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Error Study and Orbit Correction Simulation for 200 MeV Energy Upgrade at KOMAC

SeokHo Moon [a*], Seung-Hyun Lee [a], Sung-Bin Park [a], Dong-Hwan Kim [a], Han-Sung Kim [a], Hyeok-Jung Kwon [a]
[a]Korea Multipurpose Accelerator Complex, Korea Atomic Energy Research Institute, Gyeongju 38180
[*]Corresponding author: msh3069@kaeri.re.kr

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1. Introduction

The proton accelerator at KOMAC currently accelerates protons to a maximum energy of 100 MeV. However, due to the increasing demand for high-energy proton beams for applications such as space semiconductor development, there are plans to upgrade KOMAC's proton accelerator to achieve proton energies of up to 200 MeV. This energy upgrade requires extensive preparation, including detailed beam dynamics simulation, cavity simulation, and cavity design. The error study and orbit correction simulation are part of this preparation. The error study simulation provides criteria for lattice alignment and manufacturing errors, while the orbit correction simulation offers criteria for the corrector magnet, which is used to compensate for beam centroid shifts caused by these errors.

2. 200 MeV Accelerating Beamline

The 200 MeV accelerating beamline utilizes an SDTL-type lattice. The magnetic quadrupole doublet controls the transverse size of the beam, and the DTL tank accelerates the proton beam.

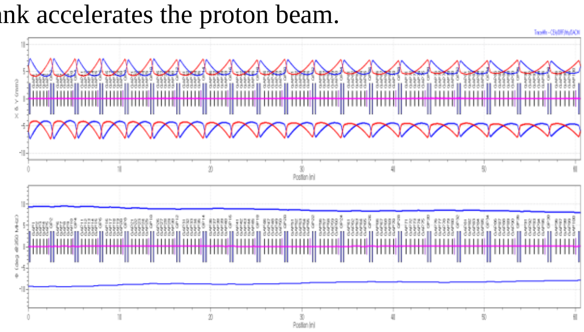

Fig. 1. The envelope simulation result for the 200 MeV accelerating beamline.

Figure 1 shows the envelope simulation result for the 200 MeV accelerating beamline. The beam is well-matched and accelerated from 100 MeV to 200 MeV. This simulation result serves as the baseline. In the error study, the beam size will increase, and the beam centroid will shift due to the effect of errors.

3. Error Study

The error study was conducted using the TRACEWIN simulation code and includes an analysis of the lattice and input beam.

Table I: Error Type and Range

Error Type	Error range
Magnet displacement	300 um
Magnet rotation	0.5 degree
Magnet gradient	3 %
Cavity displacement	300 um
Cavity rotation	0.5 degree
Cavity field	3 %
Cavity phase	3 degree
Input beam center shift (x)	2.5 mm
Input beam center shift (y)	5 mrad
Input beam angle shift (x)	2.5 mm
Input beam angle shift (y)	5 mrad

The table 1 lists the types of errors and their ranges used in the error study. Although these error values are relatively large for a normal conducting accelerator, we aim to assess the maximum limitations of these errors.

Fig. 2. Error study result for the magnetic quadrupole error

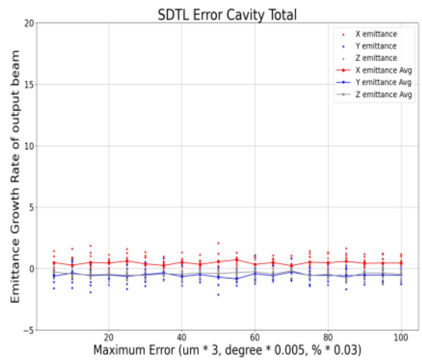

Fig. 3. Error study result for the cavity error

Figures 2 and 3 show the error study results for magnetic quadrupole and cavity errors. The results indicate that the lattice is robust against lattice errors. Even if the error in the magnet reaches its maximum value, the emittance growth rate is kept below 20%.

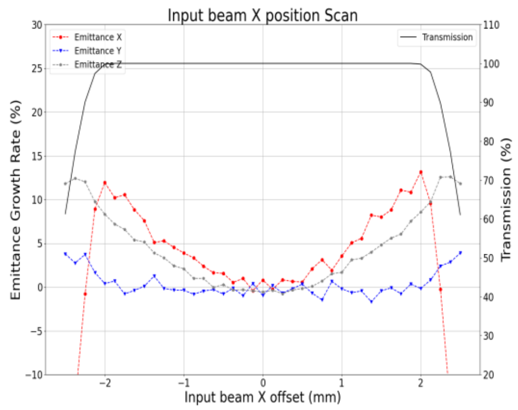

Fig. 4. Input beam position center shift result

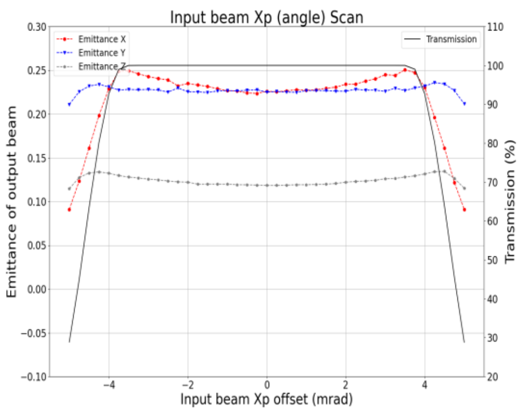

Fig. 5. Input beam position angle shift result

Figures 4 and 5 show the results for input beam center shift and angle shift. The effects of input beam centroid shift and angle shift are much more significant than lattice errors. If the input beam centroid shifts by more than 2 mm, the transmission rate starts to decrease rapidly, and the emittance begins to increase. Similarly, with an angle shift, the transmission rate decreases sharply after a 4 mrad angle shift.

3. Orbit Correction

The centroid of the beam and other beam parameters are affected by errors in the accelerator. Corrector magnets are used to control these centroid shifts. Although installing a corrector magnet at every periodic lattice might be the most conservative approach, finding an optimal placement can save resources. Therefore, we conducted orbit correction simulations. The errors used in the orbit correction simulation are the same as those listed in table 1.

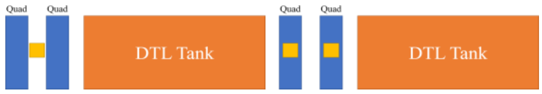

Fig. 6. Corrector magnet type (left: Plan 1, right: Plan 2)

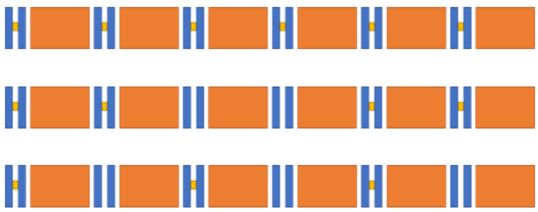

Fig. 7. Corrector magnet installation plan (Plans 1,2,3)

Figures 6 and 7 show the types of corrector magnets and installation plans. The yellow box represents the corrector magnet. We can manufacture corrector magnets that control both the x and y directions simultaneously, or corrector magnets integrated with quadrupole magnets that control only a single direction. Figure 6 illustrates these two types of magnets, while Figure 7 shows the three installation plans. With two types of corrector magnets and three installation plans, there are six possible configurations. We conducted orbit correction simulations for all cases, naming them as ‘1.1’, ‘1.2’, etc. For example, if a case uses magnet type 2 and installation plan 3, it is referred to as case ‘2.3’.

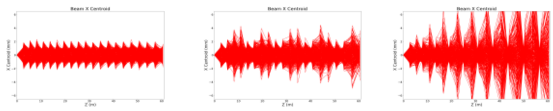

Fig. 8. X centroid correction result (Case 1.1, 1.2, 1.3)

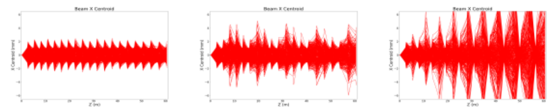

Fig. 9. X centroid correction result (Case 2.1, 2.2, 2.3)

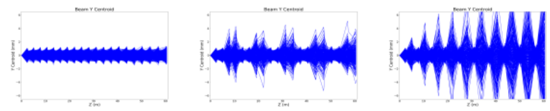

Fig. 10. Y centroid correction result (Case 1.1, 1.2, 1.3)

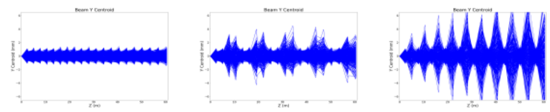

Fig. 11. Y centroid correction result (Case 2.1, 2.2, 2.3)

Figures 8 to 11 show the results of centroid correction simulations. There is no significant difference between magnet types 1 and 2. However, in the case of installation plan 3, the centroid is not controlled effectively, suggesting that the viable plans are cases 1.1, 1.2, 2.1, and 2.2. The orbit correction simulation provides insight into the corrector magnet type and installation plan and also defines the criteria for the magnet strength.

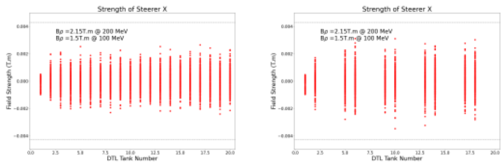

Fig. 12. Corrector magnet X axis strength (Case 1.1, 1.2)

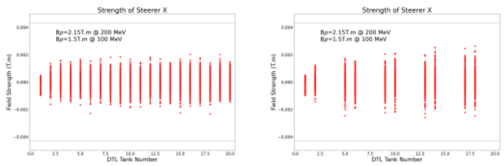

Fig. 13. Corrector magnet X axis strength (Case 2.1, 2.2)

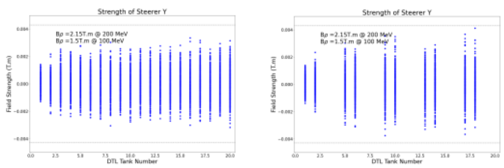

Fig. 14. Corrector magnet Y axis strength (Case 1.1, 1.2)

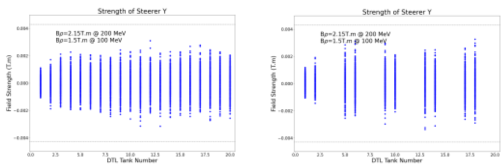

Fig. 15. Corrector magnet Y axis strength (Case 2.1, 2.2)

Figures 12 to 15 show the corrector magnet strengths for the simulation cases. The gray dotted line represents the value of 0.0043 T·m, corresponding to the required magnet strength for a 2 mrad angle shift. In all cases, the required magnet strength is below 0.0043 T·m.

4. Conclusion

We conducted error studies and orbit correction simulations to prepare for the energy upgrade of KOMAC. The error study, performed using the TRACEWIN simulation code, evaluated lattice and input beam errors. The results indicate that the lattice is robust to geometrical errors, but input beam errors can significantly affect beam transmission and emittance growth.

The orbit correction simulation explored different plans for corrector magnet types and installation strategies. The results suggest possible plans for corrector magnet installation and provide criteria for the required magnet strength.

ACKNOWLEGEMENTS

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