Design Study of a Heavy Ion RFQ Linac

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A 4-rod RFQ cold-model with 6-posts structure was build and tested for preliminary design study of a heavy ion RF linac. We obtained a general dependance of the resonant frequency upon the height of the electrode-supporting-structure. Measurements were also done for Q-values, and the longitudinal electric-field distributions. Meanwhile a computer program has been developed for cutting a RFQ electrode on NC-milling machine. This program's final output is a file which contains a table of cutter-path's coordinates and corrected transverse radii of curvature.

KEY WORDS: 4-rod RFQ/RFQ electrode/

1. INTRODUCTION

4-rod RFQ presents relatively less rigorous engineering difficulties compared with 4-vane RFQ, nevertheless still there are important subjects we have to work and improve on. Those are structural rigidness and cost performance. Our 100 MHz 4-rod proton RFQ was only 75 cm long so it was not too heavy and sufficiently rigid with just 4 supporting structures [1] . For a heavy ion RFQ with output energy reaching 100 KeV/nucleon, the resonator must be operated much lower frequency and its length becomes around 200 cm. If the structure is made with just 4-supporting posts, the droops of the electrode associated with its own weight will not be negligible and cannot be kept under machining and assembly tolerances. On the other hand, with 6-supporting posts, the height of the post must be made much bigger than that of 4-supporting posts structure. The results are increase in construction cost of the vacuum tank due to its larger diameter. The purpose of this model study is to search for the final dimension of the RFQ in reasonable size and to check its RF characteristics.

RFQ-electrode profile is calculated by numerically founding the solution of an inverted "two-term potential" equation with boundary conditions [2] . Both longitudinal coordinate points and corresponding transverse radii of curvature are found in small interval in entire length and after cell-joint smoothing those results are translated to coordinates of the tool path and to the corrected transverse radii of curvature. The results of calculations are presented in this report.

2. DROOP OF ELECTRODE

The maximum displacement of the RFQ electrode, Y, can be estimated from the following equation [3] : .,

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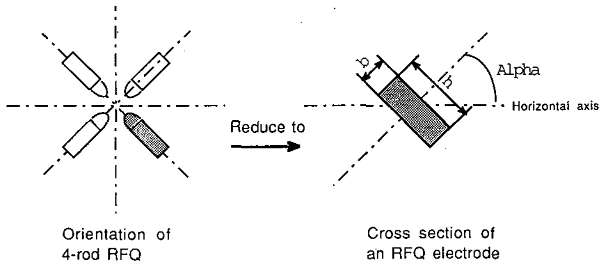

Fig. 1. Schematic drawings of orientation and cross section of 4-rod RFQ electrode.

$Y = w\ L^4/(8\ E\ I)$, where w is weight distribution, L is length, E is Young's modulus, and I is the second moment of system which is obtained by an equation [4] :

$$I = b\ h/12\ ((h\ \mathrm{Cos}[\mathrm{Alpha}])^2 + (b\ \mathrm{Sin}[\mathrm{Alpha}])^2)$$

The orientation and cross-section of a RFQ electrode is schematically shown in Fig. 1. The cross-section is approximated by a rectangle of 24 by 60 mm, and it is tilted 45 degree from the horizontal axis. The material is C 1020-1/2 H copper. The result is that when one end of an 50 cm long electrode-rod is fixed to the post, the maximum displacement becomes approximately 30 microns, which is less than what we expect for machining or assembly tolerances, 50 microns.

3. RF CHARACTERISTICS

Fig 2. shows the resonant frequencies of our 4-rod RFQ as a function of the height

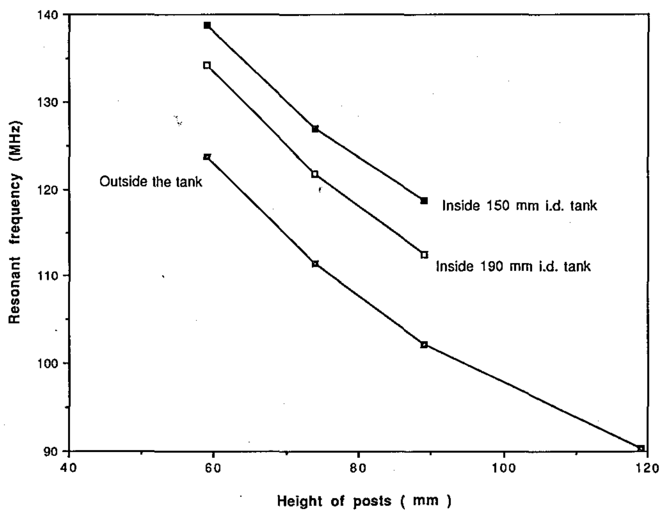

Fig. 2. Plot of 4-rod RFQ resonant frequencies as a function of post height.

of the post in three different surrounding conditions: inside 190 mm diameter tank, inside 150 mm diameter tank, and outside the tank. The number of the post is six— this means a pair of RFQ electrode is supported by three posts. The width and thickness of the post are 80 mm and 15 mm, respectively. The posts are evenly spaced at 150 mm from each other. The electrode is un-modulated and its length is 793 mm. The aperture radius is 2.7 mm. RF contact between the tank and the base-plate of the RFQ assembly is made by commercially available "shield fingers". Note that the center of the aperture coincides with the center of the tank only in a case where the post height is 59 mm and the diameter of the tank is 150 mm, otherwise they are eccentric.

