DESIGN OF THE CPHS RFQ LINAC AT TSINGHUA UNIVERSITY*

Q.Z. Xing#, J.C. Cai, Y.J. Bai, C. Cheng, T.B. Du, X.L. Guan, J. Wei, Z.F. Xiong, H.Y. Zhang, S.X. Zheng, Department of Engineering Physics, Tsinghua University, Beijing 100084, China
W.Q. Guan, Y. He, J. Li, NUCTECH Co. Ltd., Beijing 100084, China
J. Billen, J. Stovall, L. Young, TechSource, Santa Fe, New Mexico, USA

Abstract

The design progress of the Radio Frequency Quadrupole (RFQ) accelerator for the Compact Pulsed Hadron Source (CPHS) at Tsinghua University is presented in this paper. The RFQ will accelerate protons from 50 keV to 3 MeV, with the RF frequency of 325 MHz. The objective is to obtain the optimum structure of the RFQ accelerator with high transmission rate and tolerable total length. The beam dynamics are studied by the simulation of the proton beam in the RFQ accelerator with the code of PARMTEQM. The output proton beam from the RFQ is well matched into the DTL without Medium-Energy-Beam-Transport (MEBT) between the RFQ and DTL.

INTRODUCTION

A 325 MHz Radio Frequency Quadrupole (RFQ) accelerator will be built to produce 50mA of proton beam at 3 MeV as an injector of the 13 MeV DTL for the Compact Pulsed Hadron Source (CPHS) project at Tsinghua University. The CPHS project is a university-based proton accelerator platform (13 MeV, 16 kW, peak current 50 mA, 0.5 ms pulse width at 50 Hz) for multidisciplinary neutron and proton applications [1]. The RFQ system consists of three four-vane resonant cavity sections, one power coupler, 47 slug tuners, 8 dipole-mode stabilizer rods, the RF power supply and its low-level control, vacuum, water cooling, resonance control, beam diagnostics, support and alignment systems. Fig. 1 shows the sketch of the RFQ system and the design parameters are listed in Table 1.

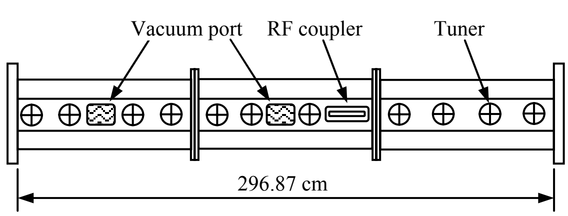

Figure 1: Sketch of the 3 MeV RFQ for the CPHS project.

To save space and cost, no Medium-Energy-Beam-Transport (MEBT) will be placed between the RFQ and DTL. The RFQ is carefully designed to match the beam from the high-energy end of the RFQ to the entrance of the DTL, by reducing the focusing in the exit of the RFQ. The cavity cross section and vane-tip geometry are tailored as a function of longitudinal position. The physics design has been completed. One test section made by aluminium has been machined to verify the capability of the numerically controlled milling machine. The final RFQ cavity is now under construction.

This paper summarizes the current physics and mechanical design of the CPHS RFQ and presents the fabrication status of the test section.

Table 1: Design Parameters of the CPHS RFQ

Parameters	Value	Unit
Species	Proton	
Type	Four-vane	
Frequency	325	MHz
Input beam energy	50	keV
Output beam energy	3.0	MeV
Peak beam current	50	mA
Emittance (norm. rms)	0.2	π mm mrad
Maximum surface field	32.1	MV/m
Pulse length	0.5	ms
Pulse repetition rate	50	Hz
RF peak power	537	kW
Beam duty factor	2.5	%
Section number	3	
Total length	296.87	cm

PHYSICS DESIGN

The RF frequency of 325 MHz is chosen so that any future high-energy extension of the linac can be operated at the 4th harmonic frequency of 1.3 GHz which is common to many modern accelerator R&D programs. The objective of the physics design is to obtain high transmission rate of the proton beam with tolerable total length of the RFQ. Moreover, there will be no MEBT following the RFQ to save space and cost. The proper match between the RFQ and DTL must be supplied.

The physics design of the 3 MeV/50 mA RFQ was completed by Lloyd Young et al. The transverse and longitudinal focusing at the high energy end of the RFQ and at the entrance of the DTL have been tailored to provide continuous restoring forces independent of the beam current. The transverse and longitudinal zero-current phase advance are 300 deg/m and 200 deg/m

*Work supported by the "985 Project" of the Ministry of Education of China.
#xqz@tsinghua.edu.cn

respectively at the high energy end of the RFQ. The inter-vane voltage is increased with the longitudinal position which is of benefit to producing a short RFQ. The design result of the various parameters of the CPHS RFQ is shown in Fig. 2, in which *B* is the focusing strength, *X* is the focusing parameter, *A* is the acceleration parameter, *W* is the synchronous energy, Φ_s is the synchronous phase, *m* is the modulation factor, r_0 is the mean bore radius, and *a* is the minimum bore radius.

