OPTIMIZATION DESIGN OF THE RFQ TRAPEZOIDAL ELECTRODE

Li Chenxing#, He Yuan, Wang Zhijun, Institute of Modern Physics, CAS, Lanzhou, China

Abstract

In order to reduce the length of a deuteron beam RFQ, trapezoidal modulation is used in the last 3-meter-long section. Because there is no existing tested design procedure fitting for designing this type of unconventional structure, a VBA code used for designing trapezoidal modulation RFQ electrode was developed. VBA is an effective and efficient tool for completing repetitive work. So it can be used to design repetitive analogous cells of electrode of RFQ or DTL or other periodic acceleration structures. By using this VBA code, cell length and the exit energy can be obtained accurately. The feasibility and accuracy of this method have been validated by beam dynamics simulation.

INTRODUCTION

The conventional method to design RF cavities such as RFQ or DTL can be divided into three steps [1]. First, generate the basic parameters of acceleration cells. Second, model and optimize the cavity structure. Third, evaluate the beam performance by beam dynamics simulation using the RF field generated from the RF simulation done in the second step. To achieve a reasonable solution, iterations of these three steps will be necessary. It is predictable that the repetitive work will occupy the most time of the design. The electric field in the RF cavities such as RFQ or DTL is concentrated mainly in small regions near the electrode gaps. This makes it feasible to design the local regions where the electric field concentrated independently by using 3D electrostatic codes such as CST EM Studio [2].

The secondary development based on VBA (Visual Basic for Applications) has been extensively utilized in mechanical design. The design efficiency can be improved and the design period can be shortened due to the repetitive work in the design procedure can be completed by computer code. By means of the VBA in CST, the automated design and optimization of RFQ electrode or DTL tubes using CST EM Studio can be achieved. Based on CST EM Studio, a VBA code that aims to optimization of longitudinal structure of RFQ electrodes and DTL tubes has been developed. By utilizing this code, the design of the trapezoidal modulation electrode of the last 3-m-long section of a deuteron beam RFQ has been done.

DEUTERON BEAM RFQ DESIGN

The main design parameters for the deuteron beam RFQ are listed in table 1. The RFQ will consist of five identical ~ 105 cm long segments. Figure 1 shows the full five-segment engineering model.

#lichenxing@impcas.ac.cn

Table 1: The Main Parameters for the Deuteron Beam RFQ

Parameter/Feature	Value
Input Energy	20 keV/u
Output Energy	1.7 MeV/u
Frequency	162.5 MHz
Vane Voltage	65 kV
Average Aperture Radius	4.8 mm
Length	5.25 m
Bunching	Internal

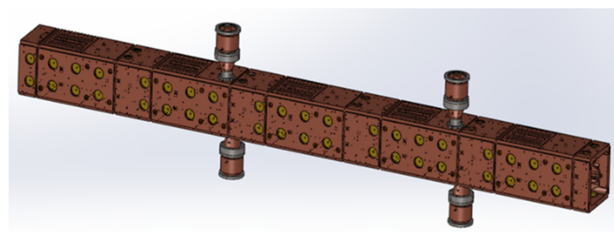

Figure 1: 3D model of the deuteron beam RFQ.

In order to increase the acceleration efficiency of the RFQ, the trapezoidal modulation electrode is introduced in this RFQ. The first 2 m section of the electrode is sinusoidal and the last 3.25 m section of the electrode is trapezoidal. As the design result, the energy at the exit is nearly 1.7 MeV/u. The first 2 m section is designed by the code DESRFQ [3]. Because there's no ready-made code to design the unconventional structure of the trapezoidal modulation electrode, a VBA code based on CST EM Studio has been developed for the design of the trapezoidal modulation electrode.

