PRELIMINARY BEAM DYNAMICS AND STRUCTURE DESIGN OF ONE 50mA/CW RFQ WITH RAMPED INTER-VANE VOLTAGE*

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Abstract

The beam dynamics and structure design of a ramped-voltage CW RFQ (Radio Frequency Quadrupole) accelerator for a NSFC (National Natural Science Foundation of China) Project at Tsinghua University is presented in this paper. The ramped-voltage RFQ, in which the inter-vane voltage increases from the low-energy end to the high-energy end, is compact and efficient. The RFQ, with the operating frequency of 325 MHz, will capture a 50 mA/CW, 50 keV proton beam from the RF source and accelerate it to 3 MeV, an energy suitable for chopping and injecting the beam in a conventional Drift Tube Linac. After optimization, the total length is as short as 2.9 m and the transmission rate is above 97%. The design of RFQ structure including the undercuts will also be shown.

INTRODUCTION

As an important part on the ongoing development of a proton accelerator for a NSFC (National Natural Science Foundation of China) Project at Tsinghua University, a CW RFQ (radio frequency quadrupole) has been designed. The basic parameters are shown in Table 1.

Table 1: Basic Parameters of the RFQ

Parameters	Value	Unit
Particle	Proton	
Type	Four-vane	
Duty factor	CW	
Frequency	325	MHz
Input beam energy	50	keV
Output beam energy	3.0	MeV
Beam current	50	mA
Maximum surface field	32.12	MV/m
RF power	573	kW

With the application of the ramped-voltage RFQ [1], we shorten the structure as short RFQs have several advantages: (1) simpler structure without coupling plate; (2) more compact; (3) lower cost.

The design details will be presented below.

RFQ WITH RAMPED INTER-VANE VOLTAGE

As known in the RFQ physics, the average peak axial accelerating field is described as $E_z=2AV/(\beta\lambda)$ [2]. In conventional RFQs, the inter-vane voltage is constant. Therefore, for these RFQs with a given modulation in the accelerator section, as the beam velocity β increases along the RFQ, the accelerating gradient decreases. To avoid this defect, people put forward that the mean accelerating gradient can be increased by using an average aperture radius r_0 varying along the length proportional to ion velocity and adjusting the tilted inter-vane voltage distribution at constant V/r_0 without affecting the sparking limit [1].

The successful practice on the 8-m long CW LEDA RFQ in LANL has proven that the four-vane RFQ with ramped inter-vane voltage can be correctly built and tuned to the designed voltage distribution [3].

Now the ramped inter-vane voltage has been adopted in many RFQs [4, 5], most of which follows this principle: the inter-vane voltage V and the average aperture radius r_0 are exactly proportional to the beam velocity, i.e. $V \propto \beta$ and $r_0 \propto \beta$. In this situation, the peak surface electric field is like the red line shown in Fig. 1, which is much lower than the maximum surface field. Therefore, in our design, the inter-vane voltage is increased to optimize the peak surface electric field, resulting in larger average peak axial accelerating field and shorter RFQ, as shown in Fig. 2.

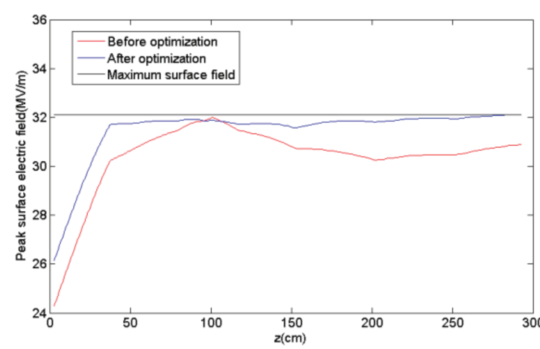

Figure 1: The peak surface electric field before and after optimization.

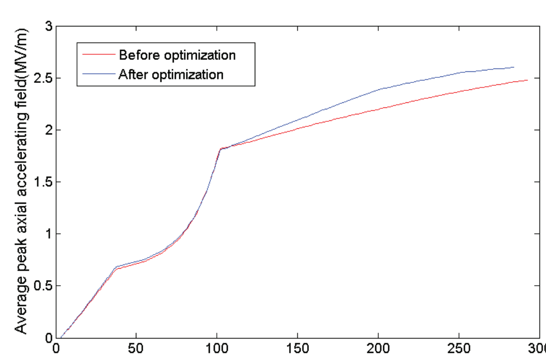

Figure 2: The average peak axial accelerating field before and after optimization.

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RFQ DYNAMICS DESIGN

The RFQ dynamics design has been completed using the PARMTEQM code, which include the effects of image charges, higher order multipole field components and two-dimensional space-charge calculation [6]. The design result of the various parameters of the RFQ is shown in Fig. 3, where Φ_s is the synchronous phase, B is the focusing strength, V is the inter-vane voltage, W is the synchronous energy, m is the modulation factor, A is the acceleration parameter, r_0 is the average aperture radius, and a is the minimum aperture radius.