Fig.3 is a typical longitudinal electric-field distribution obtained by bead-pull method. The purterber's length is 10 mm and it is made just to fit in the aperture. The frequency shift is measured by HP-4195 A network analyzer. The results are that variation of field along the axis is within 5%. To achieve this degree of flatness, the electrode alignment must be as good as 0.05 mm.

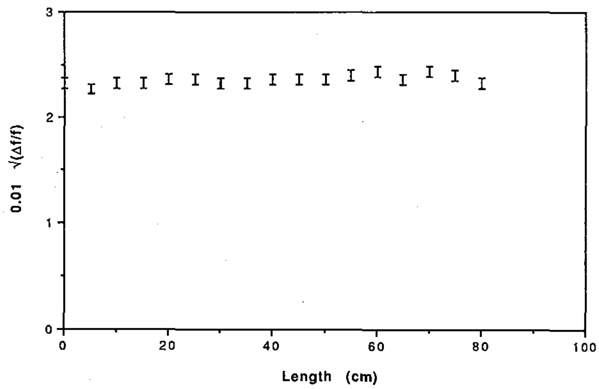

Fig. 3. A typical longitudinal electric-field distribution of 4-rod RFQ.

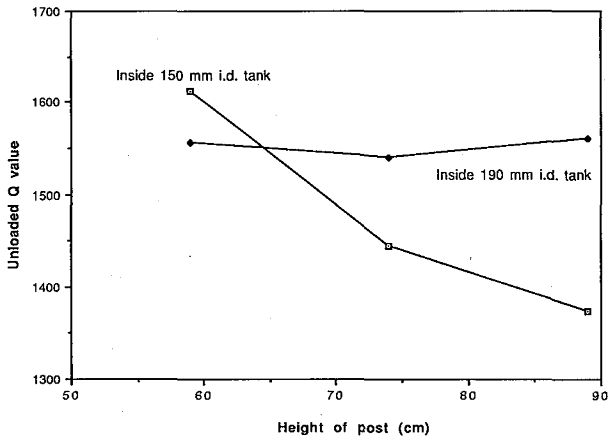

Fig. 4. Plot of unloaded Q-values as a function of post height.

Fig.4 shows the unloaded Q-values as a function of the post height in 150 mm and 190 mm diameter tank. The size of posts, the distance between the posts, and the other conditions are the same as described above. The tendency is that the Q-value is irrespective to the height of the post, but will deteriorate as the electrodes come close to the wall of the tank.

4. ELECTRODE CONSTRUCTION

The software we have developed gives a user an integrated environment for study and construction of RFQ pole-tip geometry of variable transverse radius of curvature. It reads in an output file—this contains cell parameters—from a PARMTEQ run and calculates in discrete step-increment the longitudinal curvature of radius, the longitudinal profile, and the transverse radius of curvature. A graphic routine is incorporated in the major subsection of the program—those are "profile calculation", "cell-joint smoothing" and "cutter-path" —for a quick eye-ball inspection of the calculation results. Many parameters including the step increment size, the start cell and last cell of calculation, and the number of points to be smoothed around the cell-joint can be set by users.

The maximum tool size—we use a ball endmill—have to be determined from the inspection of the longitudinal curvature radius (LCR) in entire length of the RFQ electrode. Fig. 5 shows our calculation and the minumum value of LCR is found to be 13.3 mm. The radius of the cutter must then be less than this value.

Fig. 6 shows a superposed view of a smoothed profile on the results of profile calculation. The discontinuity at the cell-joint is removed by taking the average value of electrode height at the cell-joints and also correcting for the coordinate points around the joints. A similar technique is used for smoothing of transverse radius of curvature.

Fig. 7 is the results of an overall calculation of the pole-tip profile. The top figure is for smoothed transverse radius of curvature (TRC) and the bottom one is for smoothed longitudinal electrode profile (LEP). Note that in the left part of the electrode-so called in the gentle buncher section, TRC is big at the hill of the electrode and small at the valley, in the right part—in the acceleration section—of the electrode on the other hand, TRC is small at the hill and large at the valley.

An electrode profile obtained in the smoothing section must be translated into the cutter path of the NC machine. Correction of a cutter-path in Y-Z plane (transverse plane) can be done in a typical NC machine but not for X-Z plane (longitudinal plane). This routine calculates the ball-endmill's path in the X-Z plane in constant increment-step and it also corrects for the transverse radius of curvature in given tool size. Fig. 8 depicts the situations at the mid-plane of the electrode for both with and without cutter-path correction. An ideal pole-tip profile and part of ball endmill's contour are shown in the figures. The radius of ball endmill is 10 mm in both cases. The consequence is that at midplane of the electrode, the distortion of the cut-surface becomes as much as 200 microns without correction.

