HIGH POWER TEST AND BEAM COMMISSIONING OF THE CPHS RFQ ACCELERATOR*

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Abstract

We present, in this paper, the high power test result and the beam commissioning status of a Radio Frequency Quadrupole (RFQ) accelerator for the Compact Pulsed Hadron Source (CPHS) at Tsinghua University. The 3-meter-long RFQ is designed to 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 repetition rate of 50 Hz. The RFQ has been designed, manufactured, and installed at Tsinghua University. High-vacuum test of the RFQ has been carried out carefully and the cooling system has been mounted. At the beginning of 2013, the high power RF test has been performed and the first 3 MeV proton beam is obtained with the peak current of 44 mA, pulse length of 50 μs, and repetition rate of 50 Hz.

INTRODUCTION

A four-vane 3 MeV Radio Frequency Quadrupole (RFQ) accelerator is constructed for the Compact Pulsed Hadron Source (CPHS) project at Tsinghua University [1~3]. The 3 MeV proton beam will be delivered to the beryllium target to produce the neutron this year. After the high-vacuum test, the water-cooling system of the RFQ accelerator was mounted and tested in Dec. 2012. RF conditioning was performed in Feb. 2013 and the first 3 MeV proton beam has been obtained with the peak current of 44 mA, pulse length of 50 μs, and repetition rate of 50 Hz. The high power conditioning and beam commissioning of the CPHS RFQ accelerator are presented in this paper.

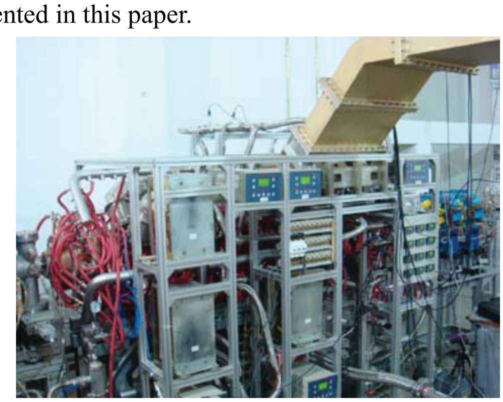

Figure 1: CPHS RFQ accelerator system at Tsinghua University.

HIGH VACUUM TESTING

To facilitate the machining and brazing, the 3-meter-long RFQ cavity is separated longitudinally into three segments. Each segment contains two major vanes and two minor vanes, with a length of about one meter. Eight ion pumps (200 l/s) are adopted for the pumping of the RFQ cavity, one of which is for the pre-pumping with one oil-free molecular pump (650 l/s) and one dry pump (8 l/s) located in the third RFQ segment. There is another ion pump (50 l/s), one oil-free molecular pump (100 l/s) and one dry pump (2 l/s) located at the side of the power coupler. High vacuum reaches 1.7×10^{-6} pa on Dec. 2, 2012, which was measured at the vacuum port of the power coupler, as shown in Fig. 2.

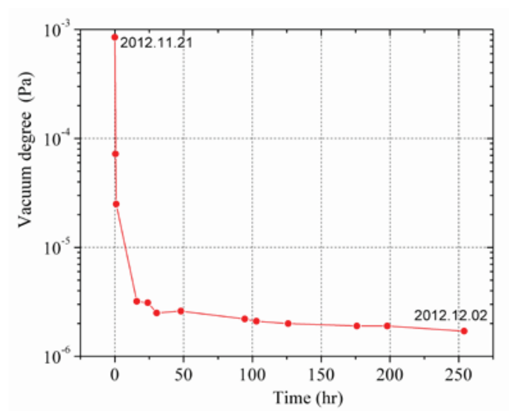

Figure 2: High-vacuum test history for the CPHS RFQ.

RF CONDITIONING

The RF power system consists of a signal generator, an exciting amplifier, a klystron, pulsed high voltage power supply (PHVPS), a modulator, crowbar protection device, and RF transmission subsystem [4]. The DTL being constructed downstream the RFQ will share the same klystron, which can supply the peak RF power of 3.0 MW with a duty factor of 3.33%. One four-port circulator and half-height WR2300 waveguides are adopted to transmit the RF power to the RFQ as shown in Fig. 3. After the DTL is constructed in 2014, a power divider, an isolating attenuator and an isolating phase shifter will be added to the RF transmission system.

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Klystron Test

The klystron is tested to ensure the desired operation before the power is fed to the RFQ. With the frequency of 325.1~325.3 MHz from the signal generator, and DC high voltage output of 70 kV to the klystron cathode, the pulsed output power of about 5 kW from the klystron is obtained with a repetition frequency of 50 Hz and pulse width of 600 µs (a duty factor of 3%).

Figure 3: CPHS RF power system.

