DEVELOPMENT OF THE INJECTOR II RFQ FOR CHINA ADS PROJECT*

Zhang Zhouli#, He Yuan, Shi Aimin, Sun Liepen, Zhang Bin, Jia Huan, Wang Xianwu, Pan Gang, Lu Liang, Shi Longbo, Xu Xianbo, Li Chenxing, Wang Wenbin, Wu Junxia, Wu Qi, Zhang Junhui, Zhu Tieming,Guo Yuhui, Zhao Hongwei, Liu Yong, IMP, Lanzhou 730000,China
D. Li, S. Virostek, M. Hoff, A. Lambert, J. Staples, LBNL, Berkeley, CA 94720, USA
C. Zhang, GSI, Darmstadt, Germany

Abstract

As one of the main components of the injector II of China ADS LINAC project, an RFQ working at 162.5MHz is used to accelerate proton beams of 15mA from 30 keV to 2.1 MeV. The four vane RFQ has been designed in collaboration with Lawrence Berkeley National Laboratory and built at the workshop of the Institute of Modern Physics, Chinese Academy of Sciences (IMP, CAS). Low power test of the cavity has been completed, and it shows the field flatness is within ±1% and the unloaded Q is 12600. RF conditioning has been completed, results of preliminary beam test show the output beam energy is 2.16 MeV with energy spread of 3.5% and the transmission efficiency is 97.9%. Continuous wave (CW) beam of 2.3 mA has been accelerated for more than one hour.

INTRODUCTION

A four-vane Radio Frequency Quadrupole (RFQ) accelerator has been designed at the Institute of Modern Physics, Chinese Academy of Sciences (IMP, CAS) for the Accelerator Driven System (ADS) project which has been launched in China since 2011. As one of the main components of Injector II of China ADS LINAC, the RFQ works at the frequency of 162.5 MHz and accelerates the proton beam of 15 mA from 30 keV to 2.1 MeV. The beam dynamics design, RF design and mechanical design of it have been introduced in detail in Ref. [1], and here fabrication, low power test, RF conditioning and preliminary beam test of it will be presented.

RFQ FABRICATION

The Injector II RFQ was designed in collaboration with Lawrence Berkeley National Laboratory (LBNL) and built at the IMP workshop. Because of the low frequency and the four-vane structure, the cross section of the RFQ is big which is 425 mm × 425 mm in dimension. There is little experiences in building of such a big RFQ, therefore, many fabrication tests including cutting tool test, machining test of single vane, brazing test and fabrication test of a half-meter long cavity have been carried out. Total length of the RFQ is 420.8 cm, and it had been divided into four modules to fabricate. 16 pairs of pi-mode rods and 80 tuners were employed in the RFQ cavity. Fabrication of the cavity (as shown in Fig. 1) had been completed by the end of 2013, and results demonstrated that the machining error of the vane modulation was within ±0.05mm, leakage rate of vacuum was less than 1×10^{-10} Pa·m3/s.

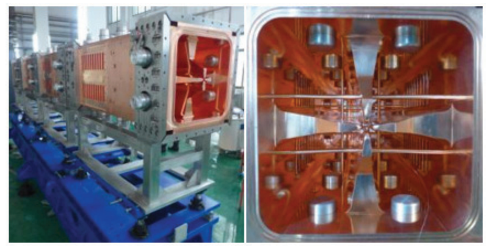

Figure 1: External and internal view of injector II RFQ.

LOW POWER TEST

Low power test of the injector II RFQ was carried out in a room with constant temperature which was 20^{o}C. The low power test bench was shown in Fig. 2, it mainly consisted of a pair of support frames which to hold the Kevlar thread, a dielectric bead whose diameter was 19 mm, a stepper motor and a vector network analyzer (VNA). Due to the big length of the cavity the dielectric bead was kept in touch with the vanes during the measurement to avoid the measurement error caused by the thread sagging. The fields was only measured in one quadrant of the cavity, because the symmetry of all the four modules was within ±1% when they were measured separately. It was the cavity frequency that was measured with the VNA, and the field could be derived from the frequency by the following formula [2]:

$$E \propto \mathrm{sqrt}\left(\frac{\omega\text{-}\omega_0}{\omega_0}\right) \quad (1)$$

where, E and ω are the local field and frequency at a certain position of the cavity, ω_0 is the cavity frequency when the bead was not in the cavity.

