CONSTRUCTION STATUS OF THE CPHS RFQ AT TSINGHUA UNIVERSITY*

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Abstract

We present, in this paper, the 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 deliver 3 MeV protons to the downstream Drift Tube Linac (DTL) with the peak current of 50 mA, pulse length of 0.5 ms and beam duty factor of 2.5%. The RFQ has been mechanically separated into three sections. A ball-end mill, instead of a forming cutter, is adopted to machine the vane tip due to its varying radius of curvature. The precision of the numerically controlled milling machine has been verified by machining test pieces of aluminum and copper. Fine machining of the vanes was completed in July, 2011. The pre-braze tuning was completed at the beginning of this August.

INTRODUCTION

A four-vane Radio Frequency Quadrupole (RFQ) accelerator is under construction for the Compact Pulsed Hadron Source (CPHS) project at Tsinghua University, which was launched on June, 2009 [1][2]. This 3-meter-long RFQ accelerates a 50 keV proton beam from the ECR source to 3 MeV. To facilitate the machining and brazing, the RFQ is mechanically separated into three segments. Electrically the RFQ accelerator is a single resonant cavity. Fine machining of the vanes was completed in July, 2011. The pre-braze field tuning has been completed. The status of the machining, assembly and pre-braze tuning of the CPHS RFQ is presented in this paper.

RFQ DESIGN

In the CPHS RFQ design, the inter-vane voltage increases with the longitudinal position z. While limiting the maximum surface field to 32.1 MV/m (1.8 Kilpatrick), the mean bore radius r_0 also increases with z. The RFQ is relatively short and has a high transmission rate. The value of •/r_0 , where • is the transverse curvature of the vane tip, is kept constant throughout the structure. A CNC machine with a ball-end mill is used to machine the vane tip.

The vanes will be brazed together in a vertical orientation in a vacuum furnace. To facilitate the machining and brazing, the whole RFQ cavity is separated longitudinally into three segments. Each segment contains two major vanes and two minor vanes, as shown in Fig. 1. There are 20 parallel cooling-loops in each segment. The plugs at the two ends of the segments have been brazed after the deep-drilling of the cooling passages followed by annealing, as shown in Fig. 2.

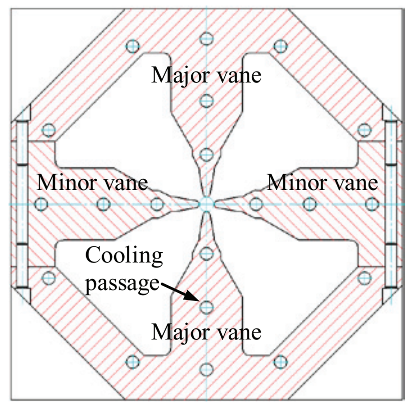

Figure 1: Cross section of the first segment at a fixed longitudinal position.

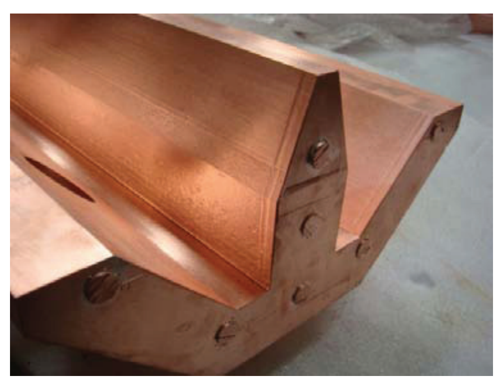

Figure 2: Brazed plugs at the ends of the cooling-passages.

Fig. 3 shows a 3D model of the CPHS RFQ cavity. It contains one RF coupling port in the center section for the ridge-loaded waveguide power coupler, nine vacuum ports among which eight are for the ion pumps and one is for a turbomolecular pump, and 47 ports for slug tuners.

