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BEAM DYNAMICS ISSUES FOR A SUPERCONDUCTING LINEAR ACCELERATOR-BASED HIGH POWER HEAVY ION MACHINE

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Abstract

The driver linac of RAON heavy ion accelerator based on the superconducting technology, which consists of a 28 GHz ECR ion source, a low energy beam transport line, a RFQ accelerator, a medium energy beam transport line, a low energy linac(SCL1), a charge stripping section and a high energy linac(SCL2), will produce the stable ion beam from proton with 600 MeV to uranium with 200 MeV/u. Many beam dynamics issues such as beam steering effect due to QWR cavities with the peak electric field of 35 MV/m, emittance growth in charge stripper due to the straggling effect, parametric resonance and envelope instability were investigated to design the high power heavy ion machine which can produce the high quality beam. In this presentation, we present our study results for achieving longitudinal acceptance larger than 27 keV/u-ns for the stable operation and minimizing the emittance growth less than 30 % in the superconducting linac for high quality beam at the in-flight target.

INTRODUCTION

The superconducting technology based heavy ion linear accelerator named as a RAON (Rare isotope Accelerator Of Newness) was launched to examine the numerous facets of basic science, such as nuclear physics, astrophysics, atomic physics, life science, medicine and material science [1]. The RAON can be classified as a driver superconducting linear accelerator to produce the high power stable ion beams from ECR ion sources and post superconducting linear accelerator to produce the high energy unstable ion beams from Isotope Separator On-Line (ISOL). Especially, the driver accelerator of RAON, which consists of a front-end system, a low energy linac, a charge stripping section and a high energy linac, produce an energy of 200 MeV/u for uranium and 660 MeV for protons with a high beam power of 400 kW and the high repetition rate of 81.25 MHz with a CW operation. The schematic layout of the driver linac is shown in Fig. 1

The front-end system, which consists of 28 GHz ECR ion source, a low energy beam transport line, a RFQ accelerator and a medium energy beam transport line, produces ion beams which has A/q ratio from 1 for proton beams with an energy of 500 keV/u and a beam current of 700 μA to 7.2 for uranium beams with an energy of 500 keV/u and a beam current of 12 pμA [2, 3, 4].

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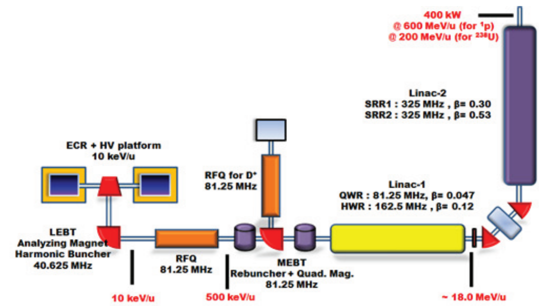

Figure 1: The schematic layout of the driver linac.

LOW ENERGY LINAC

The low energy linac which consists of 21 quarter-wave resonators (QWRs) with a geometric beta of 0.47 and 102 half-wave resonators (HWRs) with a geometric beta of 0.12 accelerates the ion beams from 500 keV/u to 18 MeV/u for uranium beam and 45 MeV for proton beam. The schematic layout for each section in a low energy linac was shown in Fig. 2.

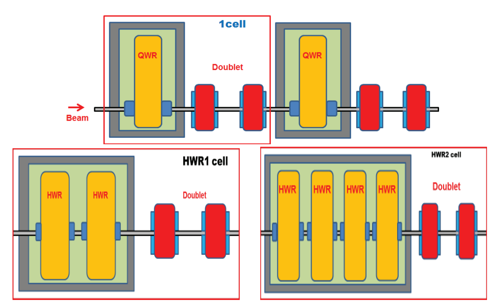

Figure 2: The schematic layout of the low energy linac.

The length of the section was minimized by reducing the physical length of the quadrupole magnets and spaces for warm and cold section to increase the longitudinal acceptance in the low energy linac because the longitudinal acceptance in the low energy linac mainly depends on the distance between cavities in the QWR section [5]. Also, the RF phase was -55 ° at the first cavity and it was increased up to -37 ° at the end of QWR section. The field gradient of the cavity was controlled to keep the phase advance lower than 90 ° and to smoothly variate the phase

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advance so long as the beam was accelerated. The longitudinal acceptance in the low energy linac is 27 keV/u-ns that is shown in Fig. 3.