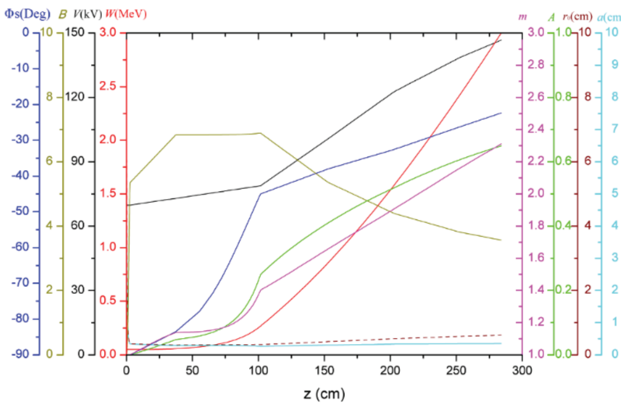

Figure 3: Various parameters of the RFQ versus longitudinal position.

The beam dynamics for the input current of 60mA is presented in Fig. 4. The transmission rate given by PARMTEQM is 97.5% with 10^5 macroparticles. The particle distribution in the transverse plane x-y at the entrance and exit of the RFQ are shown in Fig. 5. The matched input Twiss parameters are: $\alpha_{ix,y}$ =2.02 and $\beta_{ix,y}$ =5.91 cm/rad. The rms normalized transverse emittance only increases 15% when the beam reaches the high-energy end of the RFQ.

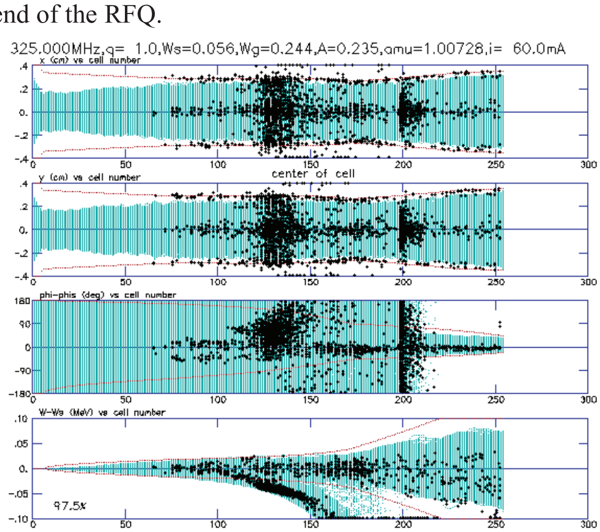

Figure 4: Beam dynamics in the RFQ by PARMTEQM for the input current of 60mA.

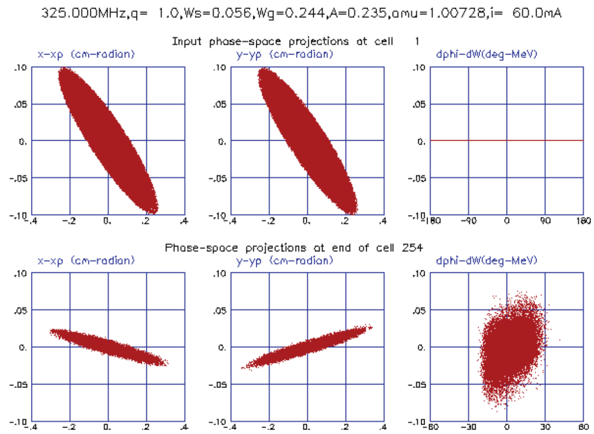

Figure 5: Particle distribution in the transverse plane x-y at the entrance and exit of the RFQ.

RFQ STRUCTURE DESIGN

Using the 40 cross sections produced by the SUPERFISH code [7], a full 3D model of the RFQ including undercuts was implemented in the CST MWS (Microwave Studio) [8] to accurately optimize structure parameters by evaluating the operating frequency and field distribution. The basic model in the CST MWS used for simulation is shown in Fig. 6.

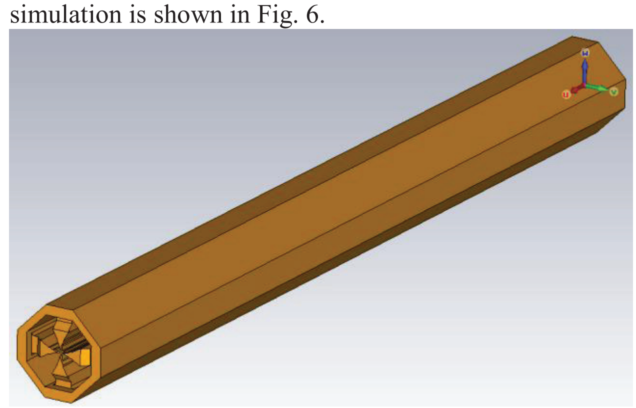

Figure 6: The basic model in the CST MWS used for simulation.

