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DESIGN AND BEAM COMMISSIONING OF THE LEAF-RFQ*

L. Lu†, W. Ma, H. Jia, Y. H. Zhai, Y. Yang, L. P. Sun, L. B. Shi, L. T. Sun, Y. He, H. W. Zhao
Institute of Modern Physcis (IMP), CAS
509 Nanchang Rd., Lanzhou, Gansu 730000, China

Abstract

An 81.25 MHz continuous wave (CW) radio frequency quadrupole (RFQ) accelerator has been designed and fabricated for the Low Energy Accelerator Facility (LEAF) by the Institute of Modern Physics (IMP) of the Chinese Academy of Science (CAS). The operation frequency is 81.25 MHz and the inter-vane voltage is a constant of 70 kV. It took about 44 hours continuous conditioning to reach RF power of 75 kW which is 1.1 time of the maximum designed operational power, and the successful CW acceleration of 150 eμA He^+ beam to the designed energy of 0.5 MeV/u. Both the results of the high power test and the beam test will be reported in this paper.

INTRODUCTION

The LEAF project was launched as a pre-research facility for the high intensity Heavy Ion Accelerator Facility (HIAF) project and a heavy ion irradiation facility for material research at IMP [1] [2]. The LEAF will consist of a 2 mA U^{34+} electron cyclotron resonance ion source, a low energy beam transport line, a CW 81.25MHz RFQ accelerator [3], a medium energy beam transport line and an experimental platform for nuclear physics. The layout of the LEAF project is shown in Fig. 1. The LEAF-RFQ shown in Fig. 2 will operate as a CW injector with the capability of accelerating all ion species from proton to uranium from 14 keV/u up to 500 keV/u. The design goal is to design a compact type cavity with lower power loss and high operation stability. Considering the LEAF-RFQ will operate in CW mode, a four-vane structure is a better choice than four-rod type, because the four-vane structure is a more stable structure for water cooling. The PISL (Pi-mode stabilizing loop) structure is adopted to suppress the dipole effect. In addition, tuners and undercuts are used for frequency tuning and field flatness. The main parameters of the LEAF-RFQ are listed in the table 1. In this paper, we report the designs and results of the low power test and the high power test.

Table 1: Main Parameters of the LEAF-RFQ

Parameters	Value
A/q	7
Operation	CW/pulsed
Vane type	Four vane
Frequency (MHz)	81.25
Input energy (keV/u)	14
Output energy (MeV/u)	0.5
Inter-vane voltage (kV)	70
Kilpatrick factor	1.55
Peak current (emA)	2
Transmission efficiency (%)	97.2
Acceleration efficiency (%)	81.7
Length of vane (mm)	5946.92
Average radius of aperture (mm)	5.805

