RECENT BEAM DYNAMICS STUDIES FOR THE SCL DEMO OF RISP

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Abstract

The rare isotope science project (RISP) has been developed the RAON accelerator to accelerate heavy ion and rare isotope beams for the various kinds of science programs. In the RAON accelerator, the beams created by a superconducting electron cyclotron resonance ion source (ECR-IS) will be accelerated by the radio-frequency quadrupole (RFQ) after passing through the low energy beam transport (LEBT) section. These accelerated beams will pass the medium energy beam transport (MEBT) section for the beam matching and be re-accelerated by the superconducting linac (SCL) for the higher beam energy. Prior to the construction of the RAON accelerator, the performance of each component of LEBT, RFQ, MEBT and SCL should be examined for the efficient mass production. Accordingly, we have been constructing the test facility, which is named SCL demo, since 2015. First beam test with an oxygen beam will be carried out at the end of 2016 and the next test with a bismuth beam will be performed in 2017. In this paper, we will present the beam dynamics studies with the recent lattice design of the SCL demo and describe the simulations results with the bismuth and oxygen beams.

INTRODUCTION

The RAON (Rare Isotope Accelerator of Newness) accelerator [1] being developed by the rare isotope science project (RISP) is designed to accelerate the stable ion beams from proton to uranium and transport these beams to the targets of experimental halls for a wide range of science programs with various rare isotopes created from the targets. An 28 GHz electron cyclotron resonance ion source (ECR-IS) creates various kinds of stable ion beams, and these beams are transported and accelerated through the low energy beam transport (LEBT) section [2], the radio-frequency quadrupole (RFQ), the medium energy beam transport (MEBT) section, and the superconducting linac (SCL) section. Here, the SCL section is divided into low and high energy sections: the low energy SCL (SCL1 and SCL3) section consists of two kinds of cavities, quarter-wave resonator (QWR) and half-wave resonator (HWR), depending on the beam velocity, and the high energy SCL (SCL2) section does two kinds of single-spoke cavities (SSR). The beam accelerated by the SCL1 or SCL3 are transported to the low energy experimental hall or can be accelerated again by the SCL2 after passing through the charge stripping section [3] for the high energy experiments. The schematic view of the RAON accelerator is shown in Fig. 1.

The lattice design of the RISP test facility started since 2014 as an injector test facility which did not include the SCL

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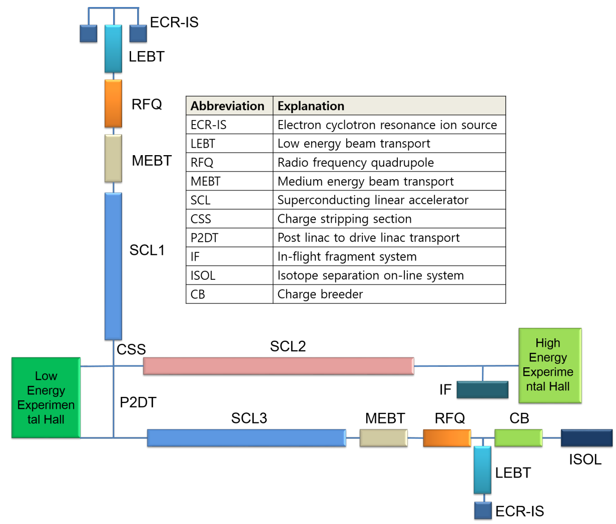

Figure 1: Schematic view of the RAON accelerator.

section [4], and then the lattice of this test facility was newly re-designed with the superconducting cavity and named SCL demo in 2015 [5]. Now the lattice of the SCL demo becomes more simplified and optimized within the limited space to test the front-end section of the RAON accelerator, and each equipment is being installed and tested individually for the beam commissioning at the end of 2016. Figure 2 shows the recent layout of the SCL demo, and one QWR cavity is located at the end of the SCL demo.

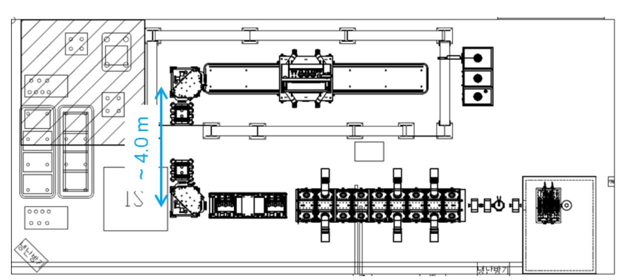

Figure 2: Layout of the SCLdemo.

