BEAM DYNAMICS STUDY FOR RAON SUPERCONDUCTING LINAC

Hyojae Jang, Hyung Jin Kim, IBS, Daejeon, Korea
Ji-Gwang Hwang, KNU, Deagu, Korea
BongHoon Oh, POSTECH, Pohang, Korea

Abstract

Rare Isotope Science Project (RISP) in Korea is going to build an ion accelerator, RAON which can generate and accelerate various stable ions such as uranium, proton, xenon and rare isotopes such as tin, nickel. Linear accelerators of RAON adopted superconducting RF cavities and warm quadruple doublet structure. In RAON, there are two low energy linacs which can accelerate the Uranium beam from 0.5MeV/u to 17.5MeV/u, charge stripping sections and one high energy linac which can accelerate the Uranium beam up to 200MeV/u. Due to the diversity of planned ions and isotopes, their A/q range lies widely from 1 to 8. As a result, the research related with linac lattice design and beam dynamics is one of the important topics to build RAON. In this presentation the current status of RAON linac lattice design and the beam dynamics simulation results for acceleration of various ions will be described.

INTRODUCTION

A high energy ion accelerator is essential to research of nuclear, material, medical science and many other areas. In Korea, Rare Isotope Science Project (RISP) project has been going on since 2009 and its goal is to build an ion accelerator which can generate high-power ion beams and rare isotopes. [1] For generation of stable ions, electron cyclotron resonance ion source (ECR-IS) will be used and for rare isotopes, isotope separation on-line (ISOL) system will be used as ion sources. Generated ions are accelerated and bunched in low energy beam transport (LEBT), radio frequency quadrupole (RFQ), medium energy beam transport (MEBT). Superconducting linear accelerators start immediately after MEBT. They consist of two low superconducting energy linacs (SCL1 and SCL3) and one high energy superconducting linac (SCL2). The layout of RAON superconducting linear accelerators is shown in Fig. 1.

SCL1 accelerates stable ion beams while SCL3 accelerates rare isotope. Ions from low energy linac are transported to high energy linac, SCL2. Charge stripping sections are placed between SCL1 and SCL2 and between SCL3 and SCL2 to enhance the acceleration efficiency. To provide high quality ion beams, RAON adopted superconducting cavity and normal conducting quadrupole doublet structure for linac lattice. The Bunch frequency of the linear accelerator is 81.25 MHz. There are four kinds of cavities in RAON. Quarter wave resonators (QWR) will be used at the beginning of low energy linac and this section is called as SCL11 and SCL31. Half wave resonators (HWR) are going to be used for the rest of low energy linac and this section is called as SCL12 and SCL32. Two kinds of single spoke resonators (SSR) are going to be used for high energy linac (SCL2) and they are called as SCL21 and SCL22. Selected optimum betas were β_g=[0.047,0.12,0.3,0.51]. Also the transit time factors according to beta are shown in Fig. 2.

Each period in linac consists of a cryomodule containing superconducting cavities, one quadrupole doublet and a beam box for diagnostics. Layout of superconducting linac is shown in Fig. 3 and configurations of each section are summarized in Table 1. SCL3 and SCL1 are identical except that SCL3 has one less cryomodule containing four HWRs than SCL1. The number of cryomodules of four HWRs is 18 in SCL32.

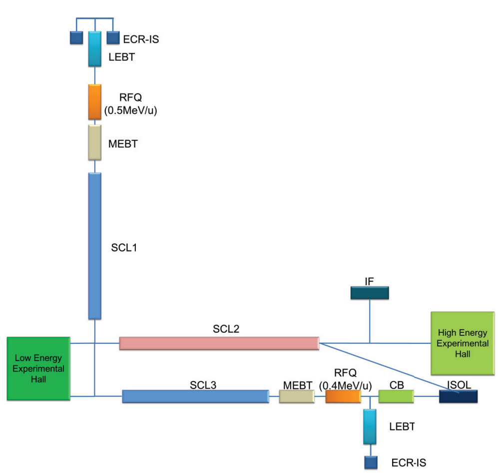

Figure 1: Layout of RAON superconducting linacs.

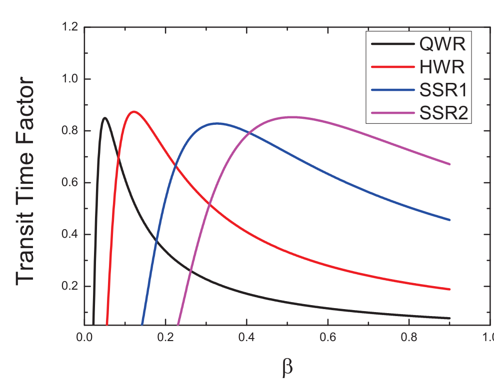

Figure 2: Transit time factors of cavities in RAON superconducting linac.