Figure 2: Low power test bench.

*Work supported by NSF under Contract No. 11079001
jolly@impcas.ac.cn

All the tuners were inserted into the cavity by 20 mm before measurement, and in the initial condition the field flatness was within ±0.039 as the black line shown in Fig. 3. Due to the large number of tuners of the cavity a tuning program [3] was developed to simplify the tuning procedure, and the field flatness reached ±0.015 after four times tunings of the tuners. The final field flatness was within ±0.01 (as the red line shown in Fig. 3) by adjusting the two gaps sizes between the endplates and vanes. The cavity frequencies and Q were measured after the tuning, and it showed the quadrupole frequency was 162.46 MHz and the adjacent dipole frequency was 183.4 MHz respectively, and the unloaded Q was 12600. Combing with the calculated unloaded Q which is14388 and cavity power which is 83.7 kW, the estimated real cavity power should be 95.5 kW.

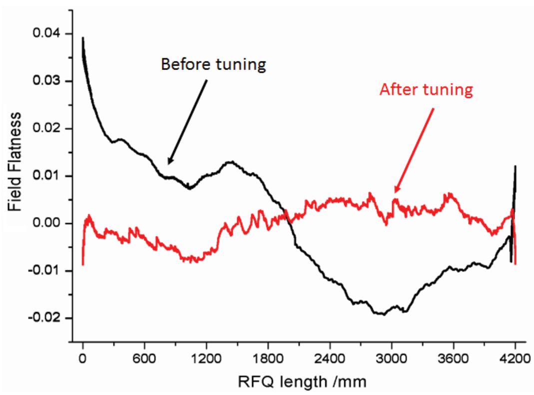

Figure 3: Field flatness before and after tuning.

RF CONDITIONING

Two couplers are used to feed RF power into the RFQ, as shown in Fig. 4. The total coupling strength is 1.324 for acceleration of 15 mA proton beams, so the coupling strength of each coupler is 0.662. A power splitter is used to divide the power from a RF amplifier into the two couplers, and a phase shifter is employed to balance the phase of the couplers.

RF conditioning started with a CW power of about 2 kW and then was conducted hard because electric sparking (as shown in Fig. 5) happened frequently. Therefore, RF power in CW mode and pulse mode were fed into the cavity alternately, and it finally took one and a half month to reach the CW power of 92.7 kW which corresponds the cavity voltage of 65 kV which was calibrated by X-ray end point method [4]. Vacuum was kept below 5×10^{-5}Pa and the ratio of reflection power to forward power was less than 5% during the conditioning process.

PRELIMINARY BEAM TEST

Preliminary beam test was carried out with pulse beam (5ms, 1Hz) and pulse RF power (150ms, 1Hz, 112kW). The RFQ acceleration system (as shown in Fig. 6) mainly consists of an ECR ion source, a low energy beam transport (LEBT) line, an RFQ and a beam test bench.

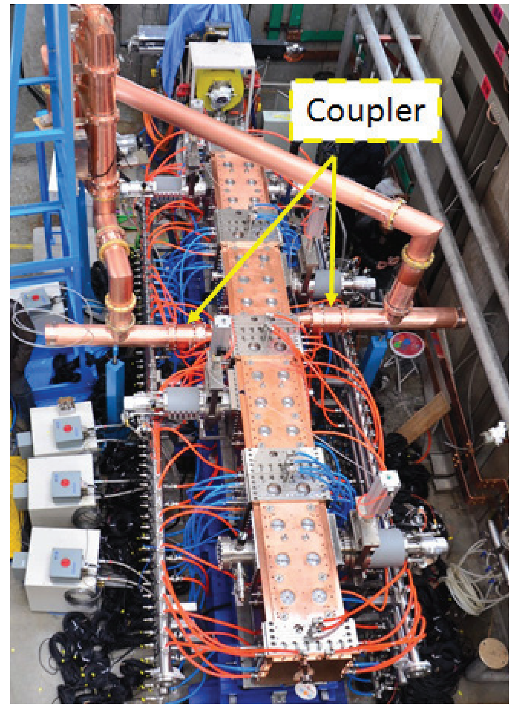

Figure 4: The injector II RFQ on site.

