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NEW 3-MeV RFQ DESIGN AND FABRICATION FOR KOMAC

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Abstract

Since the second half of 2013, the Korea Multi-purpose Accelerator Complex (KOMAC) has been supporting user beam services with a 100 MeV proton linac. Given that the proton accelerator has been in operation for over 10 years and its cumulative operating time has surpassed 33,000 hours, we believe it is an opportune moment to establish a long-term plan to address the aging of the accelerator. To replace the current RFQ, which is experiencing performance degradation (particularly in reduced beam transmission), we have designed a new RFQ with several modifications. We eliminated the resonant coupling structure located in the middle of the old RFQ to simplify the design and facilitate tuning. Additionally, we increased the RFQ length from 3,266 mm to 3,537 mm to improve beam transmission efficiency in high-current mode. An error study on the new structure has shown that the design is robust against various error sources. The details of the RFQ design, along with the fabrication status, will be presented.

INTRODUCTION

The RFQ at the Korea Multi-purpose Accelerator Complex (KOMAC) was designed to accelerate a proton beam from 50 keV to 3 MeV.

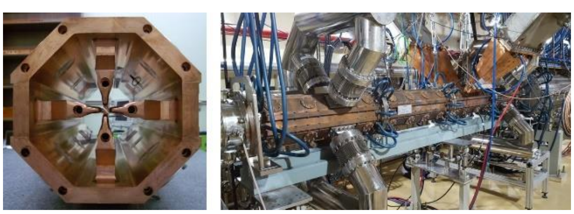

Figure 1: Existing RFQ at KOMAC.

Figure 1 shows the existing RFQ at KOMAC. This RFQ was successfully commissioned and has been in operation for approximately 20 years since its initial commissioning in 2004 [1-2]. However, the performance of the RFQ has gradually degraded over time.

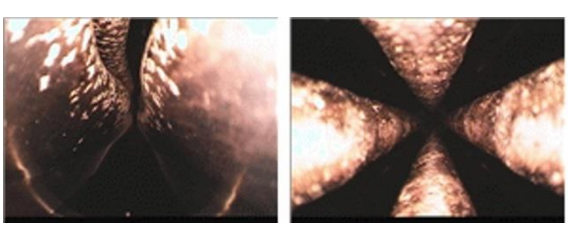

Figure 2: Observed vane electrode damage.

We suspect that the degradation in performance is due to damage to the RFQ vanes, which was confirmed through direct observation using an endoscope. We observed numerous arcing spots and surface degradation (Fig. 2). Consequently, we have decided to design a new RFQ to replace the existing one.

DESIGN OF NEW RFQ

The new RFQ incorporates several improvements and modifications but remains quite similar to the existing RFQ. Therefore, the new RFQ parameters, as shown in Table 1, are also similar to those of the existing RFQ.

Table 1: Parameters for New RFQ

Parameter	Value
Input beam energy	50 keV
Output beam energy	3 MeV
Operating frequency	350 MHz
Transverse emittance	0.2 π. mm. mrad
Longitudinal emittance	0.107 deg.MeV
RFQ type	4 - vane
Vane voltage	85 kV
ρ/r_0	0.87
Length	353 cm

While many parameters remain the same, a major change in the new RFQ is the adjustment in the energy range of the gentle buncher. In the old RFQ, the energy range of the gentle buncher varied from 86.5 keV to 550 keV, whereas in the new RFQ, it ranges from 86.5 keV to 580 keV. Although this difference is only 30 keV, we found that extending the energy range improves beam transmission rates.

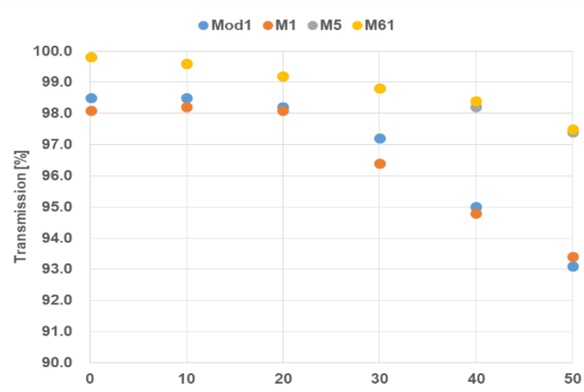

Figure 3: Beam transmission rate with various cases.

