OPTICS DESIGN AND CORRECTION OF HIGH ORDER ABERRATION OF THE CHARGE STRIPPER BEAM LINE OF RAON

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Abstract

RAON (Rare isotope Accelerator Of Newness) in Korea will be providing the 400 kW of $^{238}U^{79+}$ beam with 8 pmuA and 200 MeV/u. One of the critical components of this project in the SCL is the design of the charge stripper. Between the two segments of the SCL, the charge stripper strips electrons from ion beams to enhance the acceleration efficiency in the following SCL2. For high efficiency of the acceleration and high power in SCL2, the optimum energy of striped ion in solid carbon foil stripper for SCL1 was estimated by using code LISE++. The thickness of the solid carbon foil is $300 mg/m^2$. Based on this study, the charge stripping efficiency of solid carbon stripper is 80 %. For the charge selection from ions which produced by the solid carbon stripper, the dispersive section is required in down-stream of the foil. The designed optics for dispersive section is based on the mirror-symmetric optics to minimize the effect of high-order aberration. And the high-order aberration in designed optics was investigated and performed the correction of high-order effect using sextupole magnets.

INTRODUCTION

The RAON (Rare isotope Accelerator Of Newness) in RISP is the superconducting linear accelerator for heavy-ion beam to examine the numerous facets of basic science. The main features of this machine are a high beam power of 400 kW with an energy of 200 MeV/u for uranium and 600 MeV for protons, high repetition rate of 81.25 MHz with a CW operation and several techniques for the production of the rare isotope heavy ion beams, such as the Isotope Separator On-line(ISOL) and In-flight systems [1, 2]. The charge stripper section is one of the critical components for achieving a high beam power of 400 kW at the end of linac in the superconducting linear accelerator of RAON. The charge stripper strips electrons from the heavy ion beams to enhance the acceleration efficiency in the following linear accelerator. Main goal of the stripper beam line is to achieve the high efficiency with high purity of the beam. Many studied already done with several code for accurate calculation.

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CHARGE STRIPPER BEAM LINE

The uranium ion beam, which is one of the main operation modes in RAON, was accelerated as two charge states of 33+ and 34+ in SCL1, stripped the electrons, and accelerated as five charge states ranging from 77+ to 81+ in SCL2 to achieve a high beam power of 400 kW at the end of the linac. Hence the charge stripper is one of the critical component to achieve the high power in the designed SCL [3]. The layout of the charge stripper beam line is shown in Fig. 1.

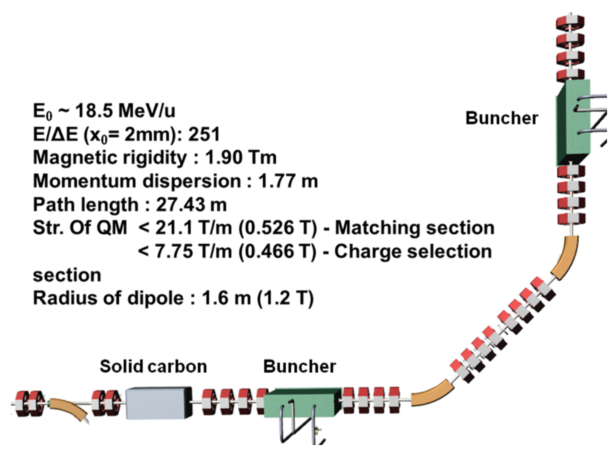

Figure 1: Layout of the charge stripper section.

In the charge stripper section, the doublet quadrupole magnet and cryomodule for bunching are installed in upstream of the solid carbon foil to control the beam distribution on transverse and longitudinal direction at the foil position. To optimize the beam energy at the end of the SCL1, the efficiency of charge stripping of ^{238}U ions with carbon foil of 300 $\mu g/cm^2$ was calculated using code LISE++ and it was decided to the energy of 18.5 MeV/u [4, 5]. Several collimators are also installed in the downstream of the solid carbon foil to prevent the damage of the cryomodule which is installed between the stripper and charge selection section by the scattered ion from carbon foil. The position of the collimator is shown in Fig. 2

The halo particle produced by the large scattering in the stripper was removed by using the collimators. The number of the halo particle in the stripping section is less than 2 % according to the calculation result of the tracking simulation using code TRACK [6]. The rate of the collimated particles is listed in Table 1.