To do the simulations as accurately as possible with limited hardware conditions, the meshing properties are very important. Two kinds of transverse meshing method in the CST are shown in Fig. 7: one has transverse meshing refinement only around the vane tip (a); another has transverse meshing refinement following the meshing style of the SUPERFISH (c). Frequencies of operating mode with different meshing methods are shown in Table 2. After several trials, we found that the simulation that follow the meshing style of the SUPERFISH will give the best result with the same meshcells.

Table 2: Frequencies of Operating Mode with Different Meshing Methods

Meshing method	Frequency/MHz
SUPERFISH(Designed)	324.00
Simulation in Fig. 7(a)	323.32
Simulation in Fig. 7(c)	323.92

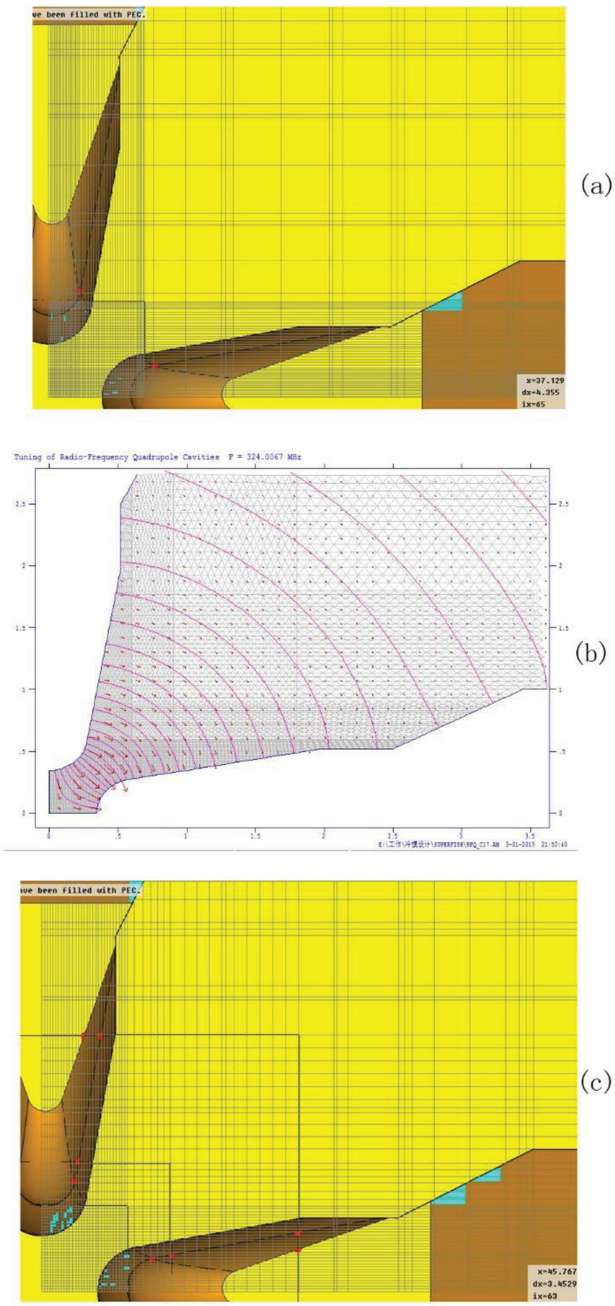

Figure 7: (a) Transverse meshing refinement only around the vane tip in the CST; (b) Transverse meshing method in the SUPERFISH; (c) Transverse meshing refinement following the meshing style of the SUPERFISH in the CST.

Undercuts at the end of the four vanes are very important to the RFQ to adjust the operation frequency and field distribution [9].

A trapezoid-shape-like undercut is adopted for the RFQ in consideration of its cooling convenience, as shown in Fig. 8 [9].

Simulating on the model shown in Fig. 6 and Fig. 7(c), the final undercuts parameters are obtained: At low-energy end, H_1=H_2=40 mm; at high-energy end, H_1=45 mm, H_2=30 mm.

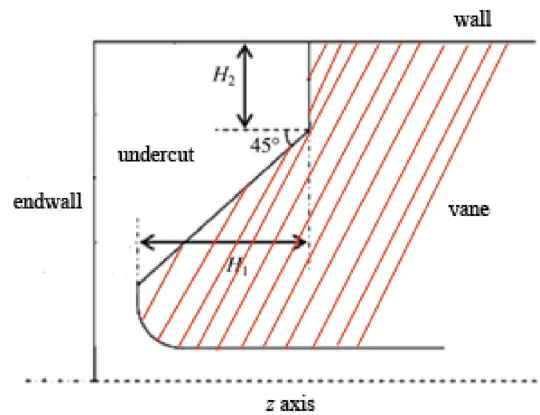

Figure 8: Undercuts parameters.

CONCLUSSION

The preliminary design of a ramped-voltage CW RFQ (Radio Frequency Quadrupole) accelerator for a NSFC Project at Tsinghua University has been done by simulations with the PARMTEQM, SUPERFISH and CST MWS codes. The total length is as short as 2.9 m and the transmission rate is 97.5%. Further design and analysis of the water cooling of the RFQ will be carried out for the next step.

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