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START-TO-END SIMULATION FOR RAON SUPERCONDUCTING LINAC

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Abstract

An ion accelerator, RAON is going to be built in Daejeon, Korea by Rare Isotope Science Project(RISP) team in Institute of Basic Science(IBS). The linac part of RAON consists of two low energy linacs, one high energy linac and two bending section for transporting accelerated low energy ions to high energy linac. It is planned to accelerate many diverse ions like proton, carbon, calcium, uranium, etc. which have different A/q values. Consequently the lattice design for each ion and to investigate beam dynamics issues for each case are one of the important topics for this project. For enhancement of beam acceleration a study to suppress emittance growth and to maximize the longitudinal acceptance is conducted while designing the RAON lattice. In this presentation the designed linac lattices for various ions and start-to-end simulation results will be described.

INTRODUCTION

Nowadays the importance of an ion accelerator is increasing as it is an essential tool for research of medical, nuclear, material, science and many other areas. Since 2009 Rare Isotope Science Project (RISP) project has been going on in Korea to build an ion accelerator which can generate high-power ion beams and rare isotopes. [1]- [2] For acceleration of stable ions, electron cyclotron resonance ion source (ECR-IS) is going to be used while electron beam ion source (EBIS) and ECR-IS are going to be used as ion sources of isotope separation on-line (ISOL) system which will generate rare isotopes. Because the ions from these systems have various charge states they will be filtered to desired charge states in low energy beam transport (LEBT). Radio frequency quadrupole (RFQ) and medium energy transport (MEBT) will be installed after LEBT for beam acceleration and bunching. Superconducting linear accelerators start immediately after MEBT. They consist of two low superconducting energy linacs (SCL1 and SCL3), one high energy superconducting linac (SCL2), two bending section for bridging of linacs and one 120m beam transport for transporting high energy ions to high energy beam transport of IF(In-flight Fragment seperator) system. 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 linacs are transported to high energy linac, SCL2. In this transport there are two charge strippers and charge selection selections between SCL1 and SCL2 and between SCL3 and SCL2. The charge state of ions become higher and it leads to the enhancement of 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 first part 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. In high energy linacs (SCL2) two kinds of single spoke resonators (SSR) which have dfferent geometrical betas are going to be used and they are called as SCL21 and SCL22. Selected optimum betas were β_g=[0.047,0.12,0.3,0.51]. Also the accelerating voltages according to beam beta are shown in Fig. 2.

Each period in linac consists of a cryomodule containing superconducting cavities, one quadrupole doublet and a beam box which will be used for vacuum pumping, installing the diagnostics. Also recently transport line for transporting high energy is designed. In this section there are two cryomodules which are similar to the cryomodules used in SCL22 section. Summarized parameters of each linac section for stable ion acceleration are summarized in Table 1.

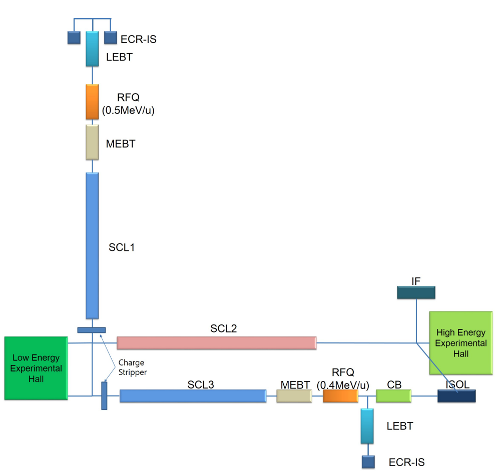

Figure 1: Layout of RAON superconducting linacs.

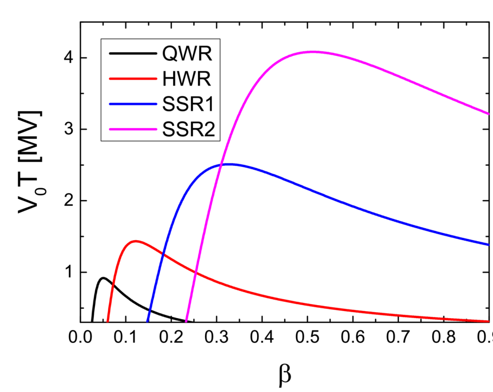

Figure 2: Effective accelerating voltage of cavities in RAON superconducting linac.