The Fig. 3 illustrates the beam transmission rate across different scenarios. Mod 1 represents the existing RFQ, while M1 is similar to Mod 1 but without the focusing

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parameter B variation. Cases M5 and M61 represent the increased energy range of the gentle buncher, with and without B variation, respectively. The data show that the beam transmission rate is higher with a wider energy range in the gentle buncher, and this effect is more pronounced in high-current situations.

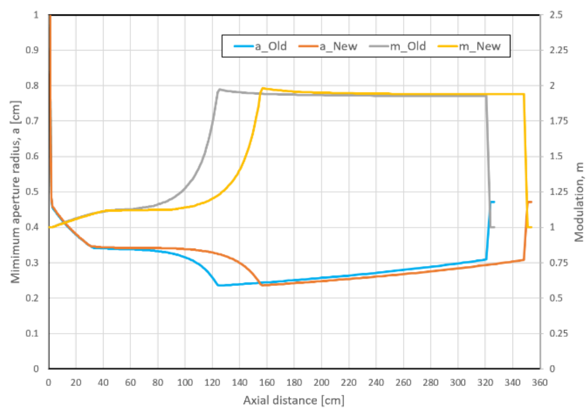

Figure 4: Comparison between old and new RFQs in terms of modulation and minimum aperture.

Increasing the energy range of the gentle buncher led to changes in the total length and geometry of the RFQ. The Fig. 4 shows the differences between the old and new RFQs in terms of the modulation parameter ‘m’ and minimum aperture ‘a’.

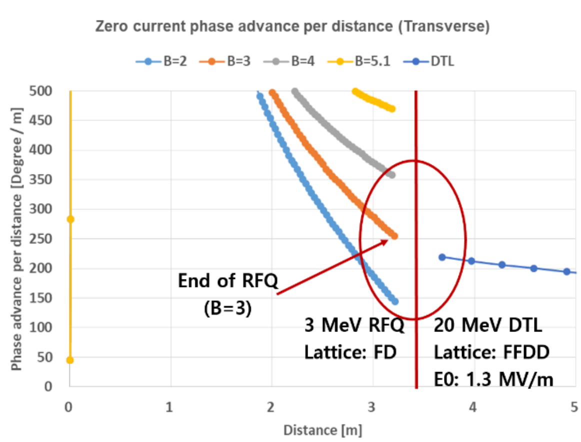

Figure 5: Optimization of focusing strength for phase advance matching with DTL.

Another aspect of RFQ design optimization is adjusting the focusing strength. We optimized the focusing strength to match the phase advance at the end of the RFQ and the start of the DTL section. The above Fig. 5 displays the phase advance per unit length for various focusing strengths and the optimized value.

ERROR STUDY OF NEW RFQ

The new RFQ design accounts for various factors, improving beam transmission and optimizing the transverse phase advance for the DTL section. However, external errors, such as geometric or RF field errors, could affect these benefits [3-4]. Therefore, we conducted an error study to assess the design’s robustness.

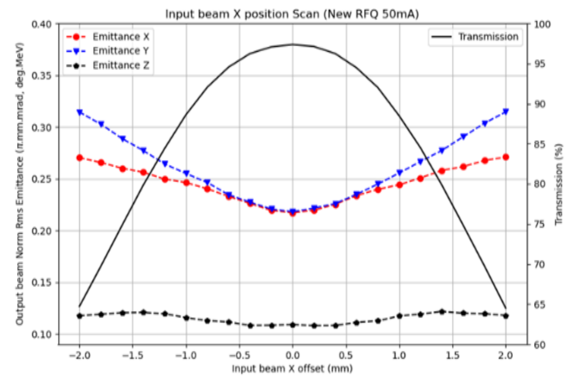

Figure 6: Input beam position scan result.

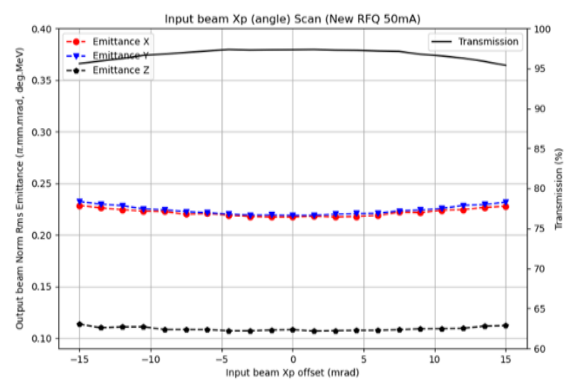

Figure 7: Input beam angle scan result.