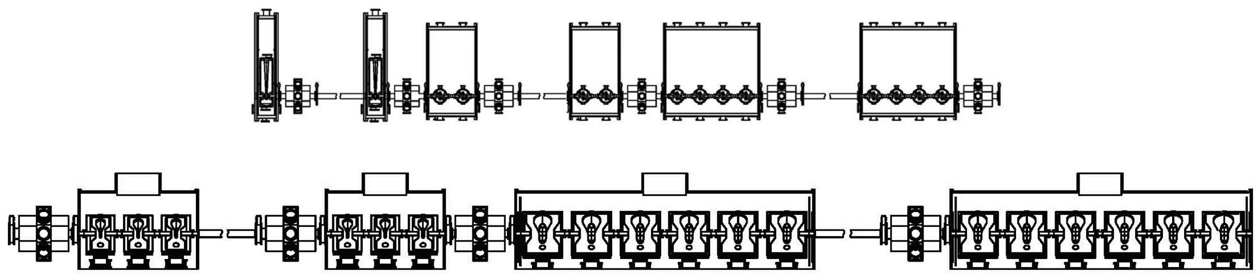

Figure 3: Layout of the superconducting linac: (top) low energy superconducting linac (SCL1 and SCL3), and (bottom) high energy superconducting linac (SCL2).

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Lattice Design for High Power Stable Ion Beams

Target beam power of RAON driver linac, SCL1 and SCL2, is 400kW in case of stable ion beam. With this condition, various instabilities such as envelope instability, parametric coupling, space charge effect, etc. can occur [2] and it can lead to a beam loss. To avoid such problems it is important to control longitudinal (1) and transverse (2) phase advance [5]. The transverse phase advance of designed linac lattice is kept under 90° and the ratio of transverse phase advance to longitudinal phase advance is about 0.8 except short section for transverse matching by controlling E_0T, ϕ_s and G. Under this condition lattice designs for uranium, a primary ion in RISP was conducted. Tracking simulation was performed with designed lattice using TRACK code [4].

$$\sigma_{ol} = \sqrt{\frac{2\pi q E_0 T N^2 \lambda sin(-\phi_s)}{mc^2 \beta_s \gamma^3}} \quad (1)$$

$$\sigma_{ot} = \frac{qGl\sqrt{LD}}{\gamma mv} \quad (2)$$

Figure 4 is the RMS envelope of uranium beam in SCL1 and SCL2 and the emittance change in linac section is shown in Fig. 5. The beam size is small enough (<3mm) to pass the linac because the radius of beam tube is 20mm for SCL1 and 25mm for SCL2. Also the transverse emittance growth was minimized.

Linac lattice design for proton, oxygen, xenon was also performed with similar design policy. In Fig. 6, the energy evolution in SCL is illustrated. Also the energy, central charge state and A/q of each ion are summarized in Table 2. Charge stripping was estimated by LISE++ [3]. From the result, we could confirm that RAON linac can accelerate ions having wide A/q value (1 ~ 8) successfully.

Table 1: Summary of Linac Dimension Design for Stable Ions.

	SCL11	SCL12		SCL21	SCL22
# of Cryomodule	22	13	19	23	23
# of cavity per period	1	2	4	3	6
# of cavities	22	26	76	69	138
Type of cavities	QWR	HWR	HWR	SSR1	SSR2

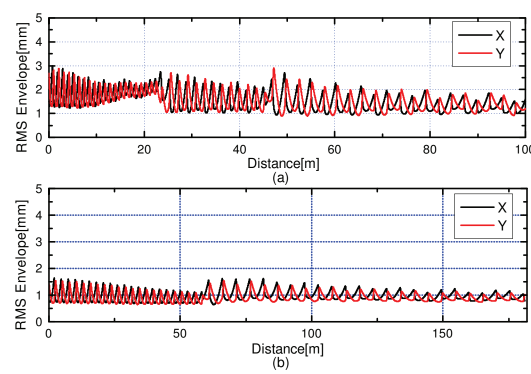

Figure 4: RMS envelope of U in SCL1(a) and SCL2(b).

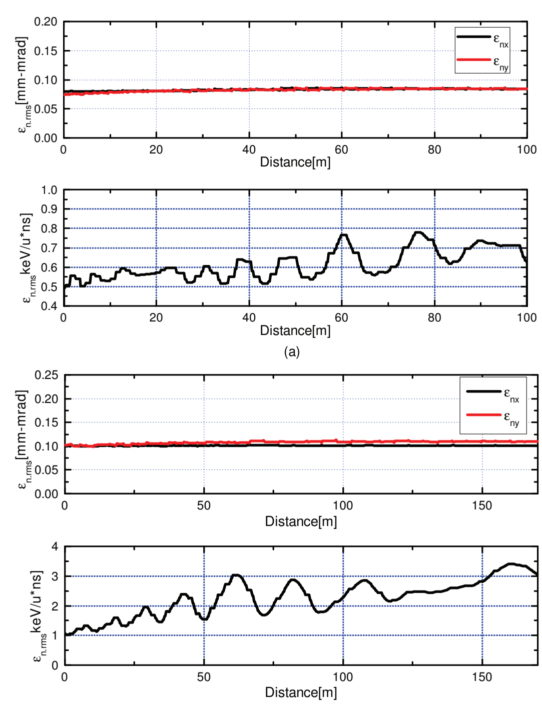

Figure 5: Normalized RMS emittance of Uranium in SCL1(a) and SCL2(b).

