DEVELOPMENT OF THE 3MeV RFQ FOR THE COMPACT PULSED HADRON SOURCE AT TSINGHUA UNIVERSITY*

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Abstract

We present, in this paper, the design and construction status of a Radio Frequency Quadrupole (RFQ) accelerator for the Compact Pulsed Hadron Source (CPHS) at Tsinghua University. The 3-meter-long RFQ will accelerate protons from 50 keV to 3 MeV at an RF frequency of 325 MHz. In the physics design we have programmed the inter-vane voltage as a function of beam velocity, to optimize the performance of the RFQ, by tailoring the cavity cross section and vane-tip geometry as a function of longitudinal position while limiting the peak surface electric field to 1.8 Kilpatrick. There will be no Medium-Energy-Beam-Transport (MEBT) following the RFQ. We have machined three test sections and the final RFQ accelerator is now under construction. We will describe the status of the RFQ system in this paper.

INTRODUCTION

A Four-vane Radio Frequency Quadrupole (RFQ) accelerator is under construction for the Compact Pulsed Hadron Source (CPHS) project at Tsinghua University. The CPHS project started its construction in June 2009 and will consist of a 13 MeV proton linac, a neutron target station, a small-angle neutron scattering instrument, a neutron imaging/radiology station, and a proton irradiation station [1][2]. As the injector of the 13 MeV Drift Tube Linac (DTL), the main parameters of the CPHS RFQ are listed in Table 1.

Table 1: Design Parameters of the CPHS RFQ

Parameters	Value	Unit
Frequency	325	MHz
Input/Output energy	0.05/3.0	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	%
Total length	296.87	cm

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PHYSICS DESIGN

The main characteristics of the CPHS RFQ are:

- 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.
- No MEBT will be placed between the RFQ and DTL to save space and cost. 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 inter-vane voltage is increased with the longitudinal position which is of benefit to producing a short RFQ. 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.
- The coupling plates are not necessary for the 3 m-long RFQ.

The physics design of the RFQ was completed by Lloyd Young et al [3]. The design result is shown in Fig. 1, with *B* the focusing strength, *X* the focusing parameter, *A* the acceleration parameter, *W* the synchronous energy, Φ_s the synchronous phase, *m* the modulation factor, r_0 the mean bore radius, and *a* the minimum bore radius.

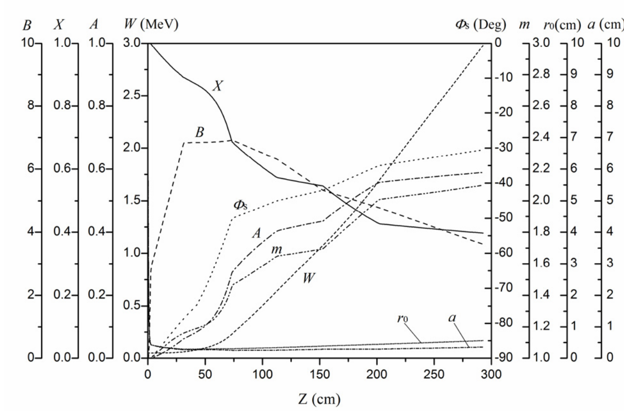


Figure 1: Parameters of the CPHS RFQ versus longitudinal position.

The inter-vane voltage versus longitudinal position is given in Fig. 2. The increased gap voltage can substantially enhance the accelerating field, thus shortening the RFQ [4]. However, the vane-tip geometry and cavity cross section vary as a function of longitudinal position, as shown of the vane base half-width in Fig. 2.

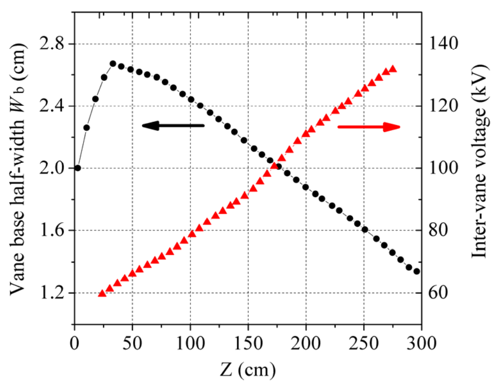


Figure 2: Vane base half-width and inter-vane voltage versus longitudinal position.