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Table 1: Important Parameters of Linacs for Stable Ion Acceleration

Section	SCL1				SCL2		
	SCL11	SCL12		CS	SCL21	SCL22	Transport
β	0.047	0.12			0.3	0.51	
Cryomodule (mm)	610	1130	2010		1852	4390	4390
Warm Section (mm)	470	670	670		820	820	2740
1 Period (mm)	1080	1800	2680		2672	5210	7130
Section Length (m)	23.9	23.4	52.9	31.8	61.5	119.8	120
Acumulated Length (m)	23.9	47.3	100.3	132.1	193.5	313.4	433.4
# of CM	22	13	19	2	23	23	2
# of cavity per CM	1	2	4	2	3	6	6
# of cavities	22	26	76	4	69	138	12
Cavity Type	QWR	HWR		HWR	SSR1	SSR2	SSR2

SCL3 and SCL1 are identical except that SCL3 has one less cryomodule containing four HWRs than SCL1. The number of cryomodules containing four HWRs is 18 in SCL32, while it is 19 in SCL12.

BEAM DYNAMICS FOR RAON SUPERCONDUCTING LINAC

In heavy ion accelerator various instabilities such as envelope instability, parametric coupling, space charge effect, etc. can occur [3] which can lead to a beam loss. To avoid such problems it is important to control longitudinal (1) and transverse (2) phase advance [4]. 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 0.8-1.2 except short section for transverse matching by controlling E_0T, ϕ_s and G. Under this condition lattice designs for uranium, proton, oxygen, xenon were conducted. In Fig. 3, the energy evolution in SCL is illustrated. Also the energy, central charge state and A/q of each ion are summarized in Table 2. For this calculation carbon foil stripper is assumed and the stripping efficiency was estimated by LISE++ [5].

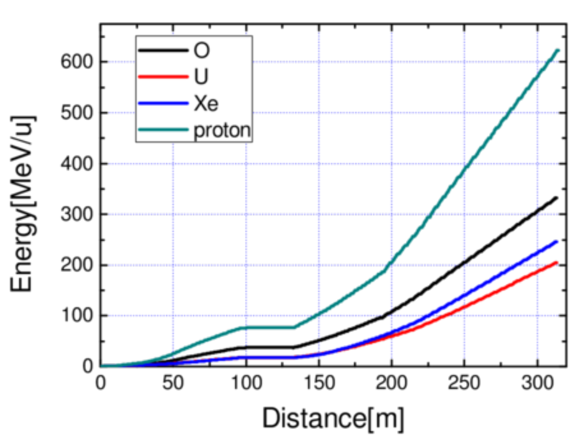

Figure 3: Ion energies in SCL.

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

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

$$\sigma_{ot} = \frac{qGl\sqrt{LD}}{\gamma m v} \tag{2}$$

Start-to-end simulation was performed with designed lattice using TRACK code [6]. Figure 4 is the RMS envelope

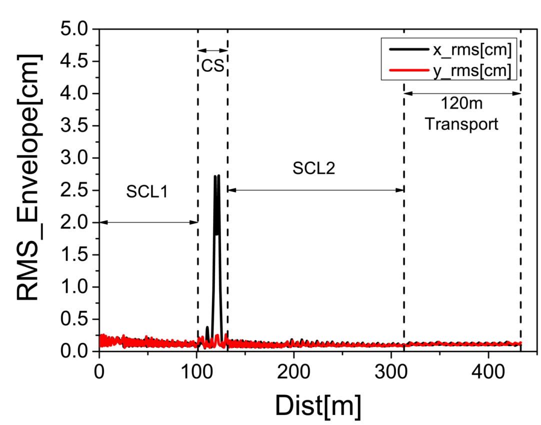

Figure 4: RMS envelope of Uranium in RAON main driver linac

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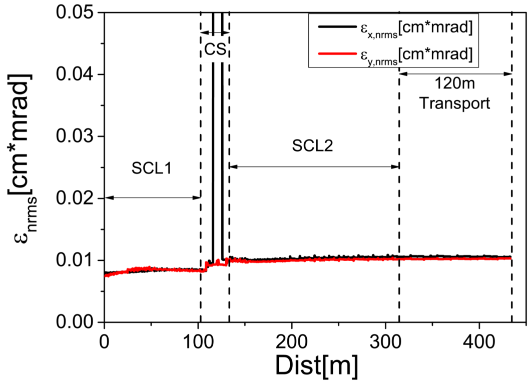