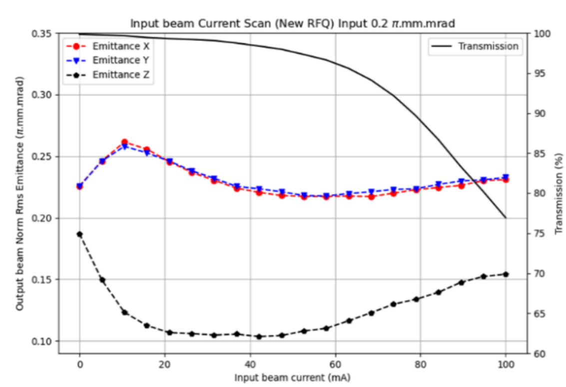

Figure 8: Input beam current scan result

Figures 6, 7, and 8 show the results of input beam scans for the new RFQ. We performed scans along both the x and y axes, with similar results observed. The input beam position scan reveals that transmission rate and output emittance are highly sensitive to the input beam position. The Fig. 7 presents the input beam angle scan, showing minimal differences in output emittance and transmission rate across a range of -15 mrad to 15 mrad. Lastly, Fig. 8

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illustrates the input beam current scan results, demonstrating that the new RFQ, optimized for high-current mode, maintains a stable transmission rate up to 50 mA.

Table 2: Lattice Error Type and Value

Error type	Maximum Value
Longitudinal profile	300 um
Transverse curvature	300 um
Field amplitude	3%
Tilt of electrode	300 um
Displacement of electrode	300 um
Tilt of whole RFQ	300 um
Displacement of whole RFQ	300 um

Geometric errors in the RFQ can significantly impact beam dynamics. Table 2 lists the geometric errors considered in the study.

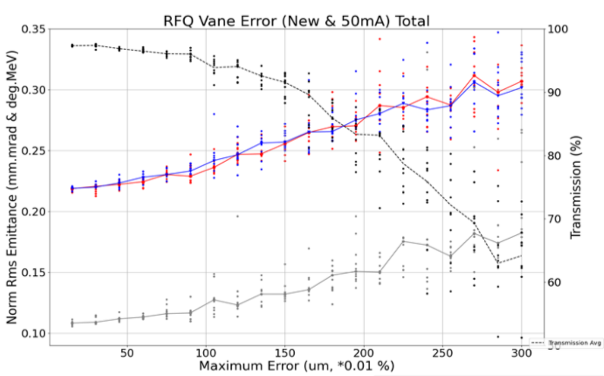

Figure 9: Geometric error study result

The above Fig. 9 shows the simulation results for the geometric errors. We ran the simulation with 200 sets of error configurations. The dots represent the simulation results for individual error sets, while the solid line represents the average value. The transmission rate and output emittance of the beam are not significantly distorted until the maximum error reaches 150 µm so we have confirmed the robustness of the new RFQ design.

FABRICATION OF NEW RFQ

Detailed beam dynamics simulations confirm the advantages and robustness of the new design. Consequently, we have proceeded with the engineering design phase.

Figure 10: Snapshot of new RFQ cad drawing

The average aperture of the RFQ varies continuously along the beam axis, necessitating adjustments to the RFQ's cross-section to match the resonant frequency. We adjusted the vane skirt width to correct the resonant frequency, calculated using SuperFish code. Figure 10 shows a snapshot of the 3D CAD drawing of the new RFQ, incorporating all design considerations.

CONCLUSION

The RFQ at KOMAC has been in operation since early 2004. Although it was successfully commissioned and operated for around 20 years, its performance has gradually degraded due to vane damage. Therefore, we have designed a new RFQ to replace the existing one. The new RFQ aims to improve transmission rates in high-current mode and is optimized for phase advance matching with the subsequent DTL section. Detailed beam dynamics and error study simulations have validated the robustness of the new RFQ design. We have now completed the 3D CAD drawing and are preparing for the manufacturing of the new RFQ.

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