THE DESIGN OF ELECTRODE WITH TRAPEZOIDAL MODULATION

The idea utilizing trapezoidal modulation electrode to increase the acceleration efficiency was initially actualized by the IHEP-Protvino group [4] and also has been implemented in ATLAS RFQ [5]. Figure 2 shows the longitudinal section of one cell trapezoidal modulation RFQ electrode and the 3D model. It can be seen that each cell of the trapezoidal modulation RFQ electrode is comprised of two flat parts and one sinusoidal transition part between them. The proportion of the flat parts in the cell length is represented by k. The electrostatic simulation can be done when the 3D model is generated. Figure 3 shows the axial component of the electrostatic field for different proportions of the flat parts. As expected, the maximum of the axial component of the electrostatic field increase as the proportion enlarges

ISBN 978-3-95450-131-1

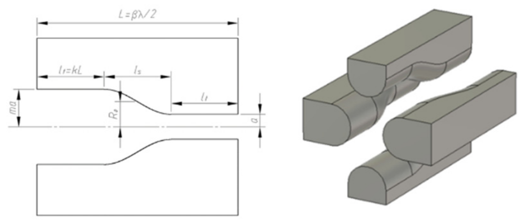

Figure 2: The longitudinal section of one cell trapezoidal modulation RFQ electrode and the 3D model.

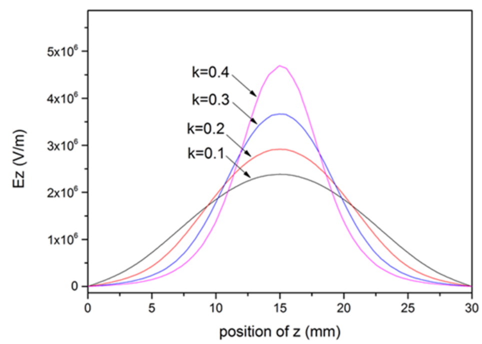

Figure 3: The axial component of the electrostatic field for different proportion of the flat part.

The input parameters are the ion energy at the entrance of the trapezoidal section of the RFQ, the RF frequency, synchronous phase, transit time factor. In order to setting the transit time factor and the proportion of the flat part in the cell length reasonably, parameter sweeps of the proportion k have been done at several certain cell length (L=30 mm, 40 mm, 50 mm, 60 mm). Figure 4 shows the results obtained when L=30 mm. As illustrated in Figure 4, the acceleration efficiency increases when the proportion enlarges. But the proportion is limited by the maximum surface electric field on the electrode in case electric break down. Through the parameter sweeps, the ranges of the trapezoidal proportions and the transit time factors are determined.

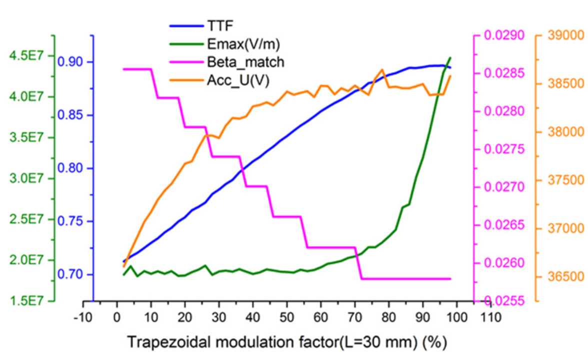

Figure 4: Parameter sweep of trapezoidal modulation factor (L=30 mm).

In the design of multi cell trapezoidal modulation RFQ electrode, the VBA code based on CST EM Studio was utilized to perform the repetitive calculation and adjustment. The algorithm of this code is elaborated in the flow chart in Figure 5. In the flow chart, the phase of a synchronous particle at the entrance of one cell is calculated by finding the zeropoint of the following function [6] using the bisection method.

$$F(\varphi_{in}) = \tan^{-1}\left[\frac{\int_0^L qE_z(s)\cdot\sin\left[\varphi_{in}+\frac{\omega_{rf}}{c}\int_0^s\frac{ds'}{\beta_z(s')}\right]\cdot ds}{\int_0^L qE_z(s)\cdot\cos\left[\varphi_{in}+\frac{\omega_{rf}}{c}\int_0^s\frac{ds'}{\beta_z(s')}\right]\cdot ds}\right]-\varphi_s$$

And the exit phase of the synchronous particle can be calculated by an integral method. Then the adjusted quantity of the cell length can be calculated. After several iterations, the difference between the phase at the exit of the cell under adjustment and the phase at the entrance of the next cell will be small enough. And the longitudinal structure of the trapezoidal modulation RFQ electrode will be ultimately determined.