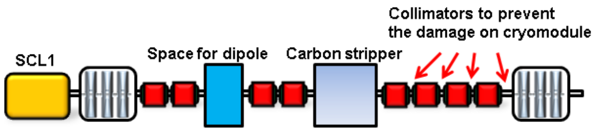

Figure 2: Beam collimators in charge stripping section.

Table 1: Collimation Rate in Each Collimator in CS Line

Equipment	Loss Rate [%]	Heat [W]
2^{nd} slit	0.145	84.7
3^{rd} slit	0.195	114
4^{rd} slit	0.105	61.4
5^{rd} slit	0.130	76.0

As listed in Table 1, the particle loss in the collimator is small enough to achieve the high power and it is close to the number of the halo particle produced by the stripper. 4 quadrupole magnets installed in the downstream of the stripper is used to match the twiss parameter at the entrance of the charge selection section. In the charge selection section, the derivative of the betatron function on the phase space should be minimized to reduce the high order aberration. The beam distribution at the entrance of the charge selection section is shown in Fig. 3.

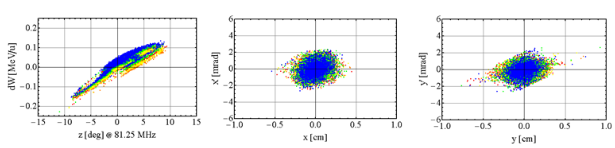

Figure 3: Beam collimators in charge stripping section.

After matching and collimation in the stripping section, the tracking simulation in the whole beam line using code TRACK was performed. The envelope of the beam size and emittance is shown in Fig. 4.

As shown in Fig. 4, the growth of the normalized transverse emittance in the charge selection section is 26.38 % on horizontal plane. It is caused by the high order aberration due to the multi-charge state of the beam. Hence the study for the high order compensation using sextupole is required to reduce the growth of the emittance.

COMPENSATION OF HIGH ORDER ABERRATION IN THE CHARGE SELECTION SECTION

The optics of the charge selection section is based on the mirror symmetry to reduce the high order aberration [7]. The high order aberration, however, is not negligible. Therefore the study for compensation the second order aberration by using sextupole magnet was performed. The calculation was done by using code ORBIT [8]. 14 sextupole magnets which has the effective length of 10 cm long was installed between the quadrupole magnet in each section that is shown in Fig. 5.

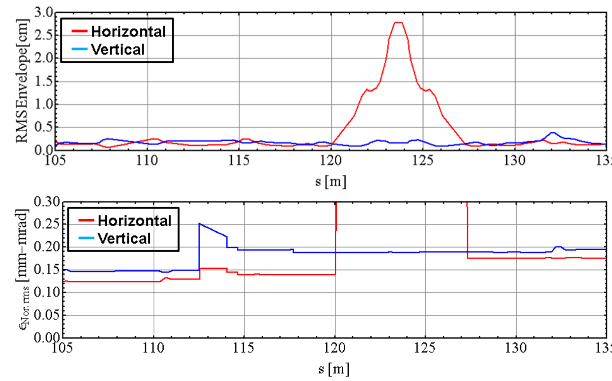

Figure 4: Layout of the charge stripper section.

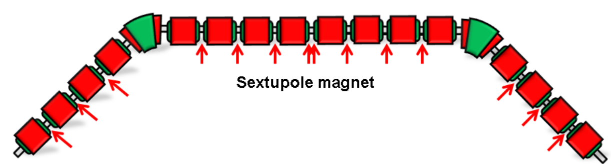

Figure 5: Layout of the charge selection section. Red arrow means the position for sextupole magnet.

