ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPORI28

INJECTOR SYSTEM DEVELOPMENT FOR 1 MeV/n RFQ AT KOMAC*

Han-Sung Kim†, Jeong-Jeung Dang, Dong-Hwan Kim, Sang-Pil Yun, Seung-Hyun Lee, Hyeok-Jung Kwon

Korea Multi-purpose Accelerator Complex/Korea Atomic Energy Research Institute, Gyeongju, Korea

Abstract

A Radiofrequency quadrupole (RFQ) system with 200 MHz frequency and 1 MeV/n output energy is under development at KOMAC (Korea Multi-purpose Accelerator Complex) for multiple purposes such as a test-stand for an ion source and low energy beam transport study, ion beam implantation for semiconductors and polymers and neutron generation for material study. We developed an injector system for the RFQ, which is mainly composed of a 2.45 GHz microwave ion source, low energy beam transport with two solenoids and a vacuum system with diagnostic chamber. The RFQ was designed to be able to accelerate beam with 2.5 mass-to-charge ratios (A/q) but we used a proton beam for initial test to characterize the injector system. Detailed description of the constructed injector system along with test results will be given in this paper.

INTRODUCTION

An RFQ (radio-frequency quadrupole) with the output beam energy of 1 MeV/n is under development at KOMAC, mainly for a test-stand to perform an ion injector and low energy beam acceleration study. We expect several research items to be carried out such as an advanced ion source operation based on the AI (artificial intelligence) technology, low energy beam diagnostics including multi-dimensional phase space reconstruction and testing of an advanced RF control technologies (adaptive feed-forward, non-IQ sampling).

In addition, the developed system can be used for the acceleration of helium beam with applications including semiconductor irradiation and membrane fabrication. The designed output energy of helium beam is 4 MeV, which is enough to penetrate the silicon wafer up to 18 um. To reduce the irradiation time and to increase throughput of ion beam treatment, higher beam current is preferred. With consideration of the ion source performance for He^{2+}, the beam current of the RFQ was determined to be 10 mA [1].

Through the acceleration of deuteron beam up to 2 MeV, a small-scale accelerator based neutron source for the neutron science and the nuclear material study is another important application in consideration.

The layout of the ion beam irradiation system based on RFQ is shown in Fig. 1. The system includes the ion injector, low energy beam transport (LEBT), RFQ, beam lines and the irradiation target. For the ion source, we use a microwave ion source with 2.45 GHz magnetron. The same type of the ion source is routinely used for the 100-MeV proton linac at KOMAC. For the LEBT system, we use two solenoids to match the beam parameters suitable for injection into RFQ. The magnetic LEBT system includes a vacuum system with a diagnostic chamber which is equipped with an emittance scanner and a beam profile monitor.

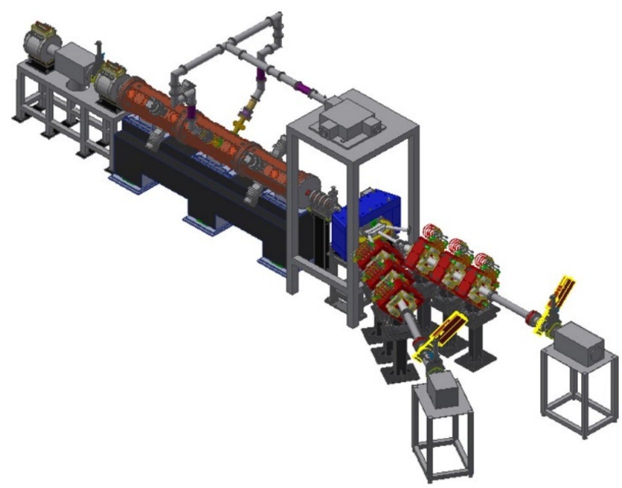

Figure 1. Layout of the ion beam system based on 200 MHz, 1 MeV/n RFQ and two beam lines.

The operation frequency of the RFQ is 200 MHz and with this choice of the RF frequency, we designed the RFQ with a four-vane type. Generally, a four-vane type RFQ is known to show better performance than the four-rod type in high duty operation point of view, while keeping the overall size of the RFQ within reasonably compact size [2].