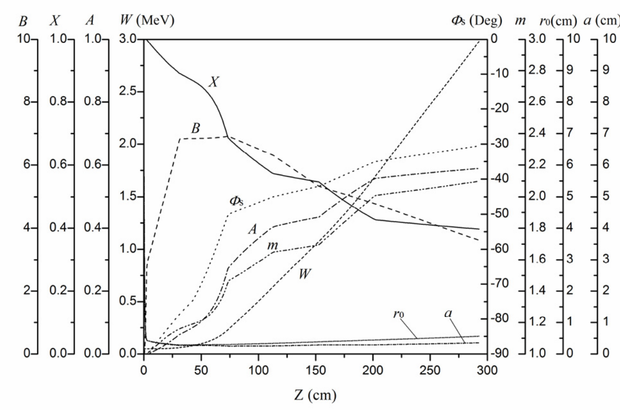

Figure 2: Various parameters of the CPHS RFQ versus longitudinal position.

The cavity cross section and vane-tip geometry are tailored as a function of longitudinal position while limiting the peak surface electric field to 1.8 Kilpatrick. Fig. 3 gives the half-width of the vane base versus longitudinal position.

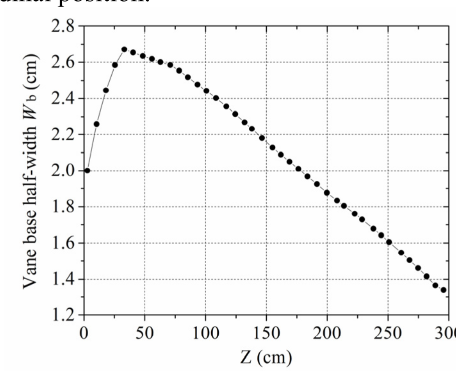

Figure 3: Vane base half-width versus longitudinal position.

The physics design and dynamic simulation of the CPHS RFQ are carried out by the code of PARMTEQM [2]. The effects of image charges, higher order multipole field components and two-dimensional space-charge calculation are included in this code. The beam dynamics for the input current of 60mA is shown in Fig. 4. The transmission rate given by PARMTEQM is 97.2%. The particle distribution in the transverse plane x-y at the entrance and exit of the RFQ are presented in Fig. 5. The matched input Twiss parameters are: $\alpha_{ix,y}$ =1.35 and $\beta_{ix,y}$ =7.73 cm/rad. The transverse emittance only increases 20% when the beam reaches the high-energy end of the RFQ.

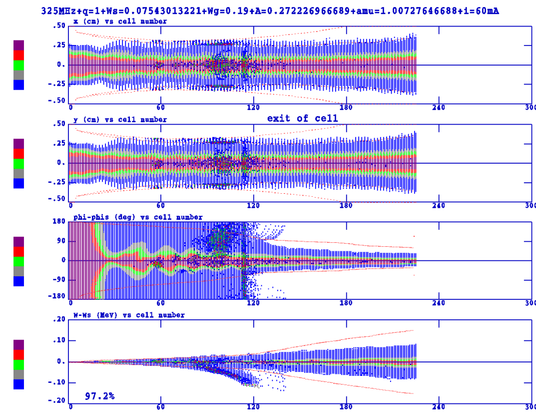

Figure 4: Beam dynamics in the RFQ by PARMTEQM for the input current of 60mA.

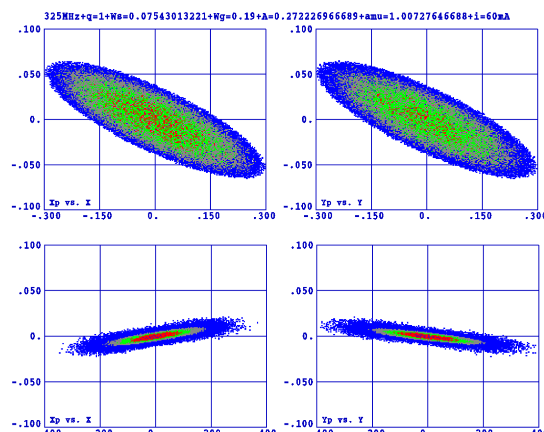

Figure 5: Particle distribution in the transverse plane x-y at the entrance and exit of the RFQ.

The dynamics calculation has been crosschecked by the code of TOUTATIS from R. Duperrier [3]. With the same input parameters, TOUTATIS gives the transmission of 95.7% (total) and 94.9% (Accelerated). The transverse emittance increases by 30%. The transmission versus position given by TOUTATIS is shown in Fig. 6.

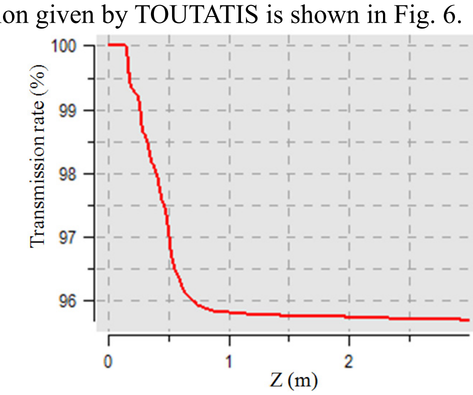

Figure 6: Beam transmission versus position by the code of TOUTATIS.

