

BEAM STEERING STUDIES FOR THE SUPERCONDUCTING LINAC OF THE RAON ACCELERATOR

Hyunchang Jin*, Ji-Ho Jang, Dong-O Jeon

Institute for Basic Science, Yuseong-daero 1689-gil, Yuseong-gu, Daejeon, Korea

Abstract

The RAON accelerator of Rare Isotope Science Project (RISP) has been developed to accelerate various kinds of stable ion beams and rare isotope beams for a wide range of science experiments. In the RAON accelerator, the superconducting linac (SCL) will be installed for the acceleration of the beams and it is composed of tens of cryomodules which include superconducting radio frequency cavities. Between two cryomodules, there is a warm section and two quadrupoles are located in the warm section with a beam diagnostics box in between. Also, in this warm section, one horizontal corrector and one beam position monitor (BPM) are mounted inside of first quadrupole, and one vertical corrector is located inside of second quadrupole for the beam steering. With these correctors and BPMs, the beam steering studies are carried out as varying the number of correctors and BPMs in the SCL of the RAON accelerator and the results are presented.

INTRODUCTION

The RAON accelerator [1] has been developed by the Rare Isotope Science Project (RISP) to accelerate and transport the rare isotope and stable ion beams from proton to uranium for a various kind of science experiments. The beams created by an electron cyclotron resonance ion source (ECR-IS) or an isotope separation on line (ISOL) system are transported to the radio frequency quadrupole (RFQ) after the low energy beam transport (LEBT) [2] and re-accelerated by the low energy superconducting linac (SCL1 or SCL3). These beams can be used for the low energy experiments or accelerated again by the high energy superconducting linac (SCL2) after passing through the charge stripping section [3] for the high energy experiments. Figure 1 shows the layout of the RAON accelerator.

The superconducting linacs of the RAON accelerator are divided into three sections, which are named SCL1, SCL2, and SCL3, depending on the type and number of superconducting cavities and the purpose of the beam acceleration. The SCL1 and SCL3 include two types of cavities, quarter-wave resonator (QWR) and half-wave resonator (HWR) and accelerate mainly the stable ion beams and the rare isotope beams, respectively. On the other hand, the SCL2 consists of two types of single spoke cavities (SSR1 and SSR2) and accelerates again the beams accelerated by the SCL1 or SCL3. The reference frequency of each section is also different depending on the type of cavity and it is 81.25 MHz for QWR cavities, 162.5 MHz for HWR cavities, and 325 MHz for

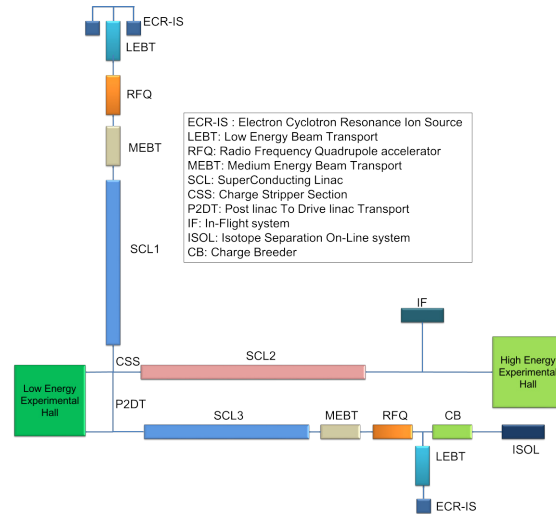


Figure 1: Layout of the RAON accelerator.

SSR cavities, respectively. For the beam focusing and diagnostics at the superconducting linac, there is a warm section, which includes two quadrupoles, between cryomodules. At each warm section, a horizontal and a vertical correctors are mounted inside of first and second quadrupoles, respectively, and a beam-position monitor (BPM) is installed at first quadrupole for the beam steering. The schematic view of the SCL1 is shown in Fig. 2. In order to steer the distorted beam orbit to the reference orbit at the RAON accelerator, the beam steering studies has been carried out from the low energy section to the high energy section by using the singular value decomposition (SVD) [4] method and a graphical user interface (GUI) has also been developed with a beam optics code, DYNAC [5] and a computing program, MATLAB [6]. In this paper, the results of the beam steering simulations at the SCL1 will be presented and we will describe the simulation results for the cases with different number and location of correctors and BPMs.

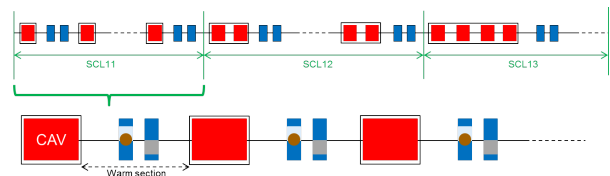


Figure 2: Schematic view of the SCL1. At each warm section, one horizontal corrector and one BPM are mounted at first quadrupole, and one vertical corrector is located at second quadrupole for the beam steering.