We used PARMTEQ code for beam dynamics optimization for the RFQ. The optimization design parameters include the shaper energy, gentle buncher energy, vane voltage, and the aperture radius. During the optimization, we restricted the RF power and total length no more than 130 kW and 3.2 m, respectively. Design parameters are summarized in Table 1.

RFQ cavity consists of 3 sections and each section is about 1 m long. Under cut region at both ends of the structure is designed such that it results in flat field distribution better than 1 %. Each quadrant of single section contains four ports and total number of ports are 48. Eight of them are used for vacuum pumping with turbo-molecular pumps, two of them are for the coaxial type RF power couplers and another two of them are used for RF pickup ports. Rest of them are dedicated for slug tuner ports as shown in Fig. 2. Water-cooled slug tuner diameter is 70 mm and the frequency shift of 1 MHz is estimated with 9.7 mm insertion.

* This work was supported through KOMAC operation fund of KAERI by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT)(KAERI-524320-22).
† kimhs@kaeri.re.kr

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPORI28

Table 1. Summary of the RFQ Design Parameters

Parameter	Value
Particle	$^{4}He^{2+}$
Vane voltage	72 kV
Input beam energy	100 keV
Shaper energy	0.112 MeV
Gentle buncher energy	1.05 MeV
Output beam energy	4 MeV
Peak beam current	10 mA
Emittance (nor. Rms)	0.2 π mm mrad
Type	Four vane
RF frequency	200 MHz
RF power	126 kW
Maximum electric field	1.63 Kilpatrick
ρ/r_0	0.87
Length	3158.92 mm
Transmission	97.6 %

Figure 2. Fabricated RFQ

RFQ cavity were fabricated, inspected with 3D scanning and finally assembled by using brazing process. 3D scanning after final machining showed machining error within 20 um at vane tip region. Before brazing, we measured the resonant frequency spectrum on single section. Quadrupole mode (TE210-like) frequency was measured to be 200.980 MHz, whereas two dipole mode (TE110-like) frequencies were 201.751 MHz and 202.321 MHz. Note that if RFQ cavity length is too short as in single section in this case, quadrupole mode frequency is lower than dipole mode frequency, contrary to the full-length cavity, where quadrupole mode frequency is higher than dipole mode frequency. Calculation with MicroWave Studio code confirmed that dipole mode frequency is higher than quadrupole mode frequency in short single section by 1.3 MHz. Brazed structure went through RF tuning process including a resonant frequency adjustment and field flatness tuning. More details on RFQ design and fabrication can be found in Ref [3].

Ancillary systems to drive the RFQ include the RF system, the control system and the cooling system. The main RF amplifier system for the RFQ is a solid-state power amplifier with peak power of 240 kW driven by a digital low-level RF system. EPICS based control system is under development. The required cooling water flow rate is estimated to be about 33 m^3/hr to limit the temperature rise of the RFQ less than 1 degree centigrade, which is provided by using a dedicated chiller and cooling water distribution system.

The overall system includes two beam lines. To distribute the accelerated beam to each beam line, we installed a switching magnet (straight and 30 deg. bending). Each beam line is equipped with a quadrupole triplet and beam diagnostic devices such as an ACCT and a wire scanner as well as an irradiation chamber as shown in Fig 3.

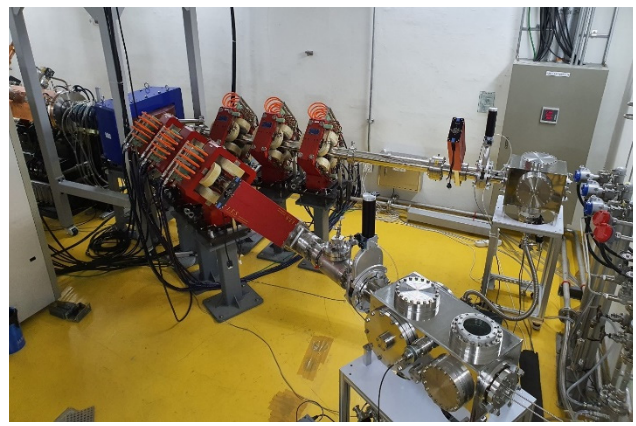

Figure 3. Installed beam line.