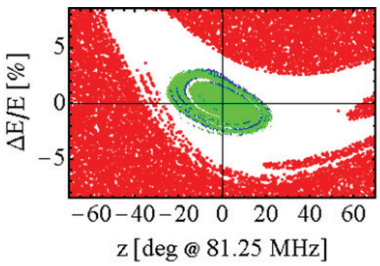

Figure 3: Longitudinal acceptance of the low energy linac for $^{238}U^{33+}$ and $^{238}U^{34+}$ beams.

The transverse phase advance was set to lower than 90° to avoid the envelop instability and the resonance with the space charge effect. The ratio between the transverse phase advance and longitudinal phase advance was also controlled to vanish the parametric resonances of transverse motion [6]. Figure 8 shows the beam envelope, and rms transverse and longitudinal emittances along the low energy linac, which is smooth along most of the linac. It was calculated by the multi-particle tracking simulation using code TRACK, which can compute multi-particle simulation of multiple component ion beams in 6D phase space [7].

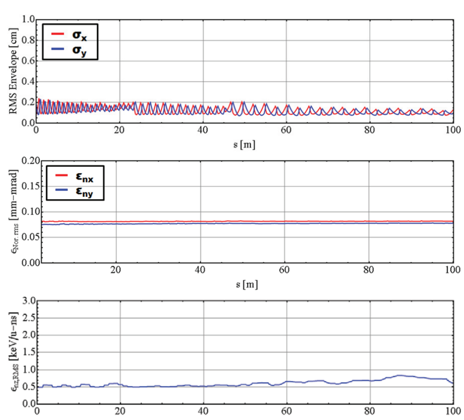

Figure 4: The beam envelope(top), transverse emittance (middle) and longitudinal emittance (bottom) in a low energy linac.

The aperture to rms beam size in the main linac is kept below 2.0 mm in transverse. The physical aperture is 20 mm, which is about ten times the rms beam size. The growths of the transverse and longitudinal emittance are ignorable.

CHARGE STRIPPING SECTION

The charge stripping section is located downstream of the low-energy linear accelerator. The energy of the uranium beam of 18 MeV/u at the end of the low energy linac is determined by the stripping efficiency of the uranium beam with a reasonable stripper thickness, 300 g/cm2, to optimize the stripping efficiency [8]. The top view of the charge stripping section in RAON is shown in Fig. 5.

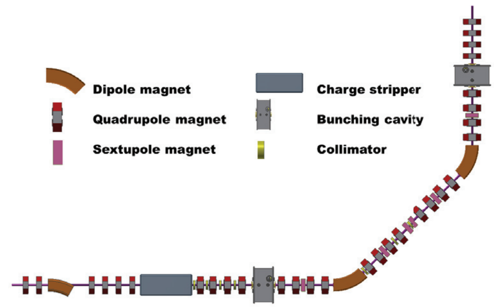

Figure 5: Layout of the charge stripper section of RAON.

In the charge stripping section, main sources of the emittance growth are straggling effects in the stripper and the high-order aberration in the dispersive section. The most important criteria for compensation of the emittance growth due to the effect of angular straggling is to reach the stripper with an upright beam ellipse in the transverse phase plane because it can be minimized when the angle of the phase ellipse in transverse phase space is minimized [9].

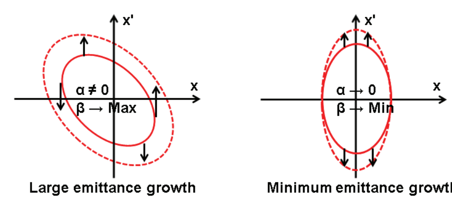

Figure 6: Schematic view to compensate for the emittance growth at the stripper.

Figure 7 shows that the growth of the emittance was minimized when the angle of the phase ellipse was minimized.

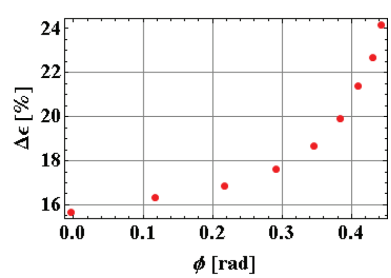

Figure 7: Normalized transverse emittance as a function of the phase angle.

The high-order aberration, which causes the emittance growth of multi-charge state beams due to the chromaticity, in the charge selection section was compensated by using six sextupole magnets. In particular, the significant terms which cause the transverse emittance growth of the

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multi-charge states ion beam in the dispersive section were carefully investigated that is $(x|\delta_p\delta_p)$, $(x'|x\delta_p)$, $(x|x'\delta_p)$, $(x|x\delta_p)$, $(x'|\delta_p\delta_p)$, and $(x'|x'\delta_p)$ in the horizontal plane, and $(y|y'\delta_p)$ and $(y'|y\delta_p)$ in the vertical plane [9].