RFQ Conditioning

The total peak power dissipated in the RFQ cavity is designed as 537 kW, including the structure power of 387 kW and beam power of 150 kW. One ridge-loaded waveguide coupler is adopted to feed the RF power into the RFQ [5]. A directional coupler in the waveguide system close to the RF input window enables the detection of the input and reflected power. Two crystal detectors are calibrated for the power measurement. The RFQ conditioning is carried out in two steps.

Firstly set the repetition frequency of 1 Hz and pulse width of 600 µs unchanged, and increase the klystron output power. Without power input the vacuum degree is read as 1.2×10^{-6} pa by one cold gauge at the vacuum port of the RFQ power coupler. The sparking is observed by one mirror through the beam hole at the high energy end. Serious sparking leads to worse vacuum and shall damage the RFQ cavity, therefore the input power is decreased when sparking happens. Another way to observe the sparking is to monitor the reflected power at the directional coupler. In this step the input power is increased up to 404 kW.

Secondly, the pulse width of 40 µs is set to be unchanged, and the repetition frequency is increased from 1 Hz to 50 Hz step by step (1, 2, 4, 8, 16, 25, 40, 50 Hz). After the repetition frequency is increased each time, the input power is raised from a low value up to 550 kW gradually. The measured power at the Klystron output port and RFQ coupler is shown in Fig. 4.

Inter-vane Voltage Measurement

The inter-vane voltage of the CPHS RFQ is planned to be measured from x-ray emissions. One High-purity Germanium (HPGe) detector system is adopted to measure the x-ray energy spectrum, as shown in Fig. 5. The peak inter-vane voltage can be extrapolated from the upper end-point energy of the spectrum [6]. The detector head is shielded by one lead sheet with about 5 mm thick. The HPGe detector is calibrated by Am241 and Cs137. During measurement electromagnetic interference is found to interfere with the detector signal (Fig. 6). Electromagnetic shielding of the cables and electronic cabinet will be performed later to obtain a correct energy spectrum.

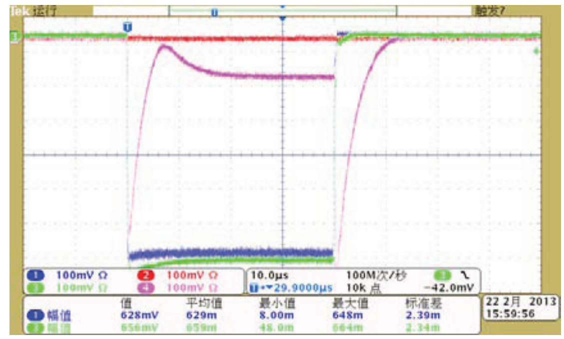

Figure 4: Power measurement during RFQ conditioning. (Channel 1: output power from Klystron; Channel 2: reflected power to the Klystron; Channel 3: input power to RFQ; Channel 4: reflected power from RFQ).

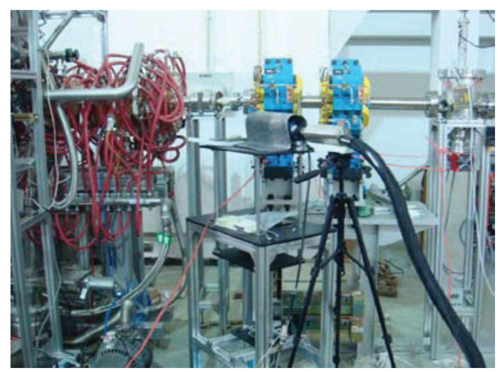

Figure 5: Inter- vane voltage measurement based on the HPGe detector system.

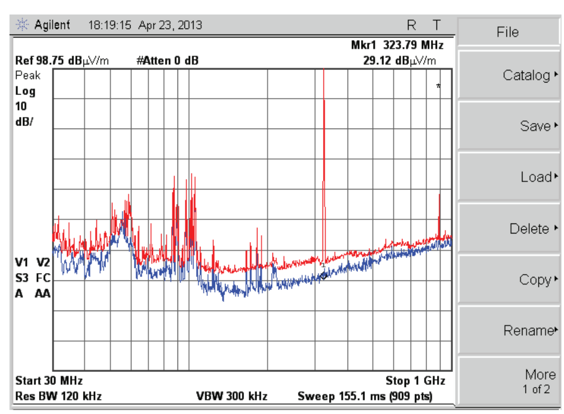

Figure 6: Electromagnetic interference signal measured near the accelerator. (Blue line: without RF power; Red line: with RF power. The highest peak of the red line is near 325 MHz).

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BEAM COMMISSIONING

To measure the beam current, one pluggable faraday cup is located at the exit of the ECR source, and one ACCT is at the entrance of the RFQ. An electron trap is placed just near the RFQ entrance to prevent the plasma electrons from flowing into the RFQ. As shown in Fig. 7, the current at the entrance of the RFQ is measured when the electron trap is turned off.