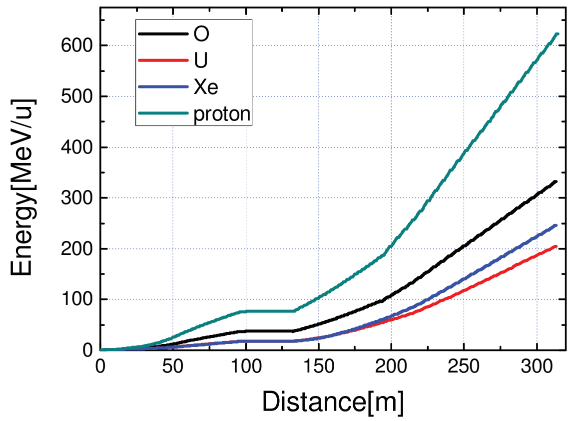

Figure 6: Ion energies in SCL.

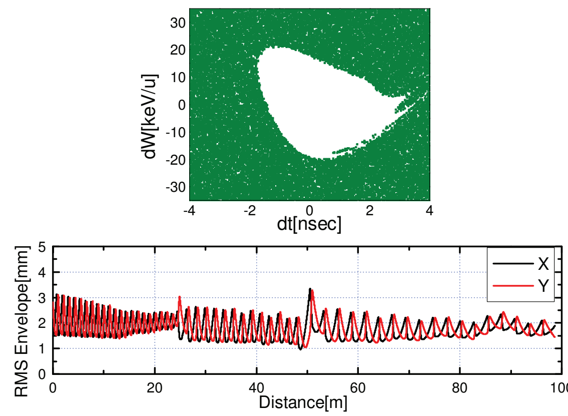

Figure 8: Longitudinal acceptance of SCL3 for Sn (top) and rms envelope(bottom).

Lattice Design for Rare Isotope

SCL3 in RAON accelerator is for acceleration of rare isotopes. ^{132}Sn is one of the nuclei with double magic number (Z=50 and N=82) thus it is attracting many nulear scientists. As a result, Sn was selected as one of the reference particles in RISP and we designed SCL3 lattice for acceleration of Sn with A/q~8 and initial energy=0.4MeV/u. Figure 7 is the energy of Sn in SCL3 and Fig. 8 shows longitudinal acceptance and rms envelope. Longitudinal acceptance is about 27KeV/u*ns and final energy is 14.5 MeV/u. Because this result is for A/q~8, it is expected that the final energy can be increased because nominal A/q of Sn from ISOL (4~7) will be higher than 8.

Table 2: Beam Energies and A/q of Stable Ions in the Driver Linac.

	Unit	SCL11	SCL12	SCL21	SCL22
^{238}Uranium	MeV/u	2.5	17.5	54	200
	Q(charge)	33.5	33.5	79	79
	A/Q	7.1	7.1	3	3
^{16}Oxygen	MeV/u	4	37	97	320
	Q(charge)	6	6	8	8
	A/Q	2.7	2.7	2	2
^{124}Xenon	MeV/u	2.3	17.6	58	240
	Q(charge)	18	18	50	50
	A/Q	6.9	6.9	2.5	2.5
Proton	MeV	6.2	77.2	187	600
	A/Q	1	1	1	1

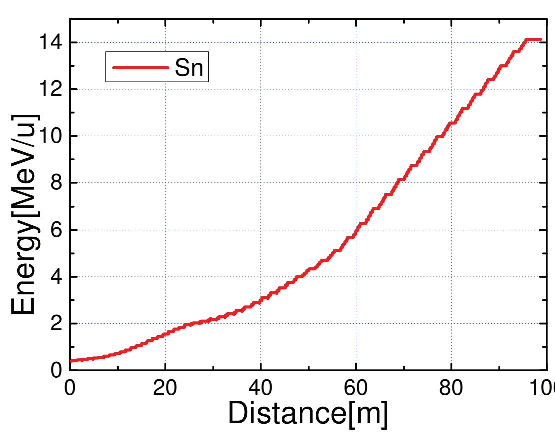

Figure 7: Rare isotope (Sn) energy in SCL3.

SUMMARY

The optics designs for stable ions and rare isotopes of RAON linear accelerator and beam simulation results are presented. According to the design, high power uranium beam could be accelerated from 0.5MeV/u to 200MeV/u with small emittance growth. Also the energy of proton, oxygen, xenon beams could be reached to 600MeV, 320MeV/u and 240MeV/u, respectively. Rare isotope, tin could be accelerated from 0.4MeV/u to 14.5MeV/u. From these results, it is verified that ions whose A/q varies from 1 to 8 could be accelerated with RAON accelerator which consists of four kinds of cavities(QWR, HWR, SSR1, SSR2) and normal conducting quadrupole doublet structure and it is capable of generating various ions which can be used in many different areas.

ACKNOWLEDGMENT

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