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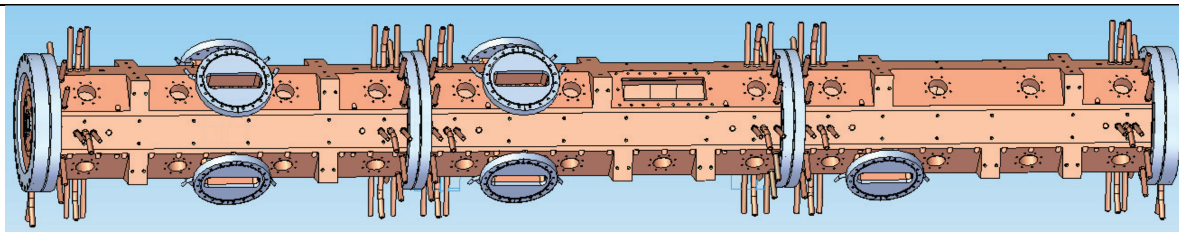

Figure 3: 3D model of the CPHS RFQ.

VANE MACHINING

The machining and brazing of the vanes are carried out at Kelin Tech Co. Ltd in Shanghai. Aluminum and copper test segments have been machined firstly with the ball-end mill in the CNC to validate the technique. Fig. 4 shows the vane-tip of one aluminum test segment being machined. After validation the machining of the copper vanes is carried out in three steps: rough machining, semi-finishing (residual depth is 0.5 mm) and fine machining. The semi-finishing and fine machining use the same machining program.

Figure 4: Vane-tip machining of an aluminum test segment with the ball-end mill.

A numerical three-coordinate measuring machine, CMM, was used to verify the accuracy of the longitudinal and transverse curvature of the vane-tip after the fine machining of each vane.

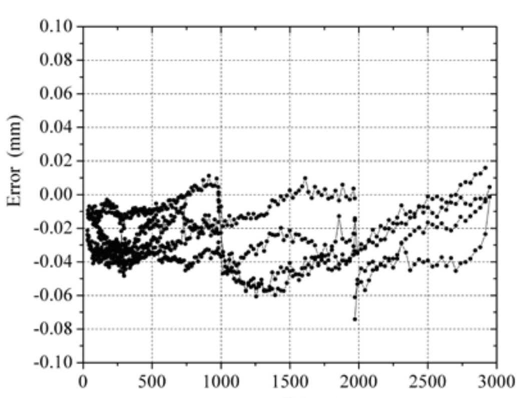

Figure 5: CMM result for the vane-tip height vs. z of all the vanes.

Fig. 5 shows the measurement result of the longitudinal curvature for all 12 major and minor vane tips. It gives the manufacturing error and refers to the difference between the measured and designed contour. The result shows that the contour error is smaller in the first segment. The deviation can be partly compensated by the adjustment of the minor vanes during the assembly of the cavity.

ASSEMBLY

After chemical cleaning, the four vanes are mounted together. The most important step is to fine-adjust the position of the minor vanes to keep the gaps between adjacent vane-tips at the designed dimensions. After the major vanes are aligned, their positions are fixed. The simple way to adjust the vane-tip gap is to push in or pull out the minor vanes in the horizontal plane. The minimum gap between the adjacent vane-tips is measured. After adjustment the gap distance is within ±50 µm of the designed value. Then the relative position of the four vanes is fixed by pins. Fig. 6 shows the assembled first segment of the CPHS RFQ.

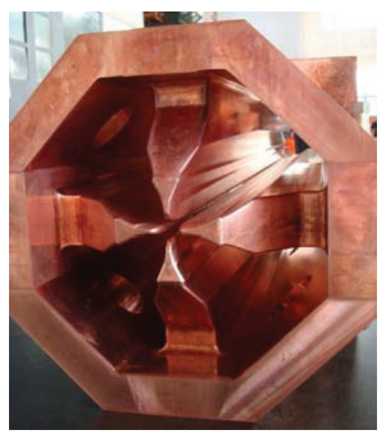

Figure 6: Assembled first segment of the CPHS RFQ.

After the assembling of the three segments, the minimum vane-tip gaps at the position of the tuners and vacuum ports are measured by pin gauges, as shown in Fig. 7. Most of the points are within ±50 µm of the designed values. The four curves represent the gap errors between the measured and designed values for the four quadrants respectively. While the errors are all small there is a small systematic error in the assembly with the gaps being larger near the centre of the RFQ.