In this paper, we will present the recent lattice design of the SCL demo and describe the results of the beam optics calculation and the particle tracking simulations with the bismuth beam and the oxygen beam. In the following beam dynamics simulations, the ELEGANT [6] and TRACK [7] codes were used.

DESIGN POINTS

For designing of the SCL demo lattice, several design points are considered as listed in Table 1. The bismuth and oxygen beams are selected as reference beams at the SCL

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demo. As satisfying these conditions, the lattice of the SCL demo is designed and optimized.

Table 1: Conditions for Lattice Design

Number	Conditions
1	Beam test from ECR-IS to SCL
2	Reference beams: ^{209}Bi, ^{16}O
3	Limited space: ~ 19m × 8m
4	Achromatic condition at bending section
5	Collimation for charge selection
6	Space for diagnostic equipments

SIMULATION RESULTS

Bismuth Beam

As reference beams in the SCL demo, the bismuth and oxygen beams are selected. The bismuth beam parameters used in the simulations are listed in Table 2. To match the (charge/mass) ratio of the bismuth beam to the reference uranium beam of the RAON accelerator, $^{238}U^{33.5+}$, a charge-state 29+ is selected.

Table 2: Bismuth Beam Information

Parameter	Value
Beam	$^{209}Bi^{29+}$
Energy	10 [keV/u]
Norm. rms. emittance	0.12 [μm]
Beam size	0.5 [cm]
Number of macro-particles	10,000
Beam distribution	4D water-bag

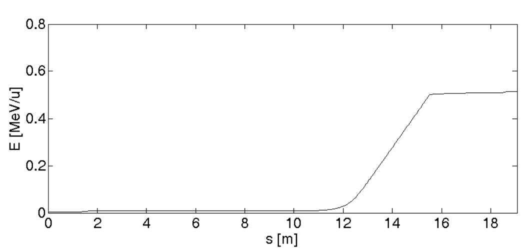

Figure 3: The energy of the bismuth beam along the SCL demo.

Figure 3 shows the beam energy along the SCL demo. After the RFQ, the beam energy becomes about 500 MeV/u which is the design value at the RAON accelerator, and then it reaches to about 515 MeV/u after the QWR cavity.

The transverse root-mean-square (rms.) beam size along the SCL demo is shown in Fig. 4. The beam size is kept much smaller than the beam pipe radii at each section (6.0 cm at the LEBT, 2.5 cm at the MEBT, 2.0 cm at the SCL) to keep the beam in stable along the SCL demo. Figure 5 shows the normalized transverse rms. emittance. Initial

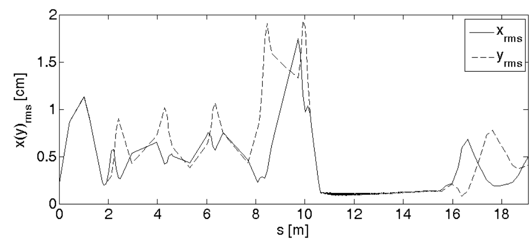

Figure 4: The transverse rms. beam size of the bismuth beam along the SCL demo.

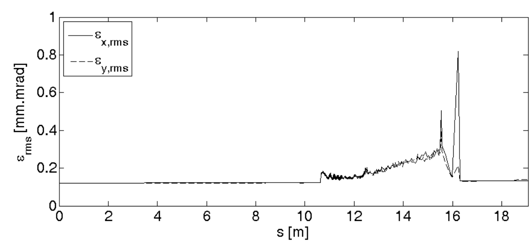

Figure 5: The normalized transverse rms. emittance of the bismuth beam along the SCL demo.

transverse rms. emittance is 0.12 [μm], and it is kept until the end of the QWR cavity. The increase of the transverse emittance at the RFQ is caused by the some particles which are not sufficiently accelerated, and those particles are clearly removed at the MEBT section.

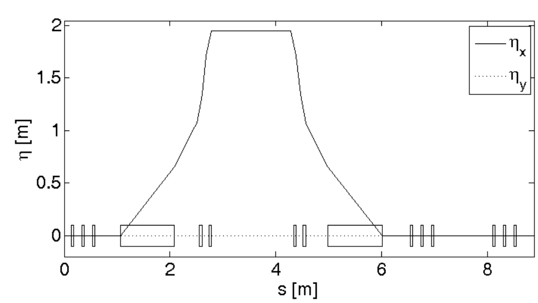

Figure 6: The dispersion function at the LEBT section of the SCL demo.

