A HIGH-DUTY FACTOR RADIO-FREQUENCY QUADRUPOLE ACCELERATOR FOR ADS STUDY IN CHINA

Huafu Ouyang, Shinian Fu, Keyun Gong, Tao Huang, Jian Li, Jiming Qiao, Taoguang Xu, Xinan Xu, Yuan Yao, Huashun Zhang, Zhonghua Zhang, Fuxiang Zhao, IHEP, Beijing, China
Xialing Guan, CIAE, Beijing, China, Jiaxun Fang, Zhiyu Guo, PKU, Beijing, China.

Abstract

A High-duty factor proton RFQ accelerator has been constructed at IHEP, Beijing for the basic study of Accelerator Driven Sub-critical System (ADS). The ADS basic study is supported by a national program for nuclear waste transmutation which is regarded essential for the rapid development of nuclear power plants in China. In the initial commissioning of the 3.5MeV RFQ with an ECR ion source showed a nice performance with a transmission rate about 93% and an output beam current of 44.5mA. The 352.2MHz RFQ is basically design for CW operation with the RF power source from LEP-II of CERN. This paper presents the beam commissioning and recent progress in high-duty factor operation from about 7% to 15%.

INTRODUCTION

Under the support of a national program, the high-duty factor proton RFQ accelerator design and construction was started in 2000 at IHEP, Beijing [1]. This is a 4.75m long 4-vane type RFQ that is composed of two resonantly coupled segments each consisting of two technological modules [2]. In table 1, the main parameters of the RFQ are listed.

Table 1: Main RFQ parameters

Parameters	Value
Input Energy	75keV
Output Energy	3.5MeV
Peak Current	50mA
Structure Type	4-vane
RF Frequency	352.2MHz
Maximum Surface E	33MV/m (1.8Kilp)
Structure Power	420kW
Beam Power	175kW
Total Power	595kW
Total Length	4.75m

When the fabrication and brazing of RFQ was finally finished at the end of 2005, the electric field measurement and tuning of the whole RFQ cavity was immediately started and finished in about two weeks due to the RFQ automatic tuning code developed together by INFN and IHEP [3]. As a result, the electric field flatness near the electrode tip was better than 2% and the component of dipole mode was less than 2%. After that, we began to install the whole accelerator that includes the ECR ion source, the low energy transport line (LEBT), RFQ and the high energy transport line (HEBT). HEBT mainly serves for beam diagnosis and beam dump. Figure 1 showed the RFQ in the installing process.

Figure 1: RFQ in the installing process

INITIAL BEAM COMMISSIONING WITH A LOW DUTY FACTOR

RFQ conditioning with a low RF duty factor but full RF power was rapidly accomplished through the following two steps: firstly to bake RFQ for vacuum conditioning without cooling water; secondly, to carry out high power conditioning with cooling water. The beam commissioning of the RFQ was started on July 10, 2006. During the beam commissioning, it took a comparative long time for us to have a reliable and stable ECR ion source. The initial beam commissioning was started at a low beam duty of 0.5% but a higher RF duty up to1.5%. At the third time of beam commissioning, we reached a transmission rate of 92% with an input beam of 44mA. This commissioning result is showed in Figure 2.

Two slits, an analyzing magnet and a multi-wire target locating at HEBT are used to carry out beam energy spectrum measurement. Both of the slits consist of two sloping planes, and for the first slits, the two sloping planes are embedded with water-cooling channels, which is also used as a beam dumper. The slits are installed upstream the analyzing magnet to align the beam and to define the beam trace in the magnet. The measured beam energy is only 40keV higher than the simulation result from PARMTEQM. As shown in Figure 3, the measured beam energy spectrum is also highly similar to that from the simulation code of PARMTEQM.

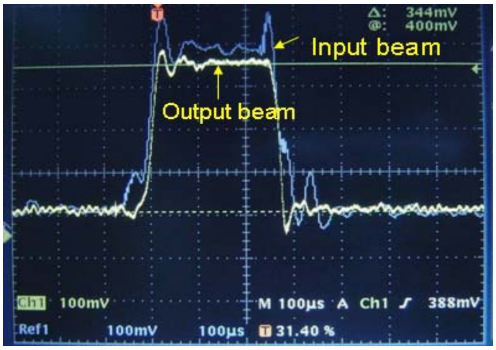

Figure 2: A beam transmission about 92% with an input beam current of 44mA and a beam duty factor of 0.5% is got in the initial beam commissioning.

