Irradiation Beam Line Design of the 1 MeV/n RFQ at KOMAC

Hyeok-Jung Kwon [a*], Dong-Hwan Kim [a], Han-Sung Kim [a], Won-Hyeok Jeong [a], Jeong-Jeung Dang [a], Seunghyun Lee [a], Yong-Sub Cho [b]
[a]*Korea Multi-purpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju 38180*
[b]*Nuclear Physics Research Division, Korea Atomic Energy Research Institute, Daejeon 34057*
[*]*Corresponding author: hjkwon@kaeri.re.kr*

1. Introduction

A Radio-frequency Quadrupole (RFQ) has been developed for several application fields at Korea Multi-purpose Accelerator Complex (KOMAC). It was designed to accelerate various kinds of beams to 1 MeV/n with maximum A/q=2.5. The considered application fields are as follows. The first is to accelerate helium beam in order to irradiate the power semiconductor devices with the purpose of improving switching performance. The second is to accelerate the heavy ion beam in order to create micro-pore of the sample of which purpose is to produce filter system with nanoscale pore. The third is to accelerate deuteron beam to produce the neutrons with beryllium target [1].

The system layout is shown in Fig. 1. There are two beam lines in the system. One is an irradiation beam line which covers semiconductor irradiation and micro-pore production. It has 30 degree bending angle with respect to RFQ and the irradiation chamber is located in the RFQ accelerator room. The other is a neutron production beam line. The neutron production target will be located in the neutron facility room beside the RFQ room. Therefore, the neutron production beam line penetrates the wall in straight line to deliver the beam to the target. In this paper, system status is introduced and the design of the irradiation beam line is discussed.

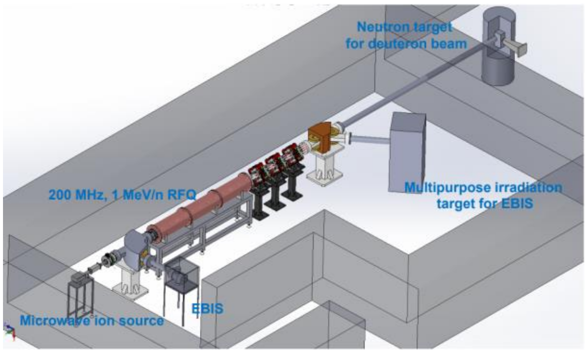

Fig. 1. Layout of the 1 MeV/n RFQ system.

2. System Status

The RFQ accelerator system consists of an ion source, a low energy beam transport (LEBT), a RFQ, two beam lines, a RF system and other ancillary system such as vacuum system, beam diagnostic system, cooling system, control system.

Two kinds of ion source were considered originally. One is a microwave ion source for helium beam and deuteron beam, the other is an electron beam ion source (EBIS) for highly charged heavy ion beam as shown in Fig. 1. A microwave ion source was installed to commission the system at first stage. It is the same type ion source with the one used for the KOMAC 100 MeV proton linac. It uses a 2.45 GHz magnetron as a microwave source. The magnetron is insulated from the high voltage section through the isolation waveguide. And the solenoid magnet is also insulated by the insulator. Therefore, there are no power supplies operated at high voltage potential, which greatly reduces the mal-function of the system caused by the high voltage arc.

A bending magnet is installed in the LEBT to filter the different A/q species. Two solenoids are installed to match the beam from the ion source into the RFQ. Also two steering magnets are installed. Recently, both the ion source and LEBT are being tested.

The design parameters of the RFQ is summarized in Table 1. The total length is 3.2 m long, and it consists of 3 sections. It was machined and brazed successfully [2]. Recently, the field tuning is underway.