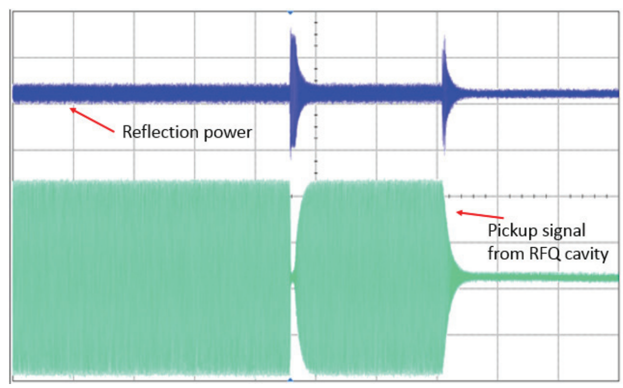

Figure 5: Sparking signal in cavity and transmission line.

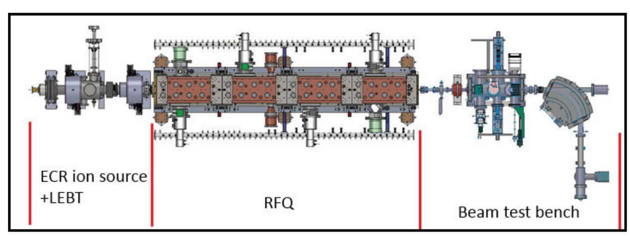

Figure 6: The injector II RFQ acceleration system.

Two ACCTs (AC current transformer) located at the exit of the RFQ are used to measure the transmission efficiency, two BPMs (beam position monitor) in the test bench are used to measure the beam energy, and a dipole magnet is used to measure the beam energy spread.

Beam signals from the Two ACCTs are shown in Fig. 7, in which the blue line is the beam signal before RFQ and the red line is the beam signal after RFQ. It shows the beam intensity injecting into the RFQ is 7.68 mA, and the output beam intensity is 7.52 mA, which means the

ISBN 978-3-95450-132-8

transmission efficiency is 97.9%. The time of flight between the two BPMs which have a distance of 1618.7 mm is 79.6 ns, from which the derived beam energy is 2.164 MeV. Energy spread is measured by the dipole magnet, and it shows the energy spread is 3.5%. Acceleration of continuous wave (CW) beam has also been tried, and beam of 2.3 mA has been accelerated for more than one hour, which was stopped due to the failure of RF amplifier.

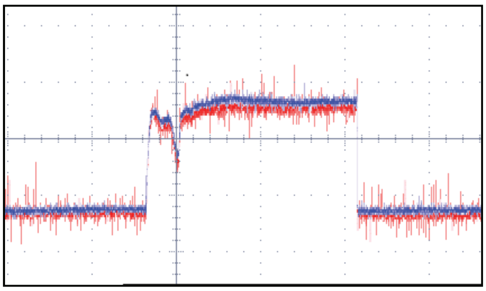

Figure 7: Beam signals from ACCTs before (blue) and after (red) RFQ.

SUMMARY

The injector II RFQ has been successfully built at IMP, and the low power test shows the field flatness achieves ±0.01 which is good for high transmission and working stably of the RFQ. RF conditioning has been completed, but it has taken a long time and electric sparking happened frequently during the conditioning process, one reason assumed is that the cavity may not be very clean. There is no circulator in the RF system up to now, therefore a circulator is required for long term stability of running of the RFQ. Low level RF system does not work well, too, hence it needs improving in the future. Meanwhile, only beam energy and transmission efficiency have been measured at present, more beam parameters need measuring in next step.

REFERENCES

[1] Zhang Zhouli, He Yuan, Shi Aimin, et al. Design of a four-vane RFQ for CHINA ADS project, in: Proceedings of LINAC2012, Tel-Aviv, Israel. THPB039. 2012.

[2] Klein. H, CERN accelerator school on RF engineering for particle accelerators, CERN 92-03,Vol.1,1992.

[3] Pan Gang, Research on tuning four-vane RFQ, dissertation of master degree, university of Chinese Academy of Sciences, 2013.

[4] P.N. Ostroumov, A. Barcikowski, B. Clifft, et al. High power test of a 57-MHz CW RFQ, Proc. Of LINAC 2006, Knoxville, Tennessee, USA, 2006, 767-769