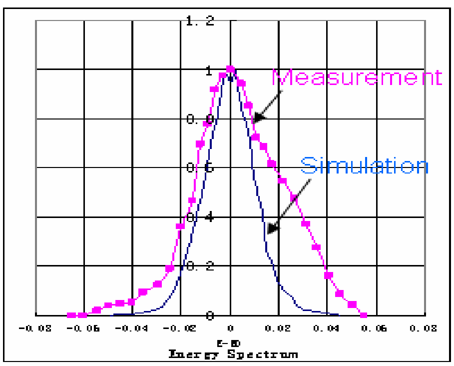

Figure 3: The measured energy spectrum is similar to the simulation result from PARMTEQM

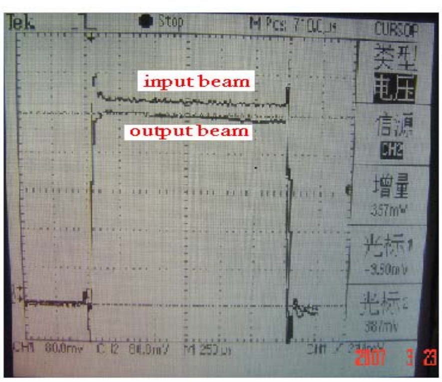

Figure 4: The output pulsed beam current is about 44.5mA with a beam transmission about 93% and beam duty factor of 7.15%.

Later on, the beam duty factor was boosted. The main performance is as follows: the output energy 3.5MeV, the output pulsed beam current 44.5mA, the beam pulse width 1.43ms, the repetition rate 50Hz, the beam duty factor 7.15%, the average beam current about 3.18mA and the beam transmission about 93%, as shows in Figure 4.

BEAM COMMISSIONING WITH A HIGHER DUTY FACTOR

In order to extend the beam duty factor, some systems or components need to be replaced, improved or examined.

The Coupling and End Plates

As to the RFQ cavity, the 352.2 MHz RFQ is basically designed for CW operation. There are 20 water-cooling channels distributed on the transverse cross section of the RFQ cavity wall and vane, and the cooling water on each channel flows through only one module and then flows back the water manifold. All the 64 tuners 8 vacuum ports and 4 RF couplers are also cooled independently. The coupling plate in the middle of RFQ and the two end plates are also water-cooling channels embedded but there is not water-cooling channel in the dipole mode stabilizer rods installed on theses plates. The rods are cooled indirectly by the cooling water in the plates. The successful beam commissioning has proved that the rods cooled by this indirect way can stand the RF dissipating power with a beam duty factor up to 7%. But the thermal analysis through simulations shows that the rods are hardly to stand the RF power with a beam duty factor higher than 15%. So a new coupling plate and two end plates on which the rods are installed and embedded with water-cooling channels are machined. Figure 5 shows the mechanical drawing of the coupling plate, on which the rods are installed and embedded with water-cooling channels.

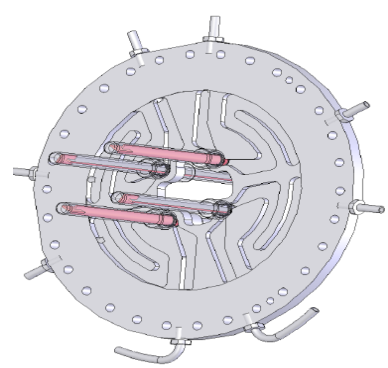

Figure 5: The mechanical drawing of the coupling plate, on which the rods are installed and embedded with water-cooling channels.

The Timing Trigger System

A new VME frame 6U timing trigger system is made to replace the original CAMAC frame timing trigger system. The maximum work repetition rate is 50Hz provided by the original timing system. But for a beam pulse width 1.4ms, which mainly limited by the energy stored capacitor of the high-voltage pulse-power supply for the RF system, we need at least a 110Hz work repetition rate to obtain a beam duty factor higher than 15%. The new timing trigger system includes 3 parts:

The first one is the main timing board that outputs the system working repetition rate. The second one is the delaying and broadening board. The third one is the differential driving board for LLRF system.