Table 1: RFQ design parameters

Particle	$^4He^{2+}$
Input beam energy	100 keV
Output beam current	4 MeV
Peak beam current	10 mA
Emittance (nor. rms)	0.2 π mm mrad
Type	Four vane
RF frequency	200 MHz
RF power	130 kW
Maximum electric field	1.63 Kilpatrick
ρ/r_0	0.87
Length	320 cm
Transmission	96.4%

The RF system is also installed. A 200 MHz, 240 kW, 10% duty solid state amplifier (SSA) is used as an amplifier. The high power test was finished with the matched load. The low level RF (LLRF) system was developed too. It uses digital technology to control the RF amplitude and phase within 1% and 1°. Especially, it uses non-IQ sampling techniques and directly reads the RF signal and produces the 200 MHz output signal without any down-conversion or up-conversion stage [3]. The system preparation is shown in Fig. 2.

Fig. 2. Installation of the RFQ (Solenoid magnet, RFQ and bending magnet from right side to left).

3. Irradiation Beam Line Design

The output beam parameter from the RFQ was summarized in Table 2. In the initial design of the irradiation beam line, the helium beam was selected as a reference particle.

Table 2: RFQ output beam parameter

Particle	$^4He^{2+}$
Output beam energy	4 MeV
Twiss alpha in x	-2.060
Twiss beta in x	0.248 mm/mrad
Emittance (nor. rms) in x	0.164 π mm mrad
Twiss alpha in y	1.001
Twiss beta in y	0.106 mm/mrad
Emittance (nor. rms) in y	0.161 π mm mrad
Twiss alpha in z	0.198
Twiss beta in z	260.643 deg/MeV
Emittance (nor. rms) in z	0.411 π MeV deg

The irradiation beam line was modified from Fig. 1 to Fig. 3. A bending magnet was installed after the RFQ and the quadrupole triplet was installed after the bending magnet because it provided better beam envelope along the beam line and longer beam line space for irradiation purpose.

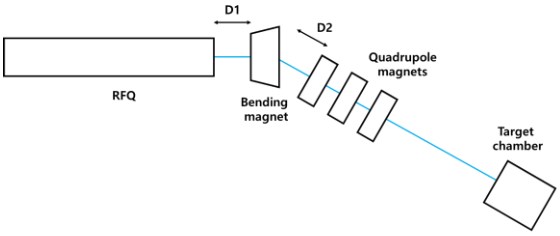

Fig. 3. Layout of the modified beam line for irradiation purpose.

The bending magnet is a switching magnet type which has five beam ports at the output. It has a normal pole face in inlet side whereas the output pole face rotation angle is a half of the bending angle to produce a stigmatic beam. The curvature radius for 30° bending angle is 635 mm and the gap between pole face is 50 mm. The effective length of the quadrupole is 200 mm, the pole face radius is 55 mm and the maximum field gradient is 5 T/m. The radius of the beam pipe along the beam line is 50 mm.

The maximum beam radius depending on the location of the quadrupole magnets defined by the distance between bending magnet and quadrupole magnet (D2) was compared according to the beam size at the target. The calculation was done with TraceWin code [4]. The distance between RFQ and bending magnet (D1) was 550 mm and the distance between bending magnet and target chamber was 3,400 mm. The typical beam envelope is shown in Fig. 4. As shown in Fig. 4, the maximum beam radius was occurred in the middle of triplet. The result is summarized in Fig. 5.

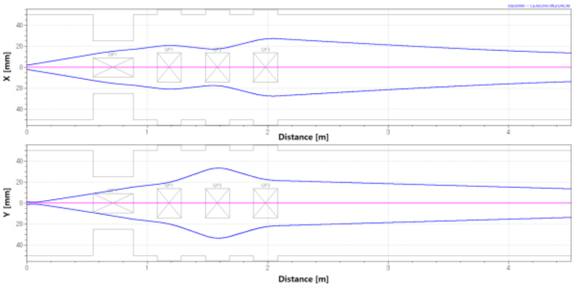

Fig. 4. Typical beam envelope in the calculation. The above beam envelope was obtained with D1=550 mm, D2=200 mm, rms beam radius at the target is 6 mm.