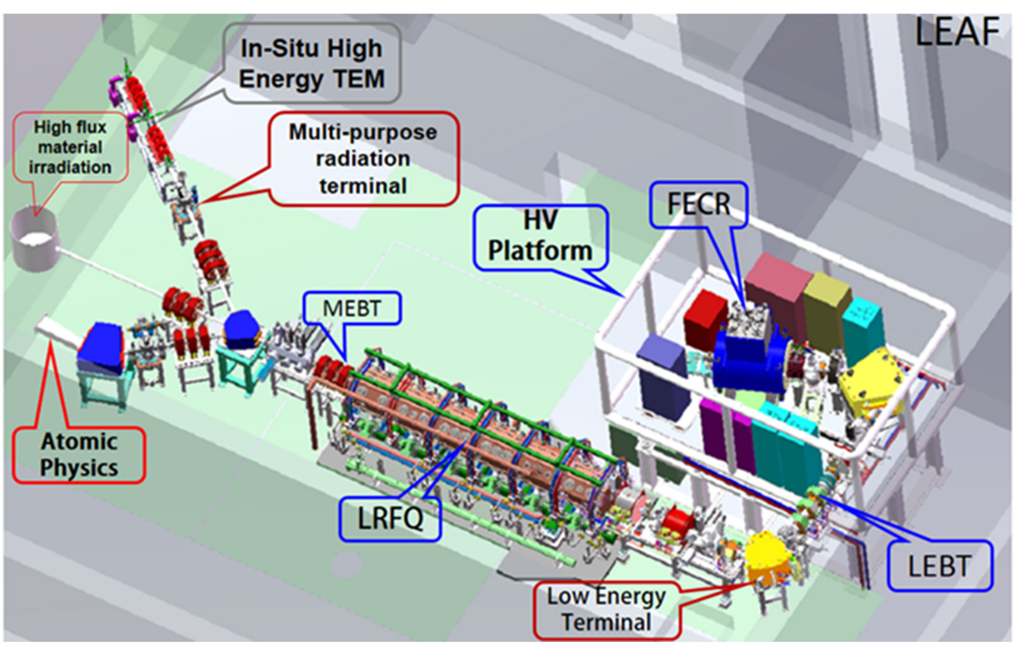

Figure 1: Layout of LEAF facility.

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†luliang@impcas.ac.cn

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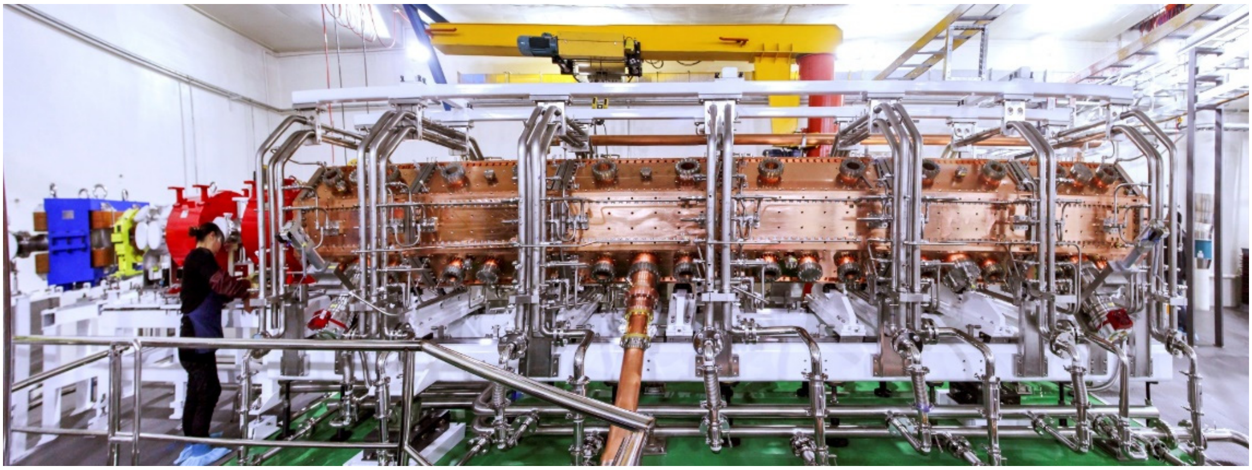

Figure 2: Side view of installed RFQ after full assembly on site.

DESIGN AND LOW POEWR TEST

The LEAF-RFQ is an octagon normal 4-vane structure with uniform-distributed 48 tuners and 12 pairs PISLs. The RFQ is 6m long and adopts two RF couplers. Based on our simulation of the thermal anlysis and multipacting, the RFQ could operate very stable. For fabrication, the RFQ was divided 6 segments. Each segment was connected by screws. The low power tests and tuning of the whole cavity were carried out through three steps. Firstly, frequencies, Q factor and fields were measured in the cavity with aluminum end-plates and aluminum tuners inserted into the cavity 26mm, the same situation as the simulation. Secondly, through the tuning code LRFQtuning (a code developed for LEAF RFQ tuning based on the Matlab), the depths of the tuners were adjusted to meet the requirements of frequency and fields. After a few iterations, a satisfactory resonant frequency and field distribution will be achieved. Lastly, the copper tuners with the final insertion and copper end-plates replaced aluminum those. This step was to check the resonant frequency and field distribution, meanwhile, the Q factor was measured.