* hcjin@ibs.re.kr

BEAM STEERING PROCEDURE

For the steering of the beam orbit at the RAON accelerator, the SVD method based on the response matrix is used. The response matrix between correctors and BPMs are obtained by the DYNAC code and the corrector kick angle to steer the distorted beam orbit is calculated by the SVD method. The procedure of the beam steering with the DYNAC code and the MATLAB program is shown in Fig. 3. Also, the GUI for the beam steering has been developed [7]. Figure 4 shows the GUI which is recently updated to be used at the superconducting linac of the RAON accelerator. At the GUI, the magnet misalignment and the calculated kick angle of each corrector are shown at the upper window, the beam orbits before and after the steering are shown at the middle window, and the lattice information is shown at the lower window, respectively.

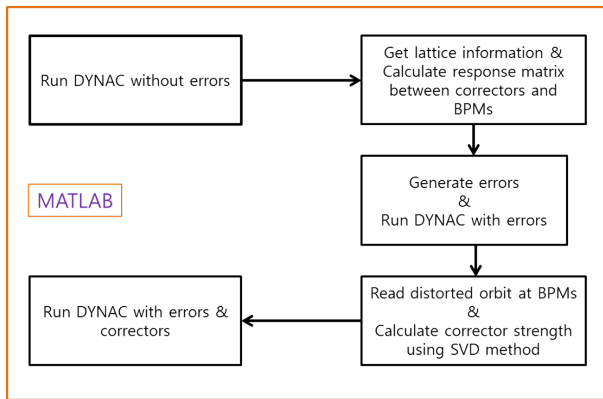


Figure 3: Procedure of the beam steering simulation.

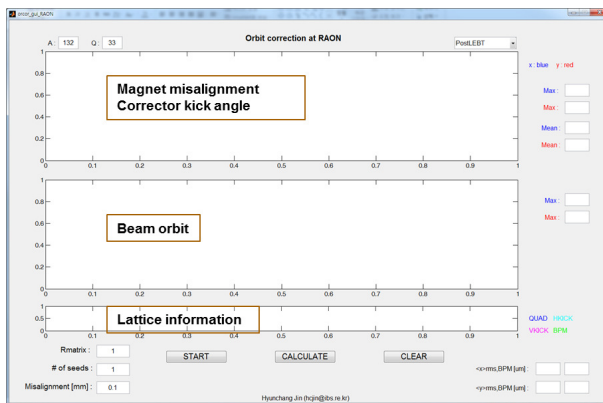


Figure 4: Initial screen of the recent beam steering GUI at the RAON accelerator.

SIMULATION RESULTS

For the beam steering studies at the SCL1, three cases with different number and location of correctors and BPMs are used. The first case (case 1) corresponds to the baseline lattice design which includes one horizontal corrector, one BPM, and one vertical corrector at each warm section. On the other hand, the case 2 and 3 represent the lattices

which include two correctors and one BPM at every two and three warm sections, respectively. Figure 5 shows the schematic view of each case for the beam steering studies. The distortion of the beam orbit at the SCL1 is induced by the misalignments of equipments, launch errors, and so on. The errors used at the following simulations are listed at Table 1. Among these errors, the quadrupole root-mean-square (rms.) transverse misalignment which gives a dominant dipole kick to the beam orbit is varied from 100 μm to 500 μm , and other errors are given as default values. In addition, the reference uranium beam, $^{238}\text{U}^{33.5+}$, is used at the following simulations and the errors with 200 random seeds are applied for the statistics.

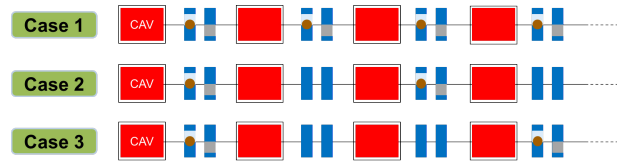


Figure 5: Three cases of the beam steering studies as varying the number of correctors and BPMs at the SCL1.