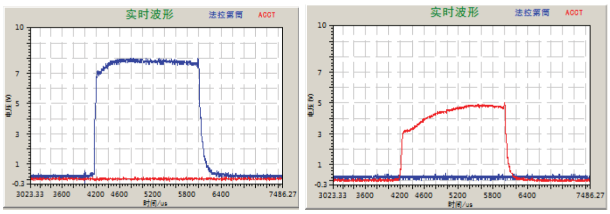

Figure 7: Output current of ECR source (left: 80 mA) and current at the entrance of the RFQ (right: 48 mA).

Fig. 8 shows the RFQ output current with the currents of the LEBT solenoids (I_{s1} and I_{s2}). The highest output current of 42.4 mA is achieved with I_{s1} =230 A and I_{s2} =349 A. With the prediction of the TRACK code [7], the highest transmission of 94% is obtained with I_{s1} =202 A and I_{s2} =396 A (the space charge neutralization rate in LEBT is set to be 97% and the input current of RFQ is 50 mA).

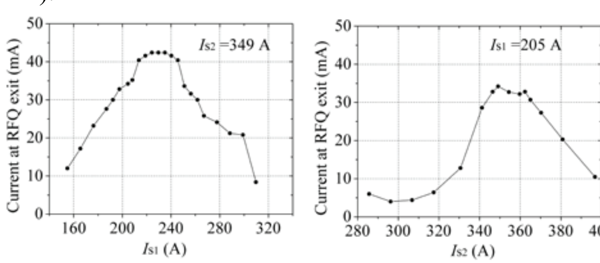

Figure 8: Current measured by ACCT at RFQ exit with currents of the first (left) and second (right) solenoids.

Highest transmission of the RFQ is obtained when the coil currents of the steering magnets in LEBT are zero, and the extraction voltage of the ECR source is 51.2 kV.

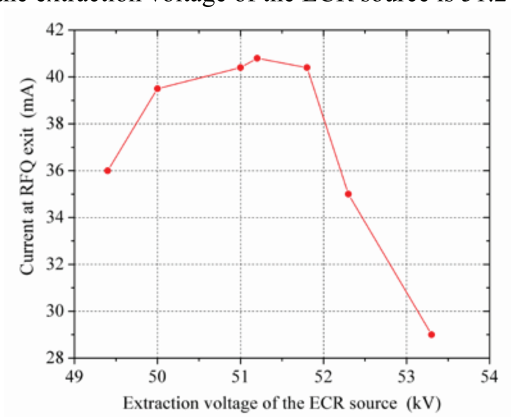

Figure 9: RFQ output current with the extraction voltage of the ECR source .

After the proton beam is accelerated by the RFQ, the output current is measured by one ACCT, and the beam stops inside one faraday cup eventually. With the pulse length increased to 50 μs and repetition rate to 50 Hz, stable beam has been achieved at the exit of the RFQ (Fig. 10). The injected power to the RFQ is 557 kW. Fig. 11 shows the ACCT signal at the entrance of the RFQ (Channel 2).

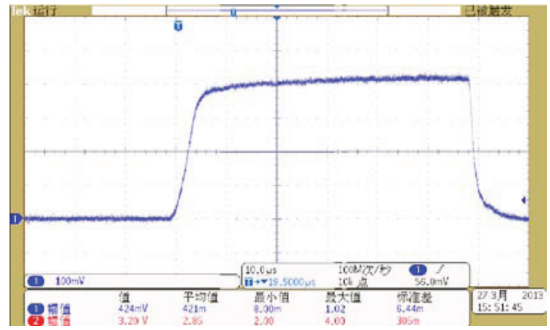

Figure 10: ACCT signal at the exit of the RFQ.

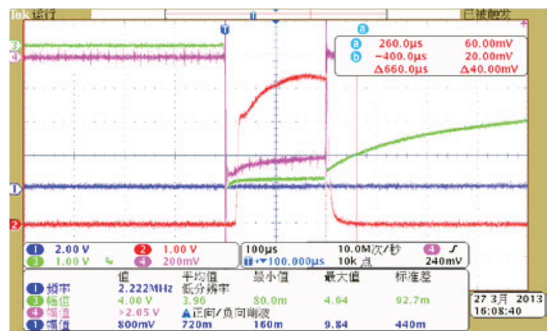

Figure 11: Channel 1: Current of the faraday cup at the exit of ECR source; Channel 2: ACCT signal at the entrance of the RFQ; Channel 3: magnetron voltage; Channel 4: magnetron current.

The 3 MeV proton beam is still in commissioning and accurate transmission measurement is expected after the electron trap works properly in front of the RFQ. Furthermore, the beam pulse length will be increased to 0.5 ms in future.

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