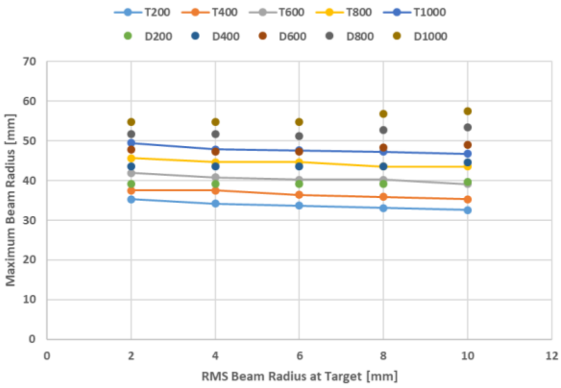

Fig. 5. Maximum beam radius depending on the beam radius at the target, magnet location and magnet configuration (triplet, doublet). Prefix “T” means triplet, “D” means doublet. The number after the prefix means D2.

The triplet (solid lines) and doublet (dots) configurations were also compared. In the comparison, the triplet parameters were obtained to produce circular beam at the target whereas the doublet were obtained to produce the same size in y direction. The results showed that the maximum beam radius of the doublet is larger than that of triplet with the above conditions. And it has larger value than the beam pipe size at some conditions.

Therefore, it is advantageous to use triplet with a view point of maximum beam size. In all cases, the field gradient was less than 4 T/m which remains within the maximum field gradient of the designed quadrupole magnet.

The maximum beam size was compared depending on the distance between RFQ and the bending magnet (D1). The result is shown in Fig. 6.

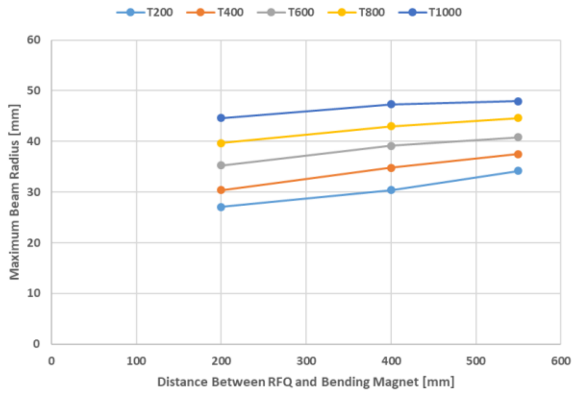

Fig. 6. Maximum beam radius depending on the distance between RFQ and bending magnet.

From the results, we could decide the distance between RFQ and bending magnet (D1), between bending magnet and triplet (D2) which produces the allowable beam size in fixed beam pipe radius, that is 50 mm. In our case, we want to limit the maximum beam size less the 60% of the beam pipe size, which means the D1 is less than 200 mm and D2 is also less than 200 mm. The maximum beam radius depending on the beam radius at target for D1 = 200 mm, D2 = 200 mm is shown in Fig. 7. The maximum beam radius is less than 30 mm (60% of beam pipe radius) for almost beam size at the target.

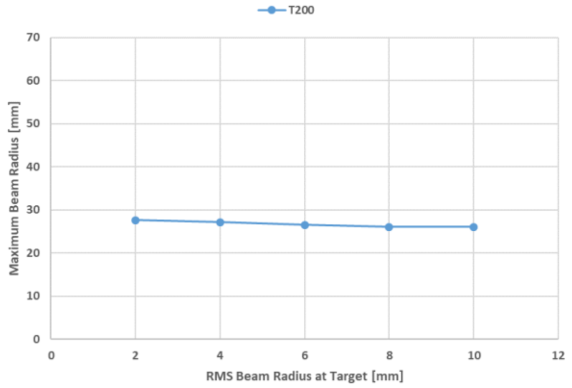

Fig. 7. Maximum beam radius depending on the beam radius at the target (D1 = 200 mm, D2 = 200 mm).

4. Conclusions

A RFQ based 1 MeV/n accelerator system is being developed at KOMAC. The ion source, LEBT and RF system are tested. RFQ itself is being field tuned. It has two beam lines and irradiation beam line is designed. To limit the maximum beam size within 60% of the beam pipe radius, the distances between RFQ and bending magnet as well as between bending magnet and triplet should be less than 200 mm. The error analysis is planned to decide the installation tolerance and location of the compensating devices. The design of the neutron beam line will be done after the design of the overall neutron target system is finished.

Acknowledgement

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