The LEAF-RFQ low power test consists of each section test and the whole cavity test. The low power tests of single section were carried out to check the machining and brazing quality. The average frequency difference between the simulated and the measured after brazed is 10.15 kHz. The average frequency difference between the measured before brazed and after brazed is 23.35 kHz. Shown in table 2, the low power test of the full length RFQ showed that the final quadrupole mode frequency is 81.253 MHz which meets well with the design value of 81.25 MHz, the measured Q factor is 16230 which is 90.3% of the simulated value and the measured frequency separation was 5.54 MHz which is enough for safe operation. Figure 3 shows the measured longitudinal field distributions of the quadrupole, two dipole fields in the cavity with the tuned tuners [4]. The relative error of the quadrupole field is less than 1% and the admixtures of the two dipole modes are within 1.5% of the quadrupole field. Therefore, the frequency and field distribution meet the operation requirement.

Table 2: Main Parameters of the LEAF-RFQ

Measured results	Value
Quadrupole frequency (MHz)	81.253
Q factor	16230 (90.3%)
Q field relative error (%)	0.8
Admixture of dipole field (%)	1.5
Separated Δf (MHz)	5.587

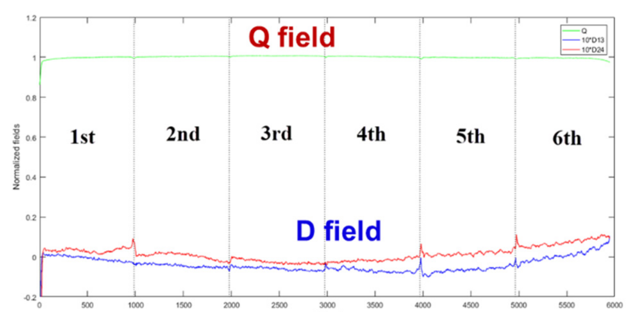

Figure 3: Measured Q and D field of the LEAF-RFQ.

RF CONDITIONING AND BEAM COMMISSIONING

After installing the equipment of vacuum, couplers, cooling routers, ARC detectors and pick-ups, and connecting with two 60kW solid state type RF source, the RF commissioning was started from Feb. 3^{rd} 2018 aiming to 75 kW (1.12 times of necessary power). With a base vacuum condition of $\sim 1\times10^{-5}$ Pa, it took about 44 hours continuous conditioning to reach the goal of 75 kW.

The LEAF-RFQ was designed for $2 \leq A/q \leq 7$ ion acceleration, and the designed Kilpatrick factor was 1.54. The He^+ beam was adopted for beam commissioning. The first pulse beam used 100 μA He^+ ions passed the RFQ in Feb. 9^{th} 2018. Under the condition of pulse beam, the beam energy was measured as 0.5 MeV which meet the designed value. And two hours late, the first CW He^+ beam passed

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the RFQ. The current of the CW beam was measured 150 μA. With supplying of correction magnet, the beam conditioning was restarted in June 1st 2018, the beam transmission and acceleration efficiency were measured 97.21% and 50.11%, respectively. The measured transmission agreed with the design. The acceleration efficiency is lower than the design because an upstream multi-harmonic buncher is not installed yet.

Shown in Fig. 4 and Fig. 5, in Sep. 5th 2018, the first N^{2+} beam was successfully accelerated 110 μA up to the designed 500 keV/u with 97.97% transmission and 56.45% acceleration efficiency measured in pulse mode (5μs), and, the CW 110μA N^{2+} beam pass 15 minutes. The high current N^{2+} beam will be operated in one month when the multi-harmonic buncher is installed.