Table 1: Errors Used at the Beam Steering Simulations

Parameter	Value	Unit
Rms. $x(y)_0$	10	$[\mu\text{m}]$
Rms. $xp(y)p)_0$	10	$[\mu\text{rad}]$
Quad. rms. misalign. x,y	300 (100 – 500)	$[\mu\text{m}]$
Cavity rms. misalign. x,y	10	$[\mu\text{m}]$

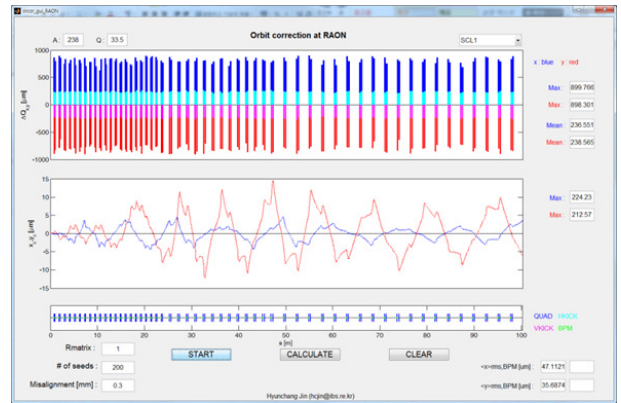


Figure 6: GUI for the case 1 before the beam steering with quadrupole rms. misalignment 300 μm .

Figure 6 shows the distortion of the beam orbit with a quadrupole rms. misalignment 300 μm for the case 1. Before the beam steering, the horizontal and vertical rms. orbit sizes are about 47.1 μm and 35.7 μm , respectively. After the beam steering, these values decrease to 3.9 μm and 2.8 μm , respectively. In order to steer the distorted beam orbit, the calculated average kick angles of horizontal and vertical correctors are about 0.37 mrad and 0.29 mrad, respectively,

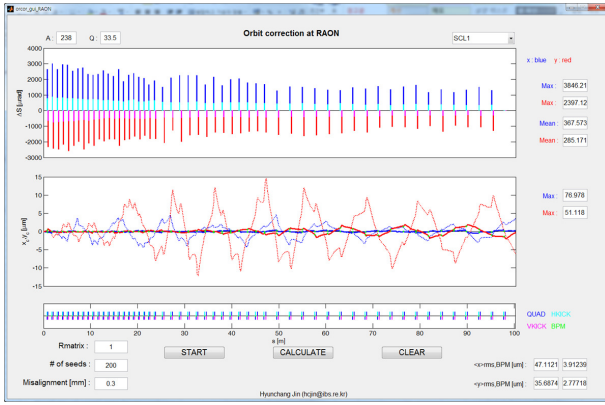


Figure 7: GUI for the case 1 after the beam steering with quadrupole rms. misalignment 300 μm .

which are much less than the mechanical maximum kick angle, about 2.0 mrad. The corrector kick angle and the beam orbit after the beam steering are shown in Fig. 7.

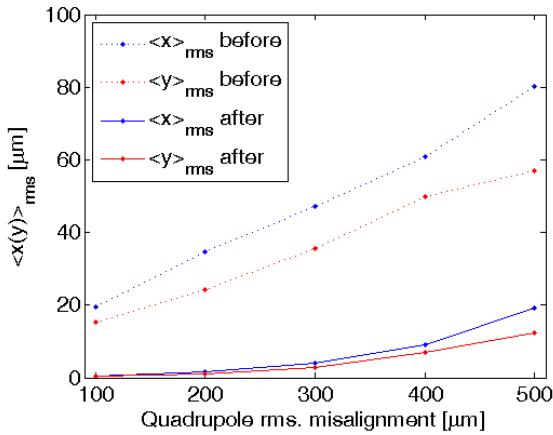


Figure 8: Rms. beam orbit sizes before and after the beam steering with quadrupole rms. misalignment 100 – 500 μm for the case 1.

Figure 8 shows the rms. beam orbit sizes before and after the beam steering as varying the quadrupole rms. misalignment from 100 μm to 500 μm for the case 1. The beam steering is carried out successfully up to 500 μm quadrupole rms. misalignment and the average kick angles of horizontal and vertical correctors for the beam steering are less than the mechanical maximum value as shown in Fig. 9.

Figure 10 shows the result of the beam steering simulation with the quadrupole rms. misalignment 300 μm for the case 2. At this case, the horizontal (vertical) rms. orbit size decreases from 45.9 (36.8) μm to 26.1 (27.5) μm , respectively. The orbit size after the beam steering does not decrease drastically at this case and the calculated kick angles of some correctors are also much larger than the mechanical maximum value.

The simulation result for the case 3 with quadrupole rms. misalignment 300 μm is shown in Fig. 11. After the beam steering, the orbit size decreases to about 7 μm which is

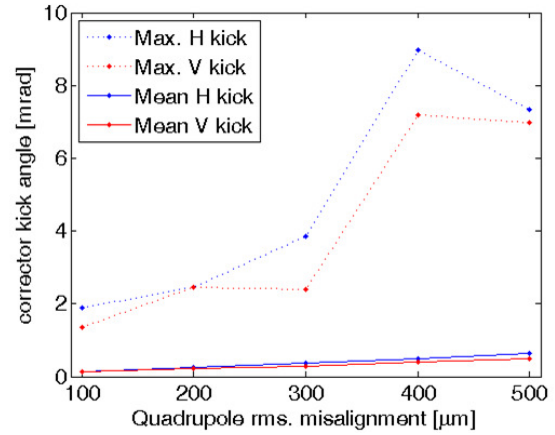


Figure 9: Maximum and average corrector kick angles for the beam steering with quadrupole rms. misalignment 100 – 500 μm for the case 1.