For the charge selection at the bending section of the SCL demo, the dispersion function is calculated to separate clearly the different charge-state bismuth beams as shown in Fig. 6. The achromatic condition is also satisfied. To select one-charge-state beam clearly among the multi-charge-state beams, two collimators are required. First collimator is located after first bending magnet and collimates the unwanted charge-state beams roughly. Also, second collimator is located at the middle of the bending section and selects a wanting charge-state beam. Figure 7 shows the horizontal beam distributions at the positions of first and second collimators, and we can select one-charge-state bismuth beam, $^{209}Bi^{29+}$, among multi-charge-state beams.

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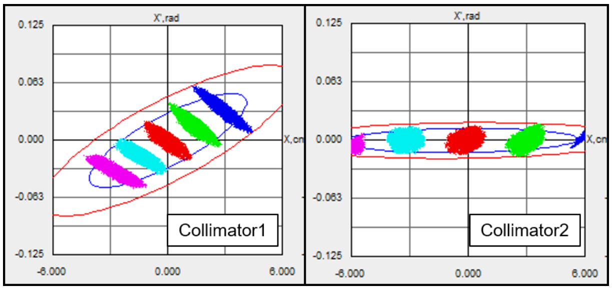

Figure 7: The horizontal distribution of bismuth beam, 27+ ~ 31+, at the collimators in the bending section.

Oxygen Beam

The oxygen beam, $^{16}O^{7+}$, will be tested at the SCL demo at the end of 2016, therefore this beam is also simulated for the successful beam commissioning. Except the (mass/charge) of the beam, the other parameters used in the simulations are same with the bismuth beam as shown in Table 2.

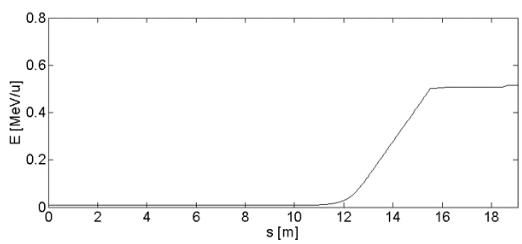

Figure 8: The energy of the oxygen beam along the SCL demo.

Figure 8 shows the oxygen beam energy along the SCL demo. The RF power of the RFQ is scaled to satisfy the target beam energy at the end of the RFQ, 500 MeV/u, and thus the beam energy becomes about 516 MeV/u at the end of the SCL demo.

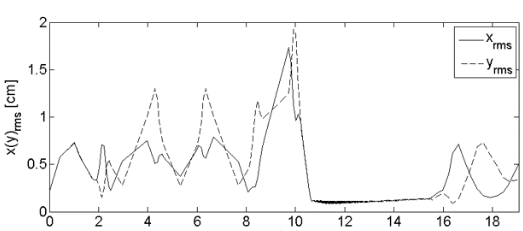

Figure 9: The transverse rms. beam size of the oxygen beam along the SCL demo.

The transverse rms. beam size of the oxygen beam is shown in Fig. 9. The beam size is much smaller than the beam pipe radii at each section like the bismuth beam. Figure 10 shows the normalized transverse rms. emittance along the SCL demo. The initial transverse rms. emittance is also kept until the end of the SCL demo.

Unlike the bismuth beam, the deviation of the (charge/mass) ratio of the multi-charge-state oxygen beams is larger. For that reason, one-charge-state oxygen beam,

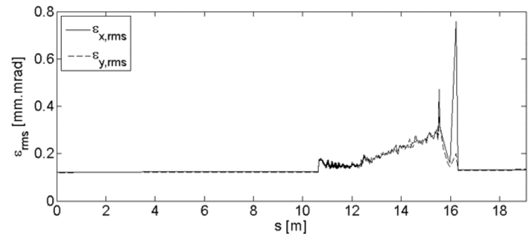

Figure 10: The normalized transverse rms. emittance of the oxygen beam along the SCL demo.

$^{16}O^{7+}$, only survives after first bending magnet, and thus the collimator is not necessary for the charge selection of the oxygen beam.

SUMMARY

We had presented the recent lattice design of the SCL demo and described the simulation results with the bismuth and oxygen beams. The first beam commissioning is scheduled at the end of 2016, and thus the beam dynamics simulations were carried out to prepare it. Transverse rms. beam sizes of both beams were kept much smaller than the beam pipe radii at each section, and the required matching conditions were also satisfied. In addition, the calculation for the charge selection at the bending section was successfully performed. These researches will be continued before the beam commissioning as accepting the changes of the equipments.

ACKNOWLEDGMENTS

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