INJECTOR SYSTEM

The injector system consists of an 2.45 GHz microwave ion source, two solenoids for beam matching, diagnostic box with vacuum pumping system and an electron trap just in front of the RFQ inlet flange. For the present, we use an ion source which is same as the one used for a 100-MeV proton linac. Because the ion source is optimized for the 50 keV proton extraction up to 20 mA, it needs optimization for extraction of heavier ion with A/q up to 2.5. The ion source is equipped with single solenoid and electrically isolated from the microwave system by using isolation waveguide, which eliminated the use of isolation transformer and high-voltage deck. Pulse length can be varied from 50 us to 2 ms with the maximum repetition rate of 120 Hz. The ion source and the isolation waveguide is shown in Fig. 4.

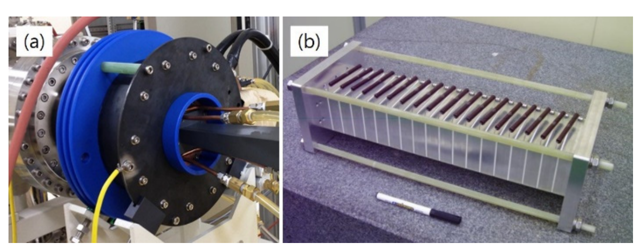

Figure 4. (a) Ion source with single solenoid, (b) Multi-layered isolation waveguide.

ISBN: 978-3-95450-215-8 ISSN: 2226-0366 doi:10.18429/JACoW-LINAC2022-TUPORI28

For beam matching to RFQ, we use two solenoids. The beam envelope can be found in Fig. 5 for proton beam and helium beam. Beam diagnostic devices includes two AC current transformer, an emittance scanner and a beam profile monitor. Overall injector system after installation is shown in Fig. 6.

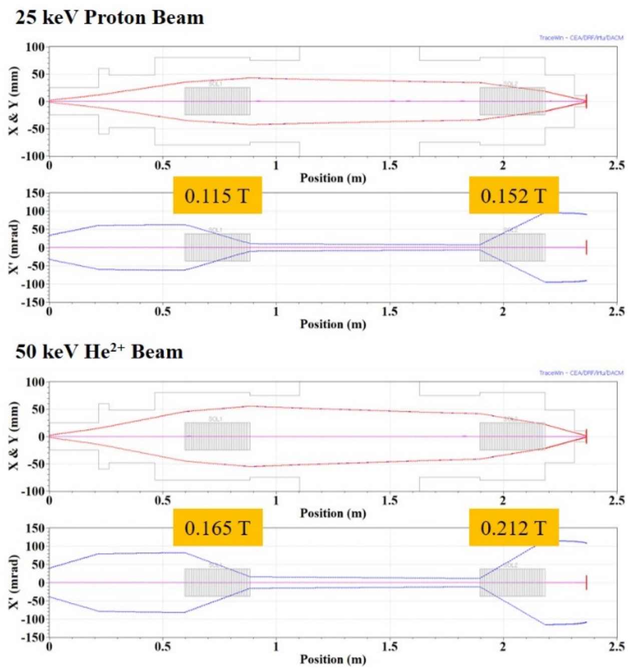

Figure 5. Beam envelope in magnetic LEBT for 25 keV proton beam and 50 keV He^{2+} beam.

