rf joints. Equivalent circuit modeling has been of considerable use in establishing fabrication and assembly tolerances.

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