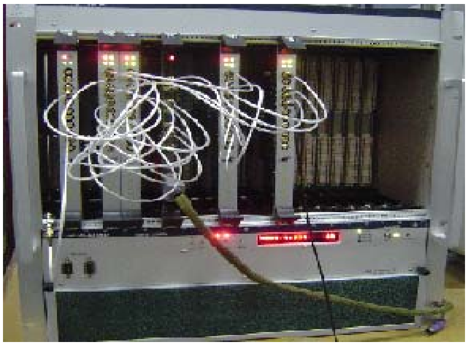

Figure 6: The VME frame timing trigger system.

The Beam Dumper

As mentioned above, the first slit consists of two slope planes which embedded with water-cooling channels. The two slope planes also acts as a dumper. This dumper is designed for a beam duty factor of 7%. In order to afford a beam duty factor higher than 15%, a new dumper is machined. For the new copper dumper, the water-cooling channel of the plane has a fish-bone structure. Its surface is plated with aluminium to decrease nuclear activation. Figure 7 shows the new dumper.

Figure 7: The new dumper with two slope plates.

Improvement of Digital LLRF Control System

After improvement of the digital LLRF control system, now the digital LLRF system can work at 200Hz repetition rate and 1.4ms pulse width. Both the feed-forward control and feedback control are incorporated into the digital LLRF control system, and the RFQ field variation can be maintained within ±1% in amplitude and ±1° in phase during the beam experiments.

Improvement of Water-cooling System

The cooling capability of the original water-cooling system located at the same experimental hall as the RFQ can only sustain a beam duty factor less than 12%. To heighten the cooling capability, additional cooling water from the IHEP water-cooling centre is got. Through the experiment, the new cooling system is proved to satisfy the cooling request of RFQ with a duty factor up to 17.5%.

RF Conditioning and Beam Commissioning with High Duty Factor of 15%

RF conditioning was carried out by increasing the repetition rate from 50Hz to 125Hz while keeping pulse width 1.4ms unchanging. In Figure 8, the time diagram of the RF conditioning is given. From this Figure, one can see that it only takes about 750 minutes to extend the RF duty factor from 7% to 17.5%.

Beam commissioning with a beam duty factor of 15% (a repetition rate of 125Hz and a beam pulse width 1.2ms) is also underway. An output pulsed beam current of 29mA from the RFQ was got at the initial commissioning. But more work is still needed for a higher beam transmission.

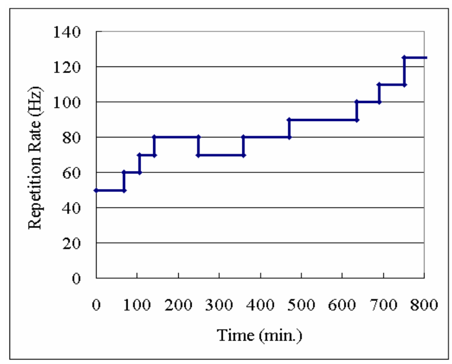

Figure 8: Time diagram of the RF conditioning.

CONCLUSIONS

We have succeeded to construct a high-duty factor proton RFQ. And a transmission of 93% and output current of 43mA was got in the initial beam commissioning with a beam duty factor about 7%. RF conditioning with a duty factor of 17.5% was also finished. Beam commissioning with beam duty factor of 15% is underway, and an output pulsed beam current of 29mA was got.

REFERENCES

[1] S. Fu, X. L. Guan et al., "R&D Status of A 3.5MeV RFQ Accelerator for ADS Study in China", LINAC'02, Gyeongju, 2002, p.155 (2002);

[2] H. F. Ouyang, S. Fu, et al., "The study on the design of an intense-beam RFQ with stabilization", LINAC'04, Gyeongju, 20042, p.750 (2004);

[3] G. V. Lammanna, S. Fu, et al., "Field tuning of the TRASCO RFQ", EPAC2002, 2002, Pairs, p.924 (2002).