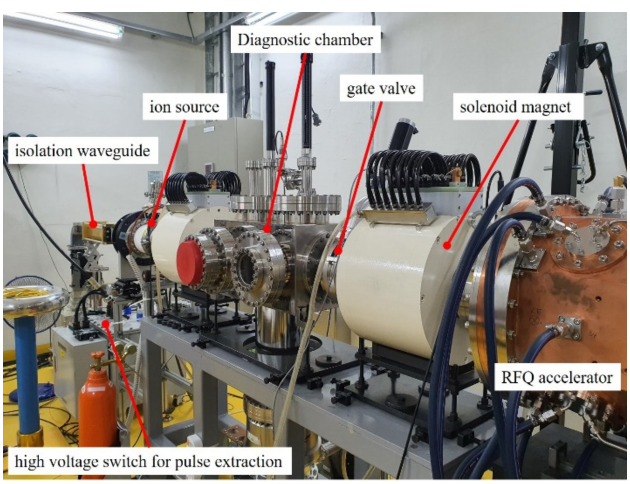

Figure 6. Installed injection system.

INITIAL BEAM TEST

To check the system integrity, we performed an initial beam test using proton beam with following conditions.

- Ion source vacuum: 8.0E-6 torr
- Microwave power: 340 W CW
- Ion source solenoid current: 70 A
- Extraction voltage: 27.5 kV
- Extraction pulse width: 1 ms
- Pulse repetition rate: 1 Hz
- LEBT solenoid current: 72.5 A / 84.0 A
- RFQ RF pulse width: 100 us
- RFQ RF peak power: 40 kW

Total extraction current from ion source was about 8.4 mA and the RFQ input current after LEBT was about 4.2 mA. The beam current at the RFQ output was about 3.1 mA with 40 kW RFQ RF peak power. We observed some portion of beam was inadvertently screened by beam profile monitor located between two solenoids in LEBT, which partially explained the discrepancy between the ion source extraction current measured right after the extraction electrode and the RFQ input current measured just before the RFQ. Proton ratio in the extracted beam (or H_2^+ fraction) was not measured directly, but we thought proton fraction could be as low as about 70%, taking the low microwave power into consideration. Maximum beam transmission of RFQ during the initial test was 84.7% without beam steering adjustment. The typical waveforms during the initial beam test is shown in Fig. 7.

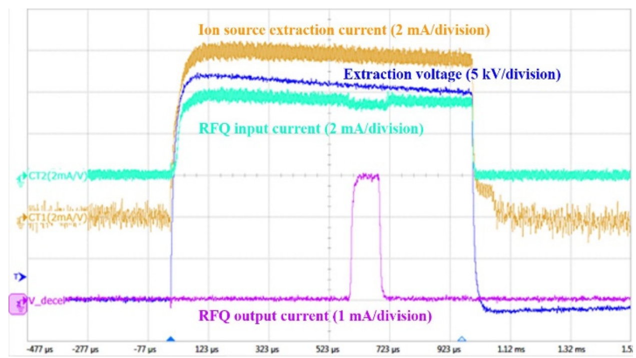

Figure 7. Typical waveform during the initial beam test, showing the ion source extraction current (8.4 mA), the extraction voltage (27.5 kV initial, 25 kV final), RFQ input current (4.2 mA) and RFQ output current (3.1 mA).

CONCLUSION

A Radiofrequency quadrupole (RFQ) system with 200 MHz frequency and 1 MeV/n output energy is under development at KOMAC (Korea Multi-purpose Accelerator Complex) for multiple purposes. We developed an injector system for the RFQ and performed the initial beam test using proton beam with over 80% transmission. By using the developed system, we expect the various machine and beam study to be performed as an accelerator test stand as well as a driver for various accelerator applications.

REFERENCES

[1] H.-J. Kwon, Y.-S. Cho, H. S. Kim, K. T. Seol, and Y.-G. Song, "Design of the 4MeV RFQ for the Helium Beam Irradiator", in *Proc. LINAC'14*, Geneva, Switzerland, Aug.-Sep. 2014, paper MOPP101, pp. 294-296.

[2] Thomas. P. Wangler, *RF Linear Accelerators*, 2nd edition, Wiley-VCH Verlag GmbH&Co., 2008

[3] H.-S. Kim *et al.,* "Design and Fabrication of 200 MHz Four-vane RFQ for Ion Acceleration", presented at IPAC'19, Melbourne, Australia, May 2019, paper MOPTS078.