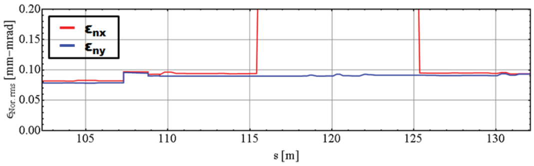

Figure 8: The envelope of the transverse emittance in a charge stripping section.

HIGH ENERGY LINAC

The high energy linac which consists of single spoke cavity with a geometric beta of 0.30 (SCL21) and a geometric beta of 0.53 (SCL22) accelerates the ion beams from 18 MeV/u to 204 MeV/u for uranium beam and 660 MeV for proton beam. The schematic layout for each section in a high energy linac was shown in Fig. 9.

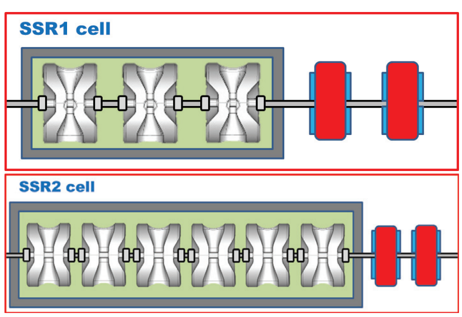

Figure 9: The schematic layout of the high energy linac.

In order to increase the longitudinal acceptance, the RF phase was -60 ° at the first cavity and it was increased up to -26 ° at the end of SCL21 section. The field gradient of the cavity was controlled to keep the phase advance lower than 90 ° and to smoothly variate the phase advance. The longitudinal acceptance in the low energy linac is 230 keV/u-ns that is shown in Fig. 10.

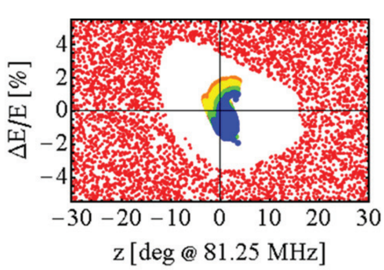

Figure 10: Longitudinal acceptance of the high energy linac for the uranium beams.

Figure 11 shows the beam envelope and rms transverse and longitudinal emittance along the high energy linac, which is smooth along most of the linac.

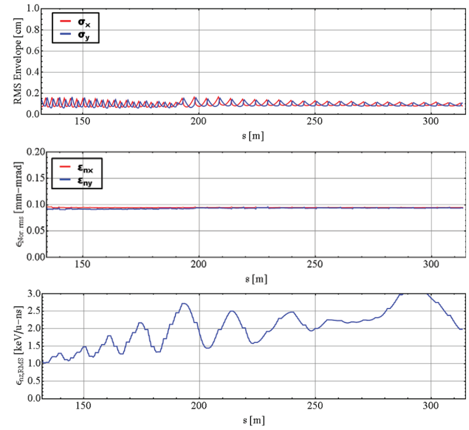

Figure 11: The beam envelope(top), transverse emittance (middle) and longitudinal emittance (bottom) in the high energy linac.

The aperture to rms beam size in the main linac is kept below 1.8 mm in transverse. The physical aperture is 25 mm, which is about ten times the rms beam size.

CONCLUSION

The design and beam dynamics studies of the driver linac with the superconducting cavities of the RAON were presented with emphasis on avoiding the emittance growth. The emittance growth in the linac was suppressed by compensating the effect of the parametric resonance and space charge effect thereby keeping the phase advance lower than 90 °. The emittance growth in the stripping section was also compensated by changing the angle of the phase ellipse in phase space.

REFERENCES

[1] http://www.ibs.re.kr

[2] Eun-San Kim, et al., Proceedings of IPAC2013, Shanghai, China, TUPWO038 (2013).

[3] Eun-San Kim, et al., Proceedings of HIAT2012, Chicago, USA, THB03 (2012).

[4] Hye-Jin Kim, et al., Journal of Korean Physical Society, **63**, 1249 (2013).

[5] A. P. Fateev and P. N. Ostroumov, Nuclear Instruments and Methods in Physics Research, **222**, 420 (1984).

[6] P. N. Ostromov, Proceedings of LINAC2002, Gyeongju, Korea, 64 (2010).

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

[8] Hye-Jin Kim et al., Nucl. Instrum. Methods B, **317**, 266 (2013).

[9] Ji-Gwang Hwang et al., Minimization of the emittance growth of multi-charge particle beams in the charge stripping section of RAON, *Nucl. Instrum. Methods A* (In press) (2014).