Figure 5: Normalized RMS emittance of Uranium in RAON main driver linac.

of uranium beam in all main driver section and the emittance change is shown in Fig. 5. In Fig. 4 the beam pipe radius in each section is illustrated by the vertical position of left right arrows indicating the sections. The beam size is smaller than 20% of beam pipe even in worst case and it means that the beam can go through without loss if there is no error. Also the transverse emittance growth was not significant in linac section and bending section except the charge selection section. In charge selection section the beam is separated in horizontal direction and it can lead to the transitory horizontal emittance growth. However the emittance goes back after the section. In Fig. 6 the phase space beam distribution of uranium beam at the exit of main driver linac. From the result, we could confirm that RAON linac can accelerate ions having wide A/q value (1 ~ 8) successfully.

SUMMARY

The linac lattice designs for stable ions 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 and the energy of proton, oxygen, xenon beams could be reached to 600MeV, 320MeV/u and 240MeV/u, respectively. Also start-to-end beam tracking simulation was performed in main driver linac and beam transport section and it showed that the RMS beam envelope was smaller than 20% of beam pipe size. From these results, we could confirm that various ions with different A/q could be accelerated in RAON linac.

ACKNOWLEDGMENT

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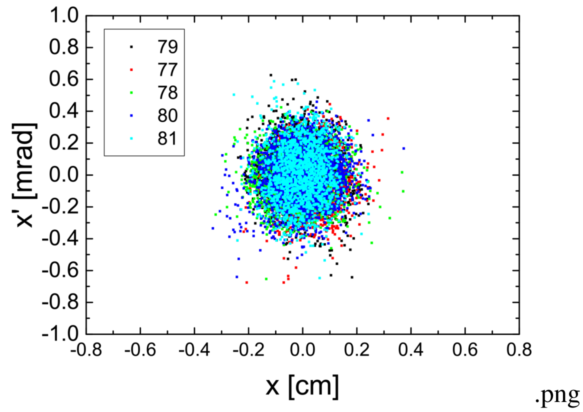
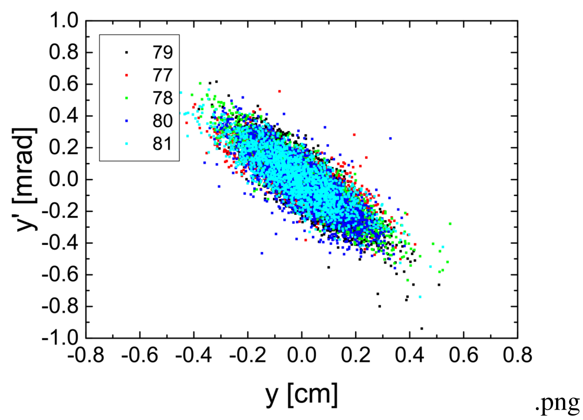
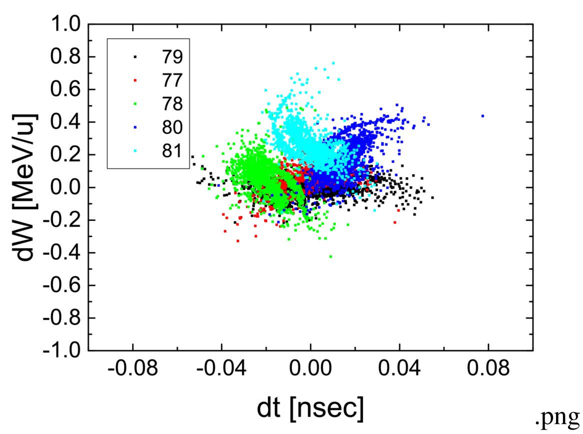


(a) Beam profile in transverse (X) phase space



(b) Beam profile in transverse (Y) phase space



(c) Beam profile in longitudinal phase space

Figure 6: Beam distribution of Uranium in 3D phase space after RAON main driver linac.