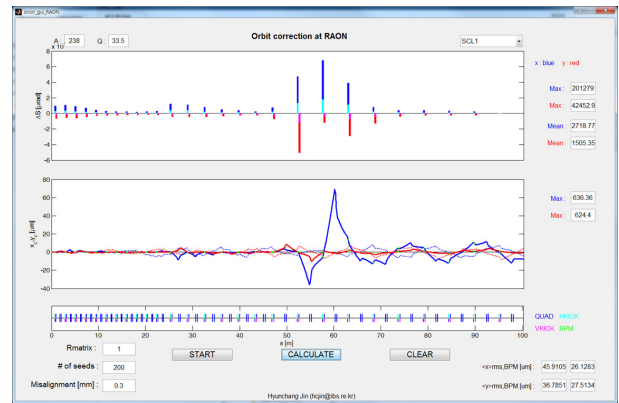


Figure 10: GUI for the case 2 after the beam steering with quadrupole rms. misalignment 300 μm .

smaller than result of the case 2. The difference of the case 2 and 3 comes from the transverse phase advance for the beam focusing and the locations of correctors and BPMs.

Figure 12 shows the comparison of beam orbit sizes after the beam steering for cases 1, 2, and 3 with the quadrupole rms. misalignment from 100 μm to 500 μm . As a result, the rms. orbit size after the beam steering for the case 3 is smaller than the one of the case 2 and close to the one of the case 1. For that reason, in order to reduce the number of correctors and BPMs, the case 3 is better than the case 2 for the current SCL1 lattice. To find the proper number of correctors and BPMs for the economical benefit, more studies with various number and location of correctors and BPMs will be continued at the superconducting linac of the RAON accelerator.

SUMMARY

We had presented the simulation results of the beam steering at the low energy superconducting linac, SCL1, of the RAON accelerator. The beam steering studies based on the SVD method were carried out with the correctors and BPMs

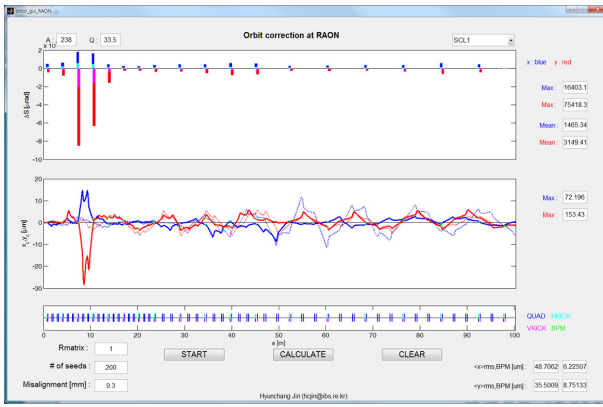


Figure 11: GUI for the case 3 after the beam steering with quadrupole rms. misalignment $300 \mu\text{m}$.

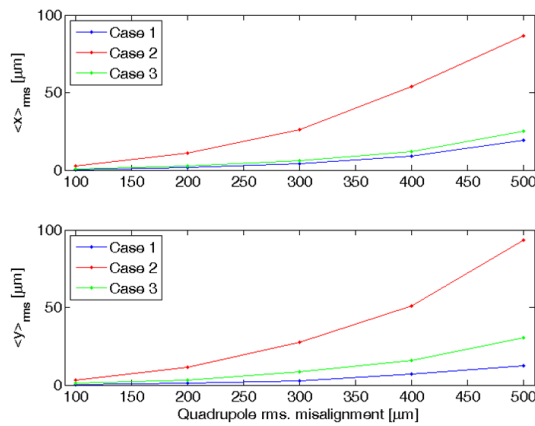


Figure 12: Comparison of rms. beam orbit sizes for cases 1, 2, and 3 with quadrupole rms. misalignment $100 - 500 \mu\text{m}$.

located at the warm section of the SCL1. For the simulation, three cases with different number and location of correctors and BPMs were investigated and the orbit size was calculated before and after the beam steering for each case. As a

result, the beam steering was performed successfully for the baseline lattice design within the mechanical maximum kick angle of the correctors. Additionally, for the beam steering at the SCL1, the result of the case including two correctors and one BPM at every three warm section was better than the one of the other case including two correctors and one BPM at every two warm section. For the economical benefit, more studies with various cases will be continued at the superconducting linac of the RAON accelerator.

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