In the original design, the space is enough for installation of the sextupole magnet. The amplitude of the second order components of $(x|x\delta_p)$, $(x'|x\delta_p)$, $(x|x'\delta_p)$, $(x|\delta_p\delta_p)$, $(x'|x'\delta_p)$, $(y|y'\delta_p)$, and $(y'|\delta_p y)$ which is related to the momentum spread were compensated by using the 14 sextupole magnets. Also, the amplitude of the second order components of $(x|xx)$, $(x'|xx)$ and $(x|xx')$ were well compensated. The effect of the high order aberration was decreased even though the component which has the zero due to the mirror symmetric was broken. The tracking simulation was performed to confirm the compensation of the effect of high order aberration in charge selection section that is shown in Fig. 6.

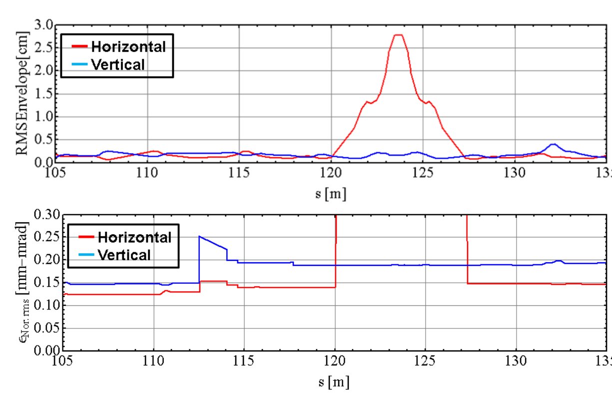

Figure 6: Layout of the charge stripper section.

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As shown in Fig. 6, the growth of the emittance on horizontal plane was well compensated to about 5 % even through the growth of the emittance on vertical plane was little increased to 1.63 %. The sextupole magnet parameters are given in Table 2.

Table 2: Parameters for the Sextupole Magnets of the Designed Beam Line

Length [m]	**Pole Tip Radius [m]**	**Field Strength** $[1/m^2]$
0.10	0.06	6.10
0.10	0.06	-1.89
0.10	0.06	10.67
0.10	0.10	12.02
0.10	0.10	-15.79
0.10	0.10	-10.71
0.10	0.10	11.22
0.10	0.10	13.79
0.10	0.10	-6.32
0.10	0.10	-28.05
0.10	0.10	17.03
0.10	0.06	25,28
0.10	0.06	-3.11
0.10	0.06	4.95

CONCLUSION

The optics of the charge stripper beam line which consist of the solid carbon stripper, charge stripping section, charge selection section, and three bunching cryomodule was well designed to get the high power with the small emittance growth and high beam transmission efficiency. Especially, the charge selection section which has the dispersion for charge selection is designed based on the mirror symmetry to reduce the effect of the high order aberration. And the study for compensation of the effect of the high order aberration using sextupole magnet was also performed. The emittance growth due to the effect of the high order aberration in charge selection section was well compensated by using 14 sextupole magnet. The growth of the horizontal emittance was reduced to about 5 % from 26 %.

ACKNOWLEDGMENT

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REFERENCES

[1] S.K. Kim et al, Rare Isotope Science Project: Baseline Design Summary, http://www.risp.re.kr/.

[2] D. Jeon et al, Status of the RAON accelerator systems, this conference.

[3] Hyung-Jin Kim et. al, Proceedings of IPAC 2013, WEPEA034, Shanghai, China (2013).

[4] H. Ryuto et al., *Nucl. Instr. Methods A*, **569**, 697 (2006).

[5] Hye-jin Kim et al., Proceedings of EMIS 2012, Matsue, Japan (2012).

[6] P.N. Ostroumov and K.W. Shepard, *Phys. Rev. ST. Accel. Beams*, 11, 030101 (2001).

[7] B. Erdelyi, J. Maloney and J. Nolen, *Phys. Rev. ST. Accel. Beams*, 10, 064002 (2007).

[8] S. Morinobu, private communication.