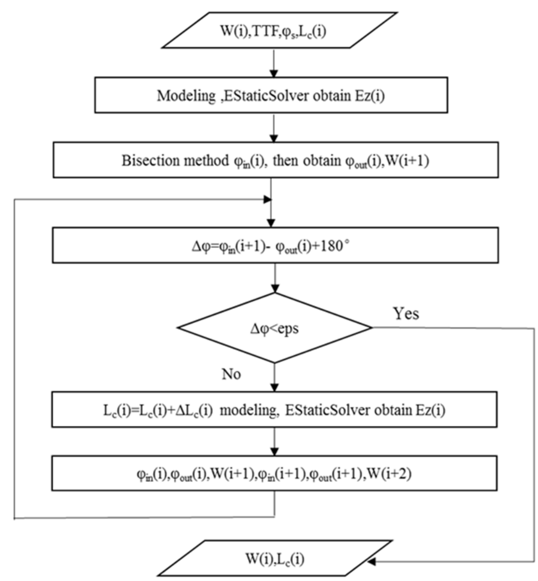

Figure 5: The flow chart of the code to design the longitudinal structure of RFQ electrode.

After running the VBA macro code, multi cell 3D model will be modelled and several results will be generated: particle energy at the exit of each cell, the length of each cell, phase differences between cells. These results are shown in Figure 6. Figure 6 (a) and (b) indicate that after adjustment the phase differences between cells can be greatly reduced and controlled into a small level below 0.015 degrees.

The code can also generate the 3D multi cell model directly and do electrostatic simulation. And then the 3D electrostatic field can be exported and utilized in beam dynamics simulation based on TraceWin [7] or CST Particle Studio [2]. Figure 7 shows the 3D model and the beam dynamics simulation using CST Particle Studio.

ISBN 978-3-95450-131-1

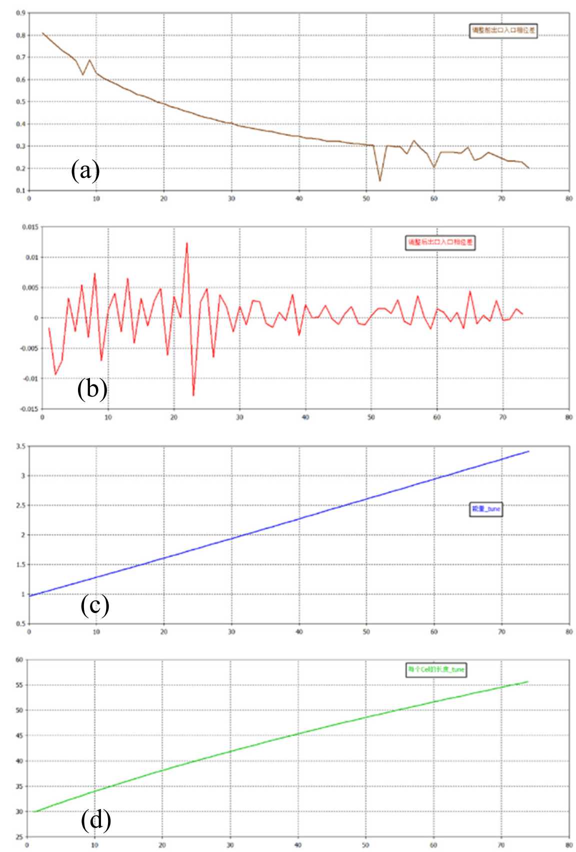

Figure 6: (a) phase differences between cells before adjustment (b) phase differences between cells after adjustment (c) energy at the exit of each cell (d) ultimate cell length of each cell.