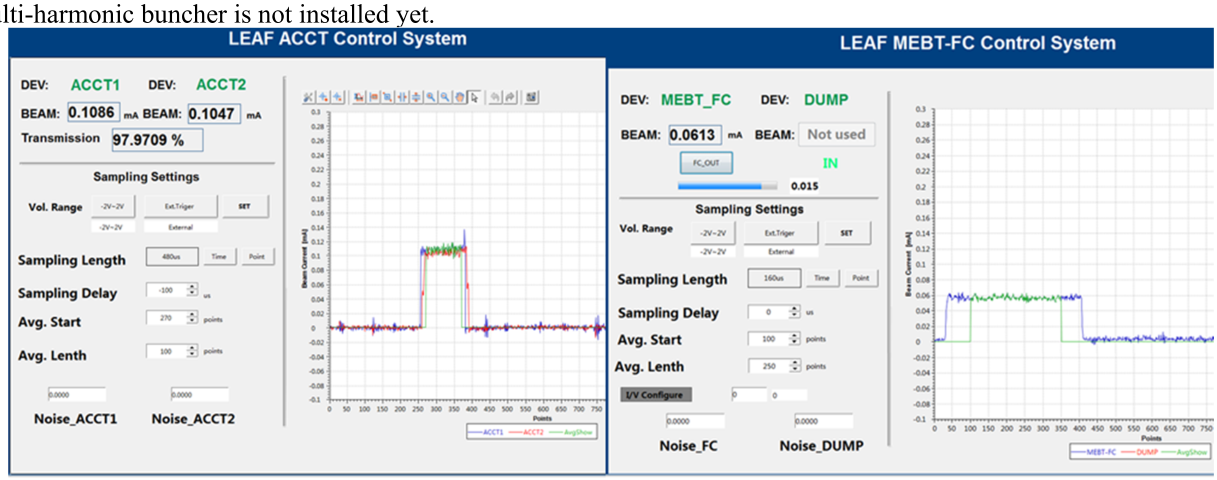

Figure 4: Measured signals of N^{2+} beam current form ACCTs and a Faraday Cup.

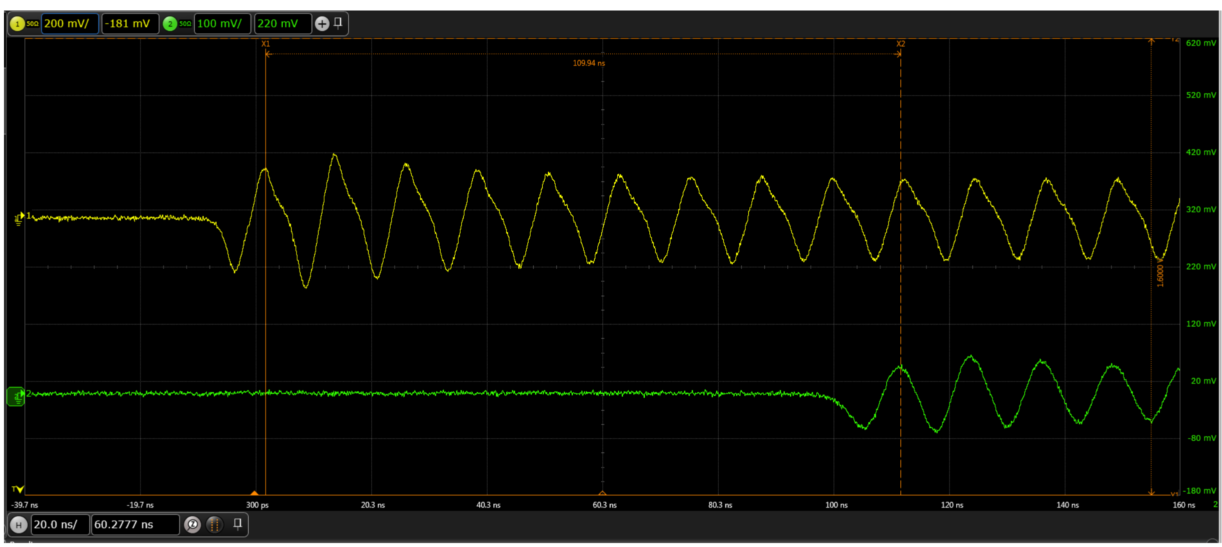

Figure 5: Measured signals of N^{2+} beam current from two BPMs.

CONCLUSION AND FUTURE PLAN

The LEAF-RFQ has been designed and simulated, and the beam test was successfully performed. The RFQ is an octagon four-vane type with 48 tuners and 12 pairs PISLs. It is about 6 m long with a good mode separation and a flat field distribution between inter-vanes. According to the high power test, several milestone goals have been achieved, such as the successful RF commissioning of LRFQ to its maximum designed power, and the successful CW acceleration of He^{+} beam and N^{2+} beam to the designed energy of 0.5 MeV/u with matched transmission. For the next, high intensity N^{2+} beam will be tested because the multi-harmonic buncher was installed already.

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