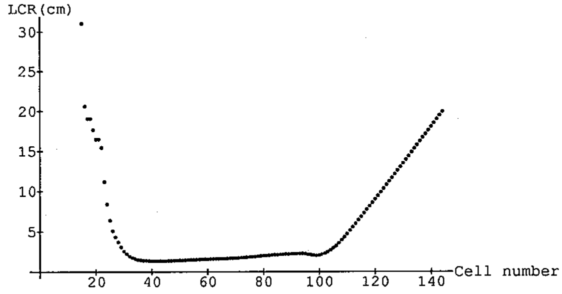

Fig. 5. Plot of longitudinal curvature of radius (LCR) from 15 to 144 cell.

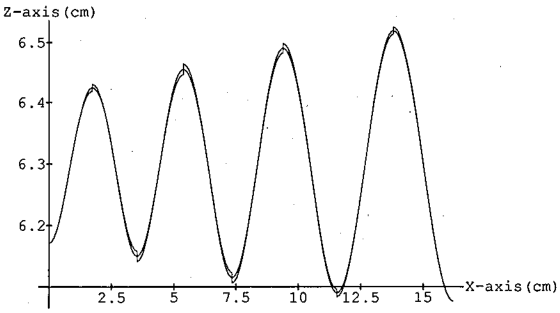

Fig. 6. Superposed view of longitudinal electrode profile after and before smoothing.

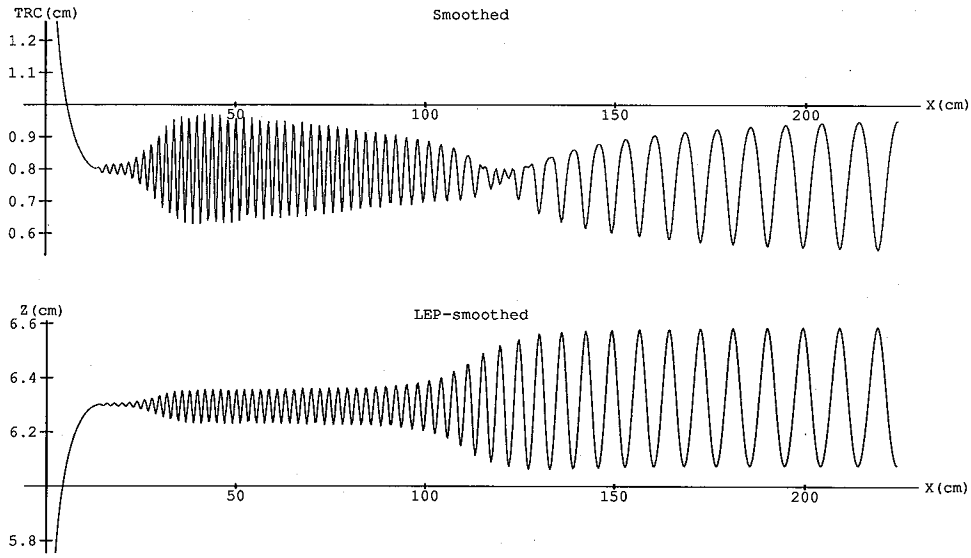

Fig. 7. Overall RFQ electrode profile: Top figure is for transverse radius of curvature and bottom one is for longitudinal profile (LEP) at the mid-plane of the electrode.

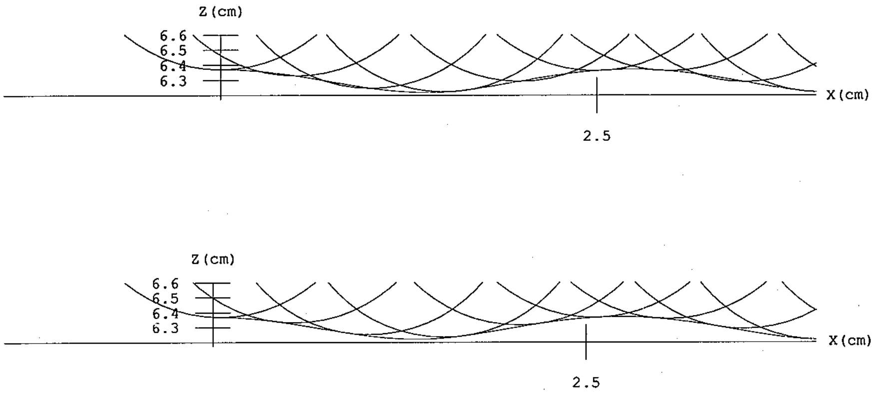

Fig. 8. Visual demonstration of RFQ electrode test-cut with and without cutter-path correction.

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REFERENCES

(1) H. Fujisawa, Y. Iwashita, and H. Takekoshi, "4-RFQ Proton Acceleration Tests", *Bull. Inst. Chem. Res., Kyoto Univ.*, **67** (1989).
(2) K. R. Crandall, "Effect of Vane-Tip Geometry on the Electric Fields in Radio-Frequency Quadrupole Linac", LA-9695-MS, April 1983.
(3) "Kikai Sekkei Binran", p 712, Maruzen (1972).
(4) "Kinzoku Binran", p 294, Maruzen (1952).