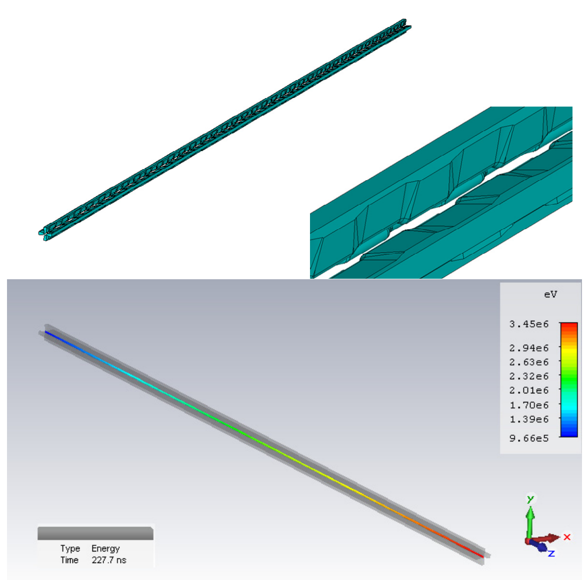

Figure 7: 3D model of trapezoidal modulation RFQ electrode and the result of beam dynamics simulation.

FABRICATION TEST

A fabrication test also was performed to validate the feasibility of fabricating the trapezoidal modulation electrode using ready-made flying cutter. In order to generate the trajectory of cutter center be suitable for fabrication, the sinusoidal transition part is substituted by two arcs and their internal common tangent (Figure 8). The trajectory of the cutter center can be generated by a simple code. After fabrication is completed, the measurement is also performed. As measured by a coordinate measuring machine (CMM), the error of fabrication is lower than 0.0309(31) mm (Figure 9).

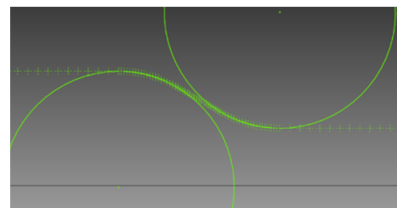

Figure 8: Substitute the sinusoidal transition part by two arcs and their internal common tangent.

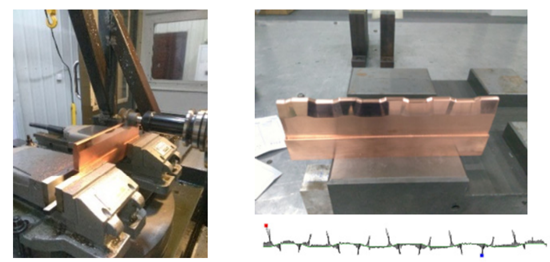

Figure 9: Fabrication and measurement of the trapezoidal modulation RFQ electrode.

CONCLUSION

A code aimed to the design of longitudinal structure of RFQ electrode has been developed based on the VBA of CST. Using this code, the trapezoidal modulation RFQ electrode of a deuteron beam RFQ was designed. The results have been validated by beam dynamics simulation using CST Particle Studio. A fabrication test was performed to validate the feasibility of fabricating the designed trapezoidal modulated RFQ electrode.

REFERENCES

[1] A. Bandyopadhyay, O. Kamigaito, S.K. Nayak, H.K. Pandey, M. Mondal, Alok Chakrabarti, Nucl. Instrum. Method A, 560 (2006), p. 182.
[2] CST EM-Studio, CST Particle Studio, CST, GmbH, Darmstadt, Germany: http://www.cst.de
[3] A.A. Kolomiets, The code DESRFQ, ITEP/ANL, Technical note, 2005.
[4] O. K. Belyaev et al, Proceedings of the 20th Linac Conference, Monterey, California, page 259.
[5] P. N. Ostroumov et al., Phys. Rev. ST Accel. Beams 15, 110101 (2012).
[6] D. Uriot, TraceWin documentation, CEA/SACLAY-DSM/Irfu/SACM.
[7] Trace Win CEA, http://irfu.cea.fr/Sacm/logiciels/index.php

ISBN 978-3-95450-131-1