The first four quadrupoles in the DTL are used to match the beam from the RFQ to DTL by TRACE3D [5], as shown in Fig. 3. The transverse and longitudinal zero-current phase advance are about 300 deg/m and 200 deg/m respectively at the high energy end of the RFQ, which are matched with the corresponding values at the entrance of the DTL.

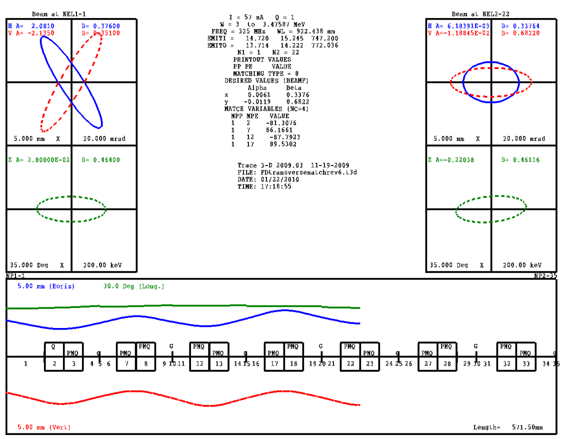
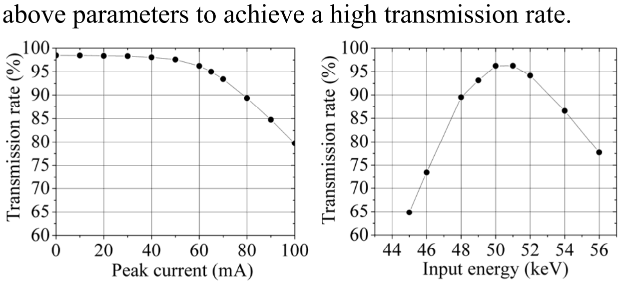
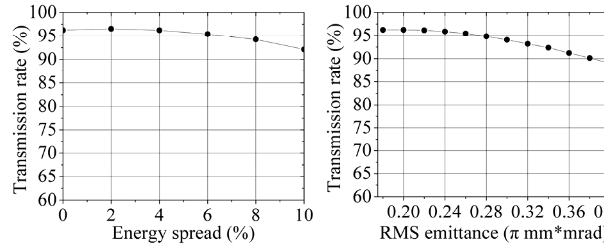


Figure 3: Match calculation from the RFQ to DTL by TRACE3D [5].

The transmission rate given by PARMTEQM [6] is 97.2%, which has been described in [3]. In the following we present the parameter analysis result by another code, TOUTATIS [7]. With the mesh level increased, the transmission rate of 97.3% (total) and 96.3% (Accelerated) are given by TOUTATIS with the same input parameters as PARMTEQM. Fig. 4 shows the transmission rate variation with the input current, energy, energy spread and emittance respectively. It gives the tolerances of the above parameters to achieve a high transmission rate.



(a) Peak current (b) Input energy



(c) Energy spread (d) Emittance

Figure 4: Transmission rate variation by TOUTATIS with the input current, energy, energy spread and emittance.

ENGINEERING DESIGN AND FABRICATION STATUS

The drawing of the CPHS RFQ structure is shown in Fig. 5. 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.

- Undercuts and dipole-mode stabilizer rods

The eight dipole-mode stabilizer rods (Fig. 6(a)) are located on the flanges at the entrance and exit of the RFQ. The optimized frequency interval between TE_{210} and its neighboring dipole modes (TE_{111} and TE_{112}) is 6.0 MHz, when the length of the rods is 17.5 cm.

- Power coupler

One ridge-loaded waveguide coupler (Fig. 6(b)) is under design which is located at the second section. 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. The CPHS RFQ and DTL share a single klystron which can supply the peak RF power of 2.5 MW with a duty factor of 3.33%.

- Vacuum system

There are totally nine vacuum ports for the CPHS RFQ. Eight of them are for the ion pumps and located in the first and second sections (Fig. 7(a)), while one is for the pre-pumping by one molecular pump located in the third section.

- Cooling system

For each section, there are 20 cooling passages in the main cavity (Fig. 7(b)). There are also separate cooling passages for the tuners, vacuum ports, RF coupler and end plates. The stabilizer rods don't need cooling. The velocity of the cooling water is chosen to be 1.6 m/s. The total consumption of the cooling water is about 770 l/min with the pipe diameter of 9 mm. The cooling water temperature is set as 25°C.