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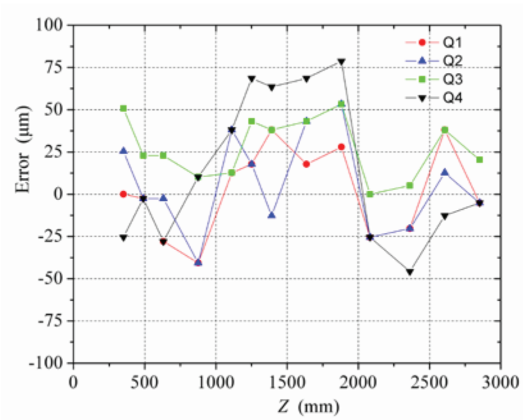

Figure 7: Measurement result of the vane-tip gaps at the position of the tuners and vacuum ports.

FIELD TUNING

The three segments are aligned longitudinally for the field tuning, as shown in Fig. 8. The objective of the tuning is: 1) acquire the required frequency; 2) obtain the measured quadrupole field within 1% of the designed values; 3) minimize the dipole modes; 4) maximize the frequency interval between the quadrupole mode and its nearest neighbourhood dipole modes.

Figure 8: Assembled CPHS RFQ for the pre-braze tuning.

To decrease the noise in the measurement, the whole cavity is kept in the tuning room for several hours before the tuning. The cavity is filled with Nitrogen gas to control the humidity inside. The tuners are initially set flush with the inner surface. The insertion depth of the dummy coupler is 0.9 mm, the same with the actual coupler. The vacuum flanges are all mounted on the ports. Four dipole tuning rods are mounted on each end flange.

The tuning step mainly contains four steps: 1) determine the insertion length of the dipole tuning rods. The length is found to be 15 cm for all the rods with the diameter of 1.5 cm, (See Fig. 9, the 3D simulation result gives 14.7 cm) which separates the nearest dipole modes from the desired quadrupole mode by 5 MHz. 2) Measure the frequency spectrum. 3) Measure the field distribution by the bead-pull method. 4) Calculate the insertion depth of each tuner with the RFQTUNE code [3] and adjust the tuners. Step 2) to 4) is iterated for several times to carry out the tuning.

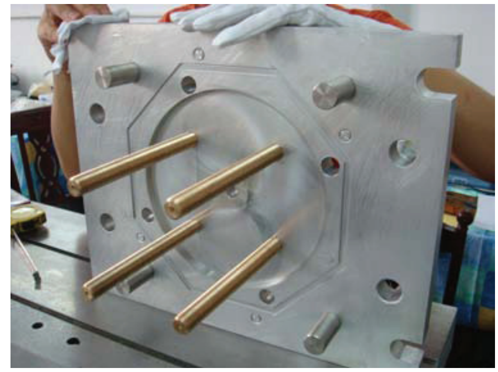

Figure 9: The dipole stabilizer rods.

Fig. 10 shows the field distribution of the quadrupole and dipole modes after the tuning is completed. The result shows that the quadrupole field is within 1% of the designed value, and the admixture of the two dipole modes are less than 1% of the quadrupole mode. The peaks in the measurement curves are from the tuner perturbations, which are not included in the analysis.

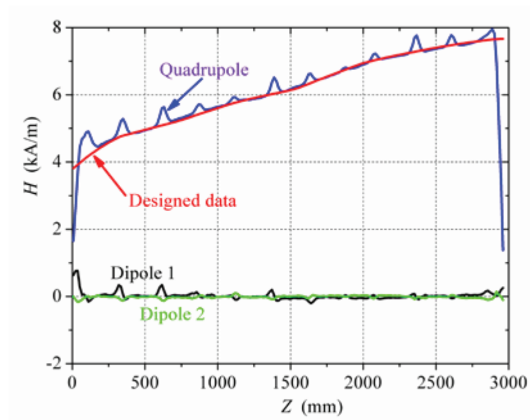

Figure 10: Field distribution of the quadrupole and dipole modes after the pre-braze tuning.

After the vanes and the flanges are brazed together, the final tuning is expected to be carried out in this September.

ACKNOWLEDGMENT

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REFERENCES

[1] J. Wei, et al., "The Compact Pulsed Hadron Source Construction Status", IPAC'10, MOPEC071 (2010)
[2] Q.Z. Xing, et al., "Development of the 3MeV RFQ for the Compact Pulsed Hadron Source at Tsinghua University", LINAC'2010, TUP046 (2010)
[3] L. Young, "Tuning and Stabilization of RFQ's", LINAC'1990, p. 530 (1990)

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