ENGINEERING DESIGN

The RFQ is mechanically separated into three sections to facilitate machining and brazing. Each of the three sections has a length about one meter. No coupling plates will be adopted between the adjacent sections. The eight dipole-mode stabilizer rods are located on the two flanges at the entrance and exit of the RFQ.

There are undercuts at the two ends of the RFQ vanes. The MAFIA code [4] has been used to establish the three-dimensional (3D) model to optimize the design of the undercuts. The modulation of the vane tip is not included in the model. The structure parameters of the undercuts are chosen to keep the calculated frequency of the TE_{210} mode equal to the designed value. Fig. 7 shows the 3D model including the undercut. There exists a ramp to ease the water cooling of the undercut region because the maximum local RF power dissipation in the RFQ occurs here.

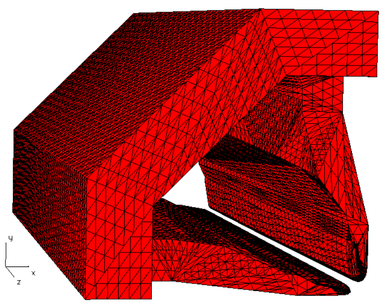

Figure 7: 3D model established by the MAFIA code to optimize the undercut design.

The dipole-mode stabilizer rods are adopted to keep the frequency interval between the operating mode and its neighboring dipole modes as large as possible. The position of the stabilizer rods are determined by the SUPERFISH code [5] to keep the frequency of the TE_{210} mode unvaried. Thereafter 3D calculation of the MAFIA code is carried out with different length of the rods. Fig. 8 gives the position of the rod designed by SUPERFISH and the relationship between the frequency interval and length of the rods by MAFIA. The result shows that when the length of the rods is 17.5 cm, the frequency interval between the TE_{210} mode and its neighboring dipole modes (TE_{111} and TE_{112}) is maximum (6.0 MHz), as shown in Fig. 8 and Table 2 (the tuners are excluded).

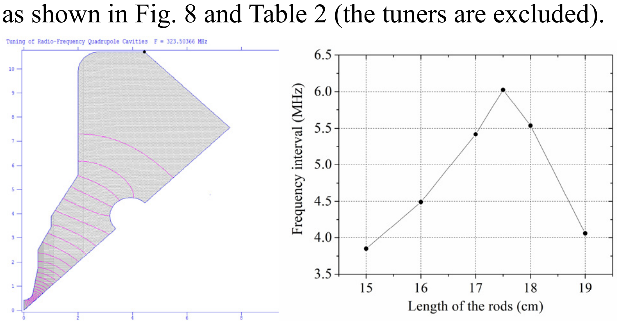

Figure 8: Design of the position and length of the dipole-mode stabilizer rods.

Table 2: Frequencies of the Modes in the CPHS RFQ

Modes	TE_{111}	TE_{210}	TE_{112}
Freq. without rods (MHz)	318.4	320.1	332.8
Freq. with rods (MHz)	314.2	320.2	326.2

The total peak power dissipated in the RFQ cavity is 537 kW, including the structure power of 387 kW and beam power of 150 kW. One iris coupler will be used located at the end of the second section, as shown in Fig. 1. The eight vacuum ports locate in the first and second sections, between two adjacent tuners. The RF coupler and vacuum system are now under design.

The velocity of the cooling water is chosen to be 1.6 m/s. Result of the theoretical calculation [6] gives that the total consumption of the cooling water is about 770 l/min with the pipe diameter of 9 mm.

PRESENT STATUS

Construction of the CPHS RFQ will be undertaken by Shanghai Kelin Tech Co. Ltd. One piece of the RFQ vane made by aluminium has been machined to verify the capability of the numerically controlled milling machine. Fig. 9 shows the test section and the three-coordinates measuring machine. Another aluminium section which consists of the RMS part and the cavity will be machined for the next step.

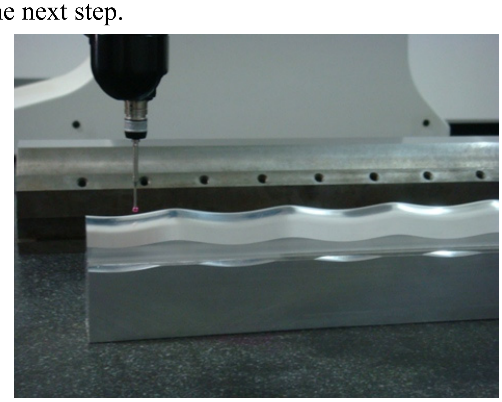

Figure 9: Test section machined by Kelin Co. Ltd.

ACKNOWLEDGMENT

The collaboration with Shanghai Kelin Tech Co. Ltd. for the machining of the RFQ cavity is highly appreciated. This work has been supported by the "985 Project" of the Ministry of Education of China.

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