- Tuner

There are totally 47 slug tuners for the whole RFQ. There ought to be one tuner at the position of the power coupler but it is occupied by the coupler. The diameter of the tuners is chosen to be 50 mm.

- End plates

The design of the low-energy end plate has been finished. Necessary adjustment of the position of the stabilizer rods is needed. The high-energy end plate is under design.

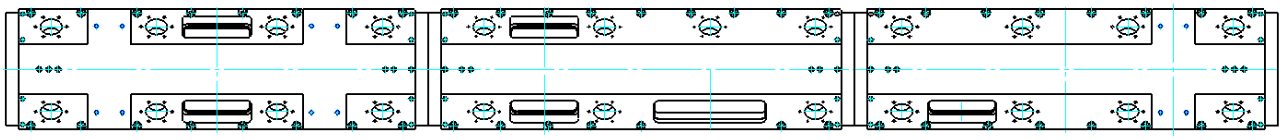
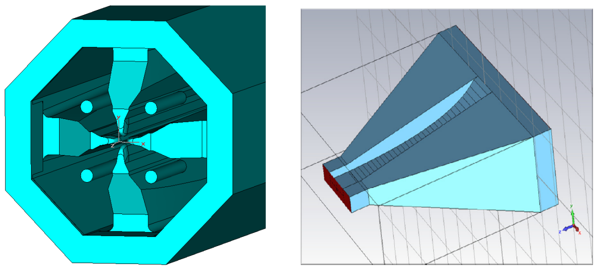
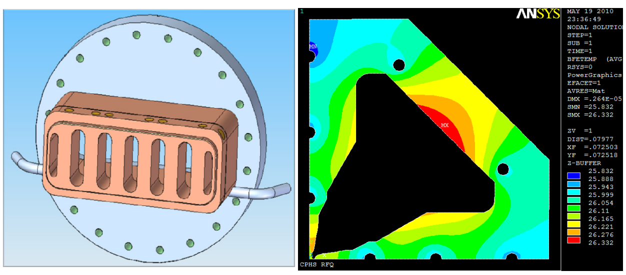


Figure 5: Structure drawing of the CPHS RFQ at Tsinghua University.



(a) Undercuts and stabilizer rods (b) Power coupler

Figure 6: Structure design of the undercuts, dipole-mode stabilizer rods and power coupler.



(a) Vacuum port (b) Cooling passages of the cavity

Figure 7: Design of the vacuum port and cooling passages.

All the three sections of the CPHS RFQ will be machined, brazed and assembled by August 2011 by Shanghai Kelin Tech Co. Ltd. Three test pieces have been machined up to now. Fig. 8 shows one test vane including the Radial Matching Section (RMS) part after the fine machining in the CNC Machine. The ball-end mill, instead of the forming cutter, is adopted to machine the vane tip due to the inconstant transverse curvature of the vane tip. As shown in Fig. 8, the width of the vane base changes with the longitudinal position apparently. This vane will be measured in the three-coordinates measuring machine.

Figure 8: One test vane after the fine machining by Shanghai Kelin Company.

The construction of the CPHS RFQ will mainly consist of the following procedures:

- Material inspection
- Segment, deep drilling and measurement
- Cavity profile machining
- Brazing of the cooling-passage plugs and leak detection
- Machining of the cavity flanges, end flanges and blind flanges
- Fine machining and cleaning of the cavity
- Three-coordinates measurement
- Assembling and RF measurement
- Machining of the locating-pin and stop slot of the end flanges
- Cleaning and assembling
- RF measurement
- Brazing of the full section
- Vacuum leak detection and RF measurement
- Assembling of the three sections
- Vacuum leak detection
- Packaging

The RFQ operating temperature and measurement temperature are both chosen to be 25˚C, the same with the design temperature. The sections of the cavity will be brazed vertically in the furnace with the height of 3m and inner diameter of 750mm. The total tolerance after the machining and brazing is expected to be ±25 μm.

The OFHC copper for CPHS RFQ has been prepared and the inspection shows that 99.97% of the pure copper is guaranteed. The copper has been sectioned into several pieces. These pieces are recognized as major vanes and minor vanes. They are being deep-drilled these days.

ACKNOWLEDGMENT

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