

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2015). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

# ERROR ANALYSIS AND CORRECTION AT THE MAIN LEBT OF RAON HEAVY ION ACCELERATOR

Hyunchang Jin, Ji-Ho Jang, In-Seok Hong, and Hyo-Jae Jang  
 Institute for Basic Science, Yuseong-daero 1689-gil, Yuseong-gu, Daejeon, Korea

## Abstract

The main Low Energy Beam Transport (LEBT) section of Rare isotope Accelerator Of Newness (RAON) heavy ion accelerator is designed to transport the ion beams which are generated by Electron Cyclotron Resonance Ion Source (ECR-IS) to the Radio Frequency Quadrupole (RFQ). In the main LEBT, one or two beams are selected among a variety of ion beams to meet the beamline experiment requirements such as beam charge and current. In a uranium beam case, two charge-state, 33+ and 34+, beams are chosen and transported to the RFQ. For transportation of two charge-state beams, beams can be seriously affected by dipole kick or unexpected dispersion caused by magnet errors. These effects of magnet or cavity errors lead to beam loss at the main LEBT or RFQ. Therefore, the effect to the beam orbit and size should be identified and the research for reducing such effect should be required in the main LEBT. In this paper, we will examine the orbit distortion and beam size growth caused by magnet errors and discuss the correction of errors by using correctors and BPMs.

## INTRODUCTION

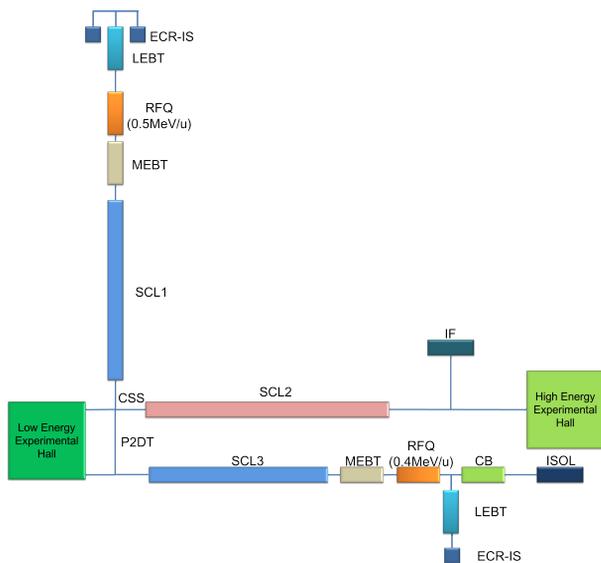


Figure 1: Schematic view of RAON heavy ion accelerator.

The RAON heavy ion accelerator [1] proposed by Rare Isotope Science Project (RISP) is in progress to become one of the world leading facilities as a rare isotope accelerator. At the RAON accelerator, the rare isotopes can be generated with two ways; one way is the isotope separation on line (ISOL) system [2] and the other is the projectile fragmenta-

tion in the in-flight fragmentation (IF) system [3]. In a wide range of science programs, we can use these rare isotopes.

For a uranium beam case, the beam generated by electron cyclotron resonance ion source (ECR-IS) with a beam energy of 10 keV/u reaches to an energy 200 MeV/u and a power 400 MW at the IF system to produce a high-intensity rare isotopes. For this process, RAON accelerator will use a low energy superconducting linac (SCL1) and a high energy superconducting linac (SCL2) [4]. The beams generated by the ECR-IS passes through the low energy beam transport (LEBT), the radio frequency quadrupole (RFQ), and the medium energy beam transport (MEBT) before entering the SCL1. The schematic layout of RAON accelerator is shown in Fig. 1.

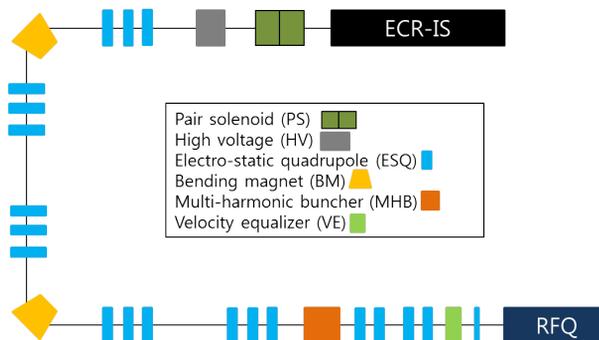


Figure 2: Layout of the main LEBT.

The main LEBT consists of many components: a pair solenoid (PS), high voltage platform (HV), 20 electro-static quadrupoles (ESQ), two 90-degree bending magnets, a multi-harmonic buncher (MHB), and a velocity equalizer (VE). All the components of it can be error sources of orbit distortion and the error of ESQs is a dominant source. The schematic layout of main LEBT is shown in Fig. 2.

We have developed the graphical user interface (GUI) for the error analysis and correction in RAON accelerator by using a multi-particle beam simulation code, DYNAC [5], and a computing language program, MATLAB [6]. In this paper, we will present the orbit distortion induced by magnet errors and correction to the errors by using correctors and beam-position monitors (BPMs) in the main LEBT.

## PROCEDURE FOR ERROR ANALYSIS AND CORRECTION

With the lattice information, the orbit trajectory is calculated with and without errors by using the DYNAC code. The whole procedure of error analysis and correction with DYNAC and MATLAB programs is listed in Table 1.

Table 1: Procedure of Error Analysis and Correction with DYNAC and MATLAB Programs

Step	Explanation
1	Run DYNAC without errors
2	Calculate response matrix
3	Run DYNAC with errors
4	Read BPM data
5	Calculate corrector strength using SVD method
6	Run DYNAC with errors and correctors

In the step 5, the singular value decomposition (SVD) method with the orbit response matrix is applied to calculate the corrector strength corresponding to the distorted orbit. The BPM-to-corrector orbit response matrix,  $M_{ij}$ , corresponding to the beam motion,  $\Delta x_i$ , at the  $i$ -th BPM per unit angle of kick,  $\Delta\theta_j$ , by the  $j$ -th corrector is given by

$$\Delta x_i = M_{ij} \cdot \Delta\theta_j. \quad (1)$$

From the Eq. 1, the SVD method provides the corrector strength corresponding to orbit distortion at BPMs.

## SIMULATION RESULTS

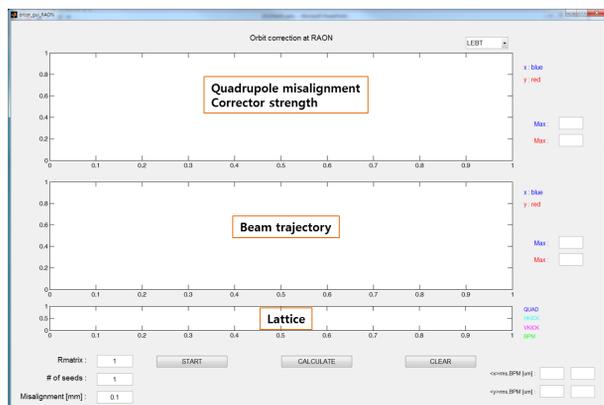


Figure 3: GUI for error analysis and correction.

For the error analysis and correction in the RAOB accelerator, the GUI has been developed based on the MATLAB and DYNAC programs. Figure 3 shows the initial screen of the GUI. In the screen, the magnet and orbit information will be displayed: the ESQ misalignment and the corrector strength in the upper section, the orbit trajectory in the middle section, and the lattice information in the lower section. In addition, the maximum and root-mean-square (rms) values of the ESQ misalignment and the beam sizes will be also displayed. The calculation of response matrix, the number of random seeds, and the initial rms misalignment of ESQs can be initially chosen. Until now, only the misalignment of ESQ, which is the most dominant error source, is applied to beam distortion. For the lack of space in the main LEBT, three BPMs will be installed along the main LEBT: the first one is at the middle point of bending section, the

second is ahead of MHB, and the third one is at the middle point between the MHB and the VE. Furthermore three horizontal and vertical correctors will be placed ahead of each BPM. For a uranium beam case, two charge-state uranium beams,  $^{238}\text{U}^{33}$  and  $^{238}\text{U}^{34}$ , will be taken at the main LEBT and transported to the RFQ to meet the current and power requirements at various targets, and the lattice is designed based on  $^{238}\text{U}^{33.5}$  beam. For that reason, a  $^{238}\text{U}^{33.5}$  beam is used in the following error simulations. The maximum kick angle of each corrector is about 11.7 mrad for 10 keV/u  $^{238}\text{U}^{33.5}$  beam.

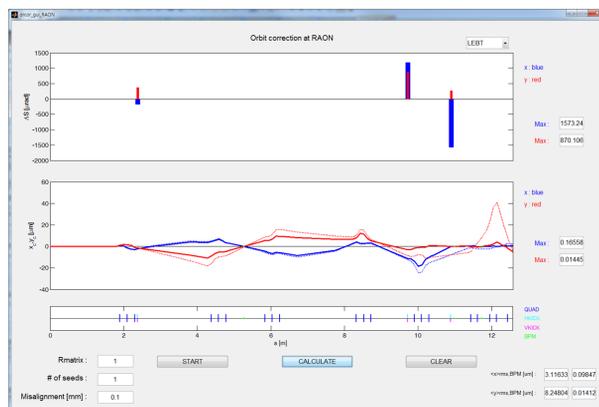


Figure 4: CALCULATE button at GUI with one random seed and 100  $\mu$  rms ESQ misalignment.

With one random seed and 100  $\mu$  rms ESQ misalignment, if the START button in the GUI is pressed, the ESQ misalignment, distorted orbit trajectory, and lattice information are calculated and displayed in the screen. After that, with the CALCULATE button, the corrected orbit trajectory and the calculated corrector kick angle are displayed as shown in Fig. 4.

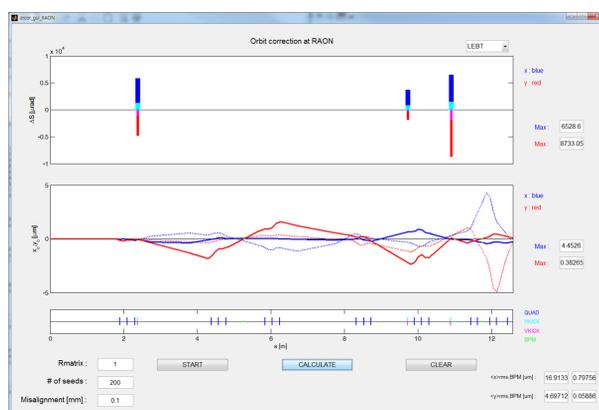


Figure 5: Error analysis and orrection with 200 random seeds and 100  $\mu$  rms ESQ misalignment.

Figure 5 shows the error analysis and correction with 200 random seeds and 100  $\mu$  rms ESQ misalignment. Before the correction, rms horizontal and vertical beam sizes at BPMs are about 16.9 and 4.7  $\mu$ m, respectively, and those values decrease to less than 1  $\mu$ m after correcting. Among 200

Content from this work may be used under the terms of the CC BY 3.0 licence (© 2015). Any distribution of this work must maintain attribution to the author(s), title of the work, publisher, and DOI.

random seeds, the maximum horizontal and vertical kick angles of correctors are about 6.5 and 8.7 mrad which are less than the mechanical maximum kick angle 11.7 mrad. Average values of horizontal and vertical correctors are about 5.4 and 5.1 mrad, respectively.

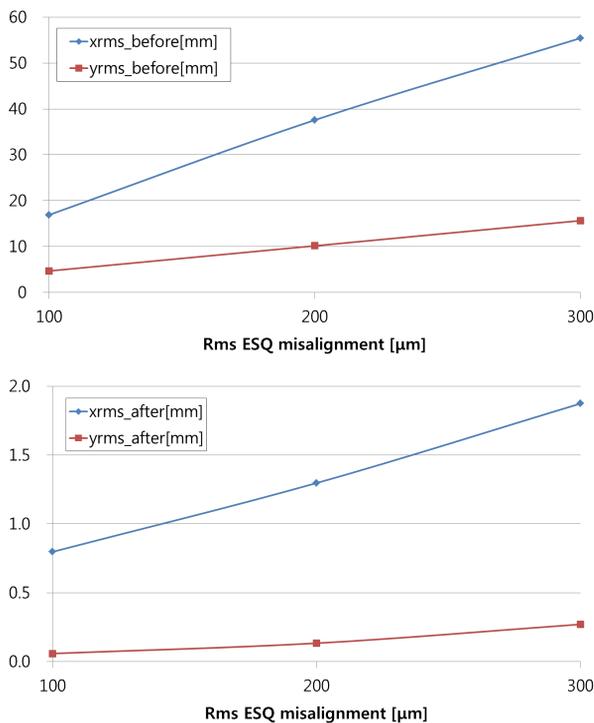


Figure 6: Rms orbit sizes at BPMs before and after correction for various rms ESQ misalignment with 200 random seeds.

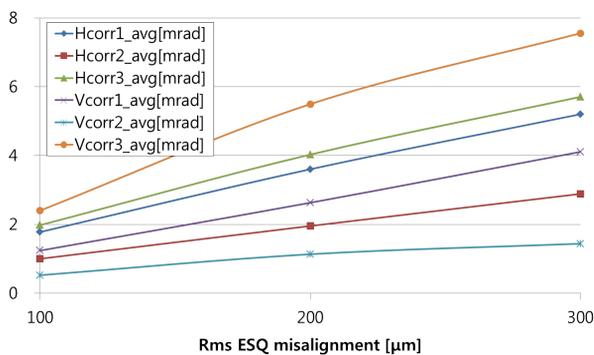


Figure 7: Average kick angle of each horizontal and vertical corrector for various rms ESQ misalignment with 200 random seeds.

After carrying out error corrections for various rms ESQ misalignments from 100 to 300 μm with 200 random seeds in the same way, Figure 6 shows the rms transverse orbit sizes at BPMs before and after the error correction. The rms horizontal and vertical beam sizes are about 55 and 16 μm for 300 μm rms ESQ misalignment respectively, before

correction. These values decrease to 1.9 and 0.3 μm after the correction respectively.

Figure 7 shows the average kick angle of each corrector for 100–300 μm rms ESQ misalignment with 200 random seeds. The first horizontal and vertical correctors require the largest kick angle. The average kick angles are less than the mechanical maximum value up to 300 μm rms ESQ misalignment. However the maximum kick angle sometimes exceeds the mechanical one for errors larger than 200 μm rms ESQ misalignment. The study of error analysis and correction with other errors will be continued and the position and number of correctors will be also adjusted to decrease the kick angle in the main LEBT.

## SUMMARY

We presented the simulation result of error study at the main LEBT in the RAON accelerator. The GUI based on MATLAB has been developed with DYNAC code to analyze the error sources and correct the distorted orbit trajectory with the correctors and BPMs. Within the mechanical maximum kick angle, the error correction was sufficiently performed with three correctors and three BPMs up to 300 μm rms ESQ misalignment. As a result, the rms transverse beam size decreases to less than 2 μm after the error correction for 300 μm rms ESQ misalignment and the calculated average kick angles of horizontal and vertical correctors are also less than the mechanical maximum value. In the future, we will include other errors like initial launch error, magnet tilt, etc. and furthermore, this study will be extended to the whole area of the RAON accelerator.

## ACKNOWLEDGMENTS

This work was supported by the Rare Isotope Science Project of Institute for Basic Science funded by Ministry of Science, ICT and Future Planning and National Research Foundation of Korea (2013M7A1A1075764).

## REFERENCES

- [1] D. Jeon et al., "Design of the RAON accelerator systems," *Journal of the Korean Physical Society* 65.7 (2014): 1010-1019.
- [2] B.H. Kang et al., "ISOL facility for rare isotope beams at RAON," *Journal of the Korean Physical Society* 63.7 (2013): 1473-1476.
- [3] C.C. Yun et al., "Beam optical design of in-flight fragment separator for high-power heavy ion beam," *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 317 (2013): 342-348.
- [4] H.J. Kim et al., "Superconducting Linac for the Rare Isotope Science Project," IPAC13, Shanghai, China, THPWO064 (2013).
- [5] E. Tanke, "DYNAC: A multi-particle beam dynamics code for leptons and hadrons," *LINAC02*, Gyeongju, TH429 (2002): 667.
- [6] P. Marchand, O. Thomas Holland, *Graphics and GUIs with MATLAB